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Production of IRON/STEEL & High-Quality Product Mix:

LATEST TECHNOLOGICAL INNOVATIONS AND PROCESSES

Edited by B.R. Nijhawan

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Production of Iron, Steel, and High-Quality Product Mix: Latest Technological Innovations and Processes

Proceedings of the
Applications of the Latest Technological Innovations
and Processes for the Production of Iron and Steel
and High Quality Product-Mix Conference
ASM/TMS Materials Week
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Chicago, Illinois, USA

Edited by
B.R. Nijhawan

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This book is a collective effort involving hundreds of technical specialists. It brings together a wealth of information from worldwide sources to help scientists, engineers, and technicians solve current and long-range problems.

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Preface

Near the end of the 19th century, world steel production was minute compared with today's standard. For example, annual steel production worldwide in 1880 was only 4-million tons, increasing to 12-million tons in 1890, and reaching 28-million tons at the turn of the century. During the 20th century, production has increased steadily overall while going through peaks and dips, reaching 705-million tons in 1974, 747-million tons in 1979, 783-million tons in 1990 and 735-million tons in 1991.

The continual emergence of advanced materials, such as composites and other hybrid materials, makes it difficult to predict what global steel output will be as we near the 21st century, what steel technologies will be dominant, and what the product mix will be. The intense competition from alternative materials not only should provide formidable challenges, but also should put a high premium on technological ingenuity and initiative.

Some of these issues were addressed at a two-day technical program, "Emerging Technologies of New Materials and Product Mix of the Steel Industry," at ASM Internationals's Materials Week '91, and also will be addressed at Materials Week '92 at a two-day technical program, "Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High-Quality Product Mix." This proceedings contains papers from both programs.

Steels and superalloys continue to "hold their own" despite the challenges of substitute materials/products, which result from the courtship of metals and nonmetallics that leads to promising hybrid composites.

The restructuring of the steel industry in the path of restructured global boundaries, while driving annual global steel output down, will eventually lead to a reorientation of the industry based on application of the latest technological innovations, elimination of obsolete capacity, and a market-oriented balance of the global steel industry.

In a global economy where the only certainty is uncertainty, gathering and disseminating information to increase knowledge is a key factor in maintaining a competitive edge. This philosophy is promoted at Materials Week, which provides a forum for the exchange and transfer of technical information.

This proceedings is not the last word on the status and progress of the steel industry, since some of the highlighted current developmental work in the world of iron and steel will become reality.

B.R. Nijhawan

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Additional Paper*

* This paper was submitted too late to be inclued in its proper location in the proceedings.

1992 Conference

The Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High-Quality Product Mix

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Changing Patterns of Industrial Development and the Steel Industry

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CHANGING PATTERNS OF INDUSTRIAL DEVELOPMENT AND THE STEEL INDUSTRY

by D.F. Anderson

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INTRODUCTION [1]

The changes in the pattern of industrial development which have occurred over the last twenty years are the symptoms of an evolutionary process towards higher levels of economic maturity manifesting themselves as rising incomes and more balanced income distribution. The changes in the pattern of industrial development are also brought about by technological progress which is both, cause and consequence of economic progress. The role of external influences, like energy price surges or profound political and policy changes, including the recent developments in Eastern Europe and the USSR, is also of importance.

While the changes in industrial development patterns have first occurred mainly in the advanced countries, their impact was very quickly also transmitted to the newly-industrializing nations NICs); this is a result of the growing interdependence of the world economy, the increasingly tightly-knit network of international trade and the rapid spread of most modern technologies.

The impact on the structure and functioning of the industrial system in general and on the steel industry in particular has varied from one region to the other, from country to country, depending on the stage of development reached, on the type of economy (share of manufacturing, services, agriculture, mining), and on the degree of export or import dependence, particularly in the field of energy; it also is a function of the prevailing economic and social system (market-oriented, State-influenced or -controlled economy) or, more generally, on government policies and government participation in the economic process.

In the following an attempt is made to highlight some of the main changes which have occurred or which are still underway, with a view to assessing their impact on the steel industry in countries at different stages of development: this should be helpful to corporate planners who have the difficult task to develop strategies for the steel industry.

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1 This paper is based on a study which has been prepared under the auspices of the IISI Committee on Economic Studies, entitled "Changing Patterns of Industrial Development and the Steel Industry", Brussels 1990.

CHANGES IN THE ECONOMIC AND INDUSTRIAL STRUCTURE

(Table 1) After rapid growth in the post World War Two era, industrial development of the advanced economies has assumed a somewhat slower pace, as it was entering a phase of maturity, with the services sector (transport, communication, finance, distribution, medical care, education, etc.) expanding rapidly, accounting for an ever-rising share of the Gross Domestic Product (GDP). Taking Germany, Japan and the United States as representative of this group of countries, services in the United States produced at the end of the 1980s almost 70 per cent of GDP, and in Germany and Japan their share is rising towards 60 per cent. As agriculture is in the advanced industrial economies of relatively small significance, the size of industry is inversely proportional to services, and its share in the creation of national wealth is on the decrease.

(Table 2) A few of the newly industrializing countries have been selected to illustrate the structural changes which are also manifesting themselves in these economies. The selection was, however, mainly determined by the availability of statistical information. It should also be pointed out that "1990" refers to a year at the end of the 1980s, as close as possible to 1990.

When looking at the data for the newly industrializing countries it should also be borne in mind that in these economies structural changes are often overlaid by the all-dominating forces of the ongoing industrialization process; furthermore, the lines of economic evolution are often blurred by financial difficulties which have, particularly in Latin America, interrupted or at least delayed the development process.

As is to be expected, agriculture still holds a larger share of GDP than in the advanced economies, but this share is on the decrease, with both industry and services rising in importance. It is noteworthy that in a number of the countries shown the proportion of services is closing in on the 50 per cent mark.

(Table 3) Within the industry sector, manufacturing holds the largest share in the industrialized countries, and the share has been on the rise over the last twenty years. Industry, it should be noted, also covers mining, construction and electricity, gas and water production, all of which hold their ground to manufacturing.

(Table 4) Among the NICs, Brazil and India have lower or falling shares of manufacturing in total industrial output; both countries are less export-oriented than Mexico or the Rep. of Korea where the part of manufacturing has risen to levels comparable to those obtaining in the advanced economies.

(Table 5) One group within manufacturing, namely the metal-using industries, is of particular importance for steel planners; it comprises the production of electrical and non-electrical machinery, motor vehicles and ships, and also the production of scientific and professional equipment.

(Table 6) Metal-using is an important sub-sector indeed, and it accounts for a rising share within total manufacturing in terms of value added, reaching now over 50 per cent in Japan and the United States, and closing in on that level in Germany. In other industrialized countries this part has tended to remain at around 40 per cent. The consumption of steel is concentrated in the metal-using sector, and together with construction -the other main outlet for steel products- metal-using industries account for about 15 per cent of GDP (in the USA), for 21 per cent in Germany and 23 per cent of GDP (in Japan). Thus, steel consumption is dependent on two relatively small segments of total economic activity.

(Table 7) In the metal-using industries of the industrialized countries, the production of electrical and non-electrical machinery accounts for the largest part, for between 55 and 60 per cent. This is followed by transport equipment, predominantly motor vehicles (between 60 and 90 per cent of transport equipment, depending on the country); other metal products such as structural parts, containers, tools and furniture give a further 8 to 14 per cent, and the remaining 4 to 6 per cent consist of professional and scientific equipment.

(**Table 8**) Although expanding in all countries, the metal-using sector is in most of the NICs less important than in the advanced economies. This is because other manufacturing activities like food production, textiles, wood, non-metallic minerals and even basic chemicals still hold a higher share in manufacturing than machinery, transport equipment and fabricated metal products taken together.

The traditional sub-division of machinery into electrical and non-electrical is rather misleading since for example Office, Computing and Accounting Machinery is classified as non-electrical; furthermore, much of the industrial machinery classified as non-electrical is powered by electricity and contains an ever-increasing portion of electronics for control and steering.

(**Table 9**) If electrical machinery and scientific equipment are singled out from among the metal-using industries, it will be seen that between 30 and 37 per cent of the total is accounted for by these items; and the share of these high-value, little steel-containing products is increasing, not only in the industrialized countries, but also (**Table 10**) in the emerging industrial economies. For the steel planner it is interesting to note that their share in total metal-using industries is also in the new countries already approaching the 30 per cent mark; the high figure for the Rep. of Korea shows an early specialization in the area of electrical and electronic equipment, as is also the case for other Asian countries.

(**Table 11**) Statistical data for a few countries permit to measure the value of output of the electronics sub-sectors, i.e. Office, Computing, Accounting Machinery; Radio, TV and Communication Equipment and Professional, Scientific, etc. Implements. Together they account in Japan for close on 29 per cent of the total production of metal-using industries, up from 22 per cent in 1980; in the United States this share is now at over 26 per cent, having been at just under 19 per cent in 1970. In Germany the percentage is still relatively low, due to the overwhelming importance of the general engineering industries. The total value of these "high-tech" products which are of course rather low in steel content have in recent years exceeded the value of road vehicles produced in both, Japan and the United States.

Clearly, electronics has been the growth area of the 1970s and 1980s: automation, robotisation and computerisation have spread through industry and services; in the household sector there has been equally rapid diffusion of such products as video recorders, microwave oven and the home computer.

The adjustment process to which both, the advanced and the emerging economies have been subject since the mid-1970s has led to the modification of production methods in manufacturing industries and other steel-consuming sectors as well as in the terms of inter-material and international competitiveness. It has brought about the emergence of entirely new sectors, particularly in the area of information and communication technologies; and it has also modified existing industries where the introduction of "mechatronics" has changed processes in mechanical and electrical engineering, or in the production of precision and scientific instruments, but also in other industries and sectors. Finally, it has given rise to the development of new materials, like carbon fibres, ceramics, advanced engineering plastics and composite materials.

To summarise, manufacturing's product mix has changed over the past two decades to become much less material-intensive, and also less steel-intensive. Along with these changes in the manufacturing sector, there has been its own decline for the creation of national wealth, as services have become the mainstay of economic life. And services are not regular consumers of steel or other engineering materials: only when hotels, office buildings and transport infrastructure are being erected do they consume materials, as a once-off stimulus to consumption; later they only require it for replacement or possible expansion.

IMPACT ON THE STEEL INDUSTRY

(Table 12) As a consequence of the various changes in the economic and industrial structure and also, of course, of the slower pace of economic development related to the maturation process, steel production in the **industrial countries** has never regained the 1974 peak level of 463 million metric tons. It rose back to 490 million metric tons in the boom year of 1979, but it has been on the decline ever since and stood at 390 million tons in 1990. The fall was less pronounced in terms of finished steel output, amounting to about 6 per cent compared with 16 per cent for crude steel.

The adjustment process in the steel industry had started with some delay: the first "oil shock" of 1973/74 had brought a sharp drop in steel demand, but the all-out export efforts to balance current accounts, together with increased investments in energy sources as well as a revival of consumer demand, had resulted in an upturn of steel consumption which lasted until 1979. This had re-inspired confidence in the steel industry, and already existing investment projects were resumed or completed. **(Table 13)** They included investments not only for rationalization and energy economy but also for capacity expansion: nominal crude steel capacity in the OECD countries taken together continued to grow until 1981 and was then 15 per cent higher than it had been in 1974. It was only after the second oil price increase in 1979 and the ensuing recession of the early 1980s that steel industry capacity adjustment started in earnest: by 1990 the industrialized countries' crude steel capacity had been reduced by 19 per cent under the 1980 level.

Capacity closures and modernization have involved considerable reduction in employment which stood in 1990 at less than half the peak figures of 1974 in the EC and the United States, and had dropped by one third in Japan. Altogether, a total of one million jobs had been shed between 1974 and 1990 in the industrialized countries, which amounts to approximately one third of the employment in 1974. The steel industry had pursued the adjustment process over a period when it suffered considerable financial losses, particularly in the early 1980s, amounting to many billions of US dollars. More recently, however, the improved outlook and the revival of the investment process in the economy at large during the second half of the 1980s which might announce the end of the adjustment phase, have brought a halt to capacity reductions also in the industrialized countries.

A positive feature of the adjustment process was the replacement of obsolete by modern equipment, the improvement of the remaining facilities, the streamlining of the product pattern and a remarkable increase in the quality of steel. The rising share of continuous casting in the industrialised countries, from 15 per cent in 1974 to nearly 85 per cent in 1990, illustrates the improvement of steelmaking technologies. The share of flat products in the total output of industrialised countries has risen from roughly 40 per cent in the early 1970s to more than two thirds at present. Within flat products the share of extremely thin sheets and coated products has increased significantly. Finally, the share of alloy steels has grown considerably, and so has the proportion of micro-alloyed high-strength steels and other steels improved by secondary metallurgy, heat-treatment and other processes. Precise statistical information on the quantity of "fine" or "improved" steels is unfortunately not available; it can, however, be estimated that they account at present for about 30 per cent of total steel output, having doubled their share since 1970.

In line with the growing internationalisation of the economies, international trade in steel has also been rising while production was falling. The export share of steel output in the industrialised countries has risen from 23 per cent in 1970 to near 40 per cent in 1989; at the same time the import share of steel consumption grew from 19 per cent in 1970 to 30 per cent in 1989. This was not necessarily always a sign of growing division of labour, but rather also a consequence of increasing competition in international trade, as steel demand in certain domestic markets grew at a slower than expected pace.

The adjustment process has also left its mark on long-term planning in the steel industry. The manifold pressures of the moment, the daily struggles for survival had, particularly in the industrialised countries, blurred the view of the future. It was only over the last years that in a number of countries corporate planning changed from survival strategies towards a positive view of the future. Apart from further efforts to raise the value-added content of steel products and the improvement of production processes, there is a distinct tendency in most countries for diversification into new materials, but also into electronics, computer and communication systems, and even into areas remote from the traditional steel industry like bio-technical and service-related activities.

A further feature of the adjustment process was that there is a trend towards concentration through mergers, resulting in streamlining the product pattern of output, improving economies of scale and rationalising investment activities. Furthermore, the number of transnational joint ventures and co-operation agreements has risen considerably.

(Table 14) The rapid growth of steel consumption in the 1960s and early 1970s had encouraged the **developing countries** to expand their steel industries: crude steel output rose from 23 million tons in 1970 to 56 million tons in 1980, and by the end of the decade it had passed the 100 million ton mark, accounting for over 20 per cent of Western World output, compared with only 5 per cent in 1970. As steel requirements continued to rise during the 1970s (to 2.6 times the initial level), there was further growth of capacities, from 28 million tons in 1970 to 60 million tons in 1980.

(Table 15) Most of the growth was in Asia and Latin America where new integrated plants using modern technologies were erected. Following the positive experience of countries like Japan which had used the steel industry as the principal vehicle for export-oriented industrialisation, steel exports from the more advanced developing countries were also rising, from 2.6 million tons in 1970 to 9.5 million tons in 1980. This trend continued in the 1980s: capacity reached 118 million tons for the developing countries taken together and their exports stood at 35 million tons (crude steel equivalent). At the same time, indirect exports of steel-containing manufactured goods produced in the newly industrializing countries made their appearance on the world market, comprising not only passenger cars and ships, but also certain types of electrical and non-electrical machinery and equipment.

There is, however, a distinct difference in patterns between the developing regions: in Latin America, domestic steel consumption was stagnating or even falling during the 1980s, while exports from the region continued to rise; in Asia home usage of steel was increasing and exports had grown only by a relatively small margin. The reasons for the Latin American situation are well known: capacity growth was because of financial and often also political constraints not met by an equally strong expansion of the domestic economy and its capacity to consume steel; furthermore, exports had to be increased to help easing the financial situation of the steel companies and balance of payments difficulties.

For these and other reasons it is difficult to discern the impact which advancing industrialization has had on the structure of the steel industries in the newly industrializing countries: the rapid growth of steel requirements for creating infrastructure and industrial capacities is the dominating factor, and it often masks any changes in the structure of the steel industry. The more advanced among the developing countries follow the traditional patterns of steel industry growth: the share of flat products is rising; in Brazil and in South Korea it has reached about 60 per cent, which is very close to the situation in the industrialized countries. The share of welded and seamless tubes gains in importance, and the proportion of alloy steels begins to grow. While the bulk of steel is produced in (often State-owned) integrated plants, electric furnace producers gain in importance. In corporate planning, the guidance provided initially by the drive for import substitution is replaced by orientation towards the demands arising from emerging, increasingly sophisticated manufacturing industries; import dependence on bulk steel products is diminished, and the product pattern of exports develops from simple off-loading of marginal quantities towards the sale of products where there is either a genuine comparative advantage or an otherwise acquired competitive edge.

IMPLICATIONS FOR STEEL PRODUCERS

Given the changes in the pattern of industrial development of the **mature economies**, corporate strategies of the steel industry are likely to place less emphasis than in other regions on quantitative expansion and rather concentrate on the following main areas:

1. Improvement of the value-added content of output by raising the quality, variety and cost-efficiency of products; this will require increased research and development efforts for creating new products of higher quality to meet increasingly diversified and sophisticated customer demands;

2. Improvement of the efficiency of production processes by introducing most modern or entirely new technologies, including automation (CAM - computer assisted manufacturing), artificial intelligence, flexible manufacturing systems, permitting among others to produce economically relatively small lots of different product qualities, etc., with a view to raise competitiveness over low-cost, low-wage producers as well as over alternative materials; this involves also the further improvement of energy economy and of the environmental compatibility of iron and steelmaking processes;

3. Improvement of marketing (market management) and customer relations, including the provision of technical guidance and assistance for solving manufacturing problems; general strengthening of co-operation with steel distributors and consumers;

4. Improvement of the image of steel as a modern industry producing a modern, easily recyclable material by employing most advanced technologies;

5. Increasing diversification into downstream activities, but also into industries producing new materials (e.g. carbon fibres, amorphous and shape-memory alloys, ceramics) and so-called high-tech industries (e.g. electronics, bio-technology) with a view to taking advantage of available corporate resources, like technical and management know-how, employee skills, knowledge of markets and material-using industries, etc., and to provide a stabilising element against the cyclical swings of steel demand which will continue to occur also in the future.

6. As a result of the continuing internationalisation of the economies in general and the steel-using industries in particular, both direct and indirect steel trade flows will change in volume, direction and product composition. Therefore, steel planners will wish to increase the flexibility of investment strategies, concerning the size and location of plants, the product range and international co-operation agreements, joint ventures and mergers and increased efficiency of distribution systems.

While the challenges which face the **newly industrializing countries** are not basically different from those listed for the now industrialized economies, there are a number of additional considerations for steel planners. As there is in the new steel-producing countries still room for growth of steel consumption, their main concern will be the problems of capacity expansion and its financing. The principal task is to balance growth of capacity with that of demand. Developments over the last twenty years or so have shown that newly industrialising countries are reaching economic and industrial maturity with relatively greater speed than has been the case in the past, so that they face problems of declining specific steel usage and rapid advance of less steel-intensive sectors much earlier than expected. In other words, while the steel intensity of the industrialisation process is certainly higher than that obtaining in the most advanced industrial countries, its further growth has often been and still is frequently over-estimated; and as steel industries are heavily capital-intensive, the burden of fixed costs of idle or under-utilised capacities can be formidable.

To make use of capacities which are, perhaps only temporarily, exceeding the needs of the domestic market, steel planners in the new countries focus their attention also on opportunities for the direct and the indirect export of steel. It is this latter area which must be the subject of most careful pre-investment analysis: the possibilities of export-led growth for steel producing and steel using industries are rather more limited than in the past, given the persisting slow-growth environment of the advanced industrial countries and of their greater competitiveness; furthermore, international markets are subject to wider fluctuations than domestic markets, thus increasing the hazards of export-dependent operations.

Apart from capacity expansion in line with the development of the volume and pattern of domestic and foreign steel demand, the new steel producing countries will also plan for introducing most modern process technologies to improve the efficiency of operations (general productivity, energy economy and lower labour-intensity as wages rise). Furthermore, the aim will be to raise the quality and range of products as domestic production of fabricated metal products and general machinery will increase and require lighter, stronger steels of consistent quality and properties. As most modern technologies are invariably labour-saving and require highly-skilled maintenance personnel, problems of quantity and quality of employment will have to be overcome.

A question of a general economic character which poses itself particularly in the developing countries is whether notoriously scarce capital resources should be devoted to make a steel industry one of the main, or even *the* main vehicle of industrialisation. Steel is among the industries which have a relatively low value added by manufacture and a comparatively low return on capital invested; furthermore, the cost per job created through steel investments tends to be relatively high. There is an increasing awareness that the imbalance between strong population growth and capital shortage could make the setting up of labour-intensive light industries rather than of capital-intensive operations a more economic proposition. As there is, however, hardly any example of sustained industrialisation without a domestic steel industry, its establishment and operation is an essential condition for economic progress in countries having a sufficiently large market. It is the task of planners in industry and government to ensure that the steel industry is part of carefully balanced industrial growth, in order to avoid that it becomes a burden rather than a driving force of economic progress. Experience in both, the advanced and the newly industrialising countries has shown that the economic success of an industry is best achieved if its financing relied on market sources and private risk for capital instead of using public funds.

Table 1

INDUSTRIALIZED COUNTRIES
SHARE OF KEY SECTORS IN G D P

Percentages

		Agriculture	Industry	Services
Germany	1970	3	53	44
	1980	2	45	53
	1990	2	41	57
Japan	1970	6	46	48
	1980	4	41	55
	1990	3	41	56
USA	1970	3	34	63
	1980	3	33	64
	1990	2	29	69

Table 2

NEWLY INDUSTRIALIZING COUNTRIES
SHARE OF KEY SECTORS IN G D P

Percentages

		Agriculture	Industry	Services
Brazil	1970	10	34	56
	1980	10	37	53
	1990	9	43	49
Mexico	1970	12	39	49
	1980	10	38	52
	1990	9	35	56
India	1970	47	29	24
	1980	37	26	37
	1990	32	30	38
S.Korea	1970	30	37	33
	1980	16	41	43
	1990	11	43	46

Table 3

INDUSTRIALIZED COUNTRIES
SHARE OF MANUFACTURING IN TOTAL INDUSTRY

Percentages

	1970	1980	1990
Germany	75	76	78
Japan	64	70	77
USA	58	64	69

Table 4

NEWLY INDUSTRIALIZING COUNTRIES
SHARE OF MANUFACTURING IN TOTAL INDUSTRY

Percentages

	1970	1980	1990
Brazil	76	79	67
Mexico	77	63	74
India	66	69	63
S. Korea	65	68	74

Table 5

METAL USING INDUSTRIES

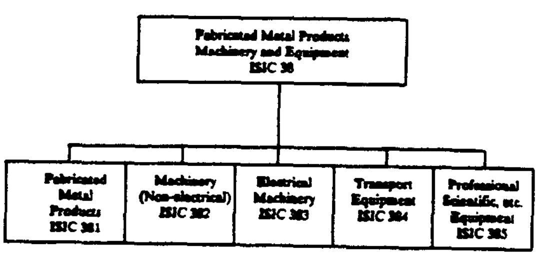

Table 6

INDUSTRIALIZED COUNTRIES
SHARE OF METAL USING IN MANUFACTURING INDUSTRIES

Percentages

	1970	1980	1990
Germany	42	44	48
Japan	30	40	53
USA	41	44	54

Table 7

INDUSTRIALIZED COUNTRIES
METAL USING INDUSTRIES : SECTOR PATTERN 1990

Percentages

	Germany	Japan	USA
Metal Products	8	12	14
Non-elec. machinery	25	24	38
Elec. machinery	33	32	20
Transport equipment	30	29	22
Scientific equipment	4	3	6
Total	100	100	100

Table 8

NEWLY INDUSTRIALIZING COUNTRIES
SHARE OF METAL USING IN MANUFACTURING INDUSTRIES

Percentages

	1970	1980	1990
Brazil	32	30	29
Mexico	24	28	30
India	26	29	31
S. Korea	16	22	31

Table 9

INDUSTRIALIZED COUNTRIES
SHARE OF SCIENTIFIC EQUIPMENT AND ELECTRICAL MACHINERY
IN METAL USING INDUSTRIES

Percentages

	1970	1980	1990
Germany	31.3	31.4	29.7
Japan	27.2	32.2	36.6
USA	27.5	30.2	33.2

Table 10

NEWLY INDUSTRIALIZING COUNTRIES
SHARE OF SCIENTIFIC EQUIPMENT AND ELECTRICAL MACHINERY
IN METAL USING INDUSTRIES

Percentages

	1970	1980	1990
Brazil	20.6	23.3	25.3
Mexico	26.3	23.9	25.7
India	31.5	29.8	32.7
S. Korea	47.8	42.3	41.7

Table 11

INDUSTRIALIZED COUNTRIES
SHARE OF HIGH-TECH INDUSTRIES IN TOTAL METAL USING INDUSTRIES

Percentages

	1970	1980	1990
Germany	-	14.8	15.4
Japan	-	21.7	28.6
USA	18.6	22.8	26.4

Table 12

INDUSTRIALIZED COUNTRIES
CRUDE STEEL PRODUCTION, 1970 -1990

Million metric tons

	1970	1974	1980	1990
EC 12	146	168	142	137
Japan	93	117	111	110
USA	119	132	102	89
Other	39	46	52	54
Total	397	463	407	390

Table 13

INDUSTRIALIZED COUNTRIES
CRUDE STEEL CAPACITY 1974 - 1990
Million metric tons

	1974	1980	1990
EC 12	177	196	154
Japan	126	143	115
USA	140	139	106
Other	57	57	61
Total	500	536	436

Table 14

DEVELOPING COUNTRIES
CRUDE STEEL PRODUCTION, 1970 -1990
Million metric tons

	1970	1974	1980	1990
Latin America	13	18	29	38
Africa	1	1	2	4
Middle East	1	1	1	4
Asia	8	11	24	55
Total	23	31	56	101

Table 15

DEVELOPING COUNTRIES
CRUDE STEEL CAPACITY

Million metric tons

	1974	1980	1990
Latin America	19	30	40
Africa	1	2	7
Middle East	1	2	6
Asia	12	26	65
Total	33	60	118

Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

Steel Authority of India's Efforts on Technological Upgrading and Modernization Front to Meet the Challenges of the 90s

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Abstract

The all pervasive use of steel in production of most of the commodities, many strategic and critical applications make it a crucial basic material to economic progress of our nation. Economic progress depends much on the industrial growth, which in turn is reflected by the quantum of steel consumption. There is a changed steel scenario in India now and to meet the challenges of critical market needs, SAIL is modernising its plants, incorporating state-of-the-art technologies and developing new grades of special steels. SAIL is gearing itself to provide indigenously high quality steel, and striding forward to become a premier steelmaking company.

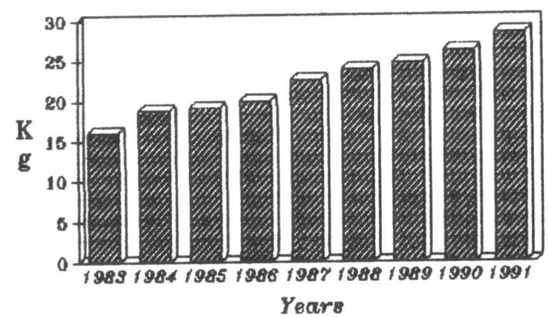


Fig. 1 : Per capita consumption of crude steel in India

AT TIME OF INDIA'S INDEPENDENCE IN 1947, there were only three steel producers in the Indian steel sector viz. Tata Iron and Steel Co. (TISCO), Indian Iron and Steel Company (IISCO) and Govt. owned Mysore Iron and Steel Works. They together produced a little over 1 MT of steel per annum.

Indigenous crude steel production in India has increased to over 16.5 MT in 1991-92. The contribution of integrated steel plants and secondary steel sector were 12.6 MT and 4.0 MT respectively in 1991-92. Of the Integrated steel plants, the contribution of Public Sector Steel Authority of India Limited (SAIL) was 9.6 MT and Vizag Steel Plant 0.59 MT; share of private sector TISCO was 2.4 MT. The per capita consumption of steel in India has picked up from 3 Kg. in 1947 to 29 Kg. in 1991-92. Figure-1 reflects the growing trend in steel consumption over the past 9 years.

Steel industry in India has emerged as a core sector with an installed capacity of about 18 MT in the integrated steel sector and about 7 MT in the mini steel sector. In the integrated sector, a capacity of 15.4 MT is in the Government Sector and 2.5 MT in the private sector.

SAIL has become the life line of several core industries viz. automobiles, consumer durables and building industry. SAIL plays a crucial role in the infrastructure sectors such as power and transport. India's agricultural sector depends much on its steel for manufacture of tractors and agricultural implements. SAIL also produces fertilizers for the agriculture sector. In the specialised high-tech fields of defence, atomic energy and space, steel from SAIL constitutes an essential input. SAIL's all round contribution to India's economy is well established.

With its current investment of Rs.8000 crores # (3150 Million US Dollar @) and turn over close to Rs.10,000 crores (3930 Million US Dollar),SAIL is India's largest corporate entity. It encompasses five integrated steel plants and four special steel plants. SAIL has an installed capacity of 12.4 MT crude steel in the integrated sector and 0.33 MT of finished steel in the alloy and special steel sector.

SAIL constantly endeavours to produce quality steel and develop new specifications through the in-house technological inputs provided by its Research & Development Centre for Iron & Steel (RDCIS), which is one of the largest of its kind in the world.

The infrastructure facilities which SAIL possesses today, enable it to support production of every type and grade of steel starting from basic raw materials viz. Iron ore, coal and fluxing agents.

With continuous upgrading of technology and effort by its skilled manpower, SAIL has steadily enhanced its competitiveness in the global market. It now has the potential to utilise the available opportunities and meet the needs of demanding customers.

MAJOR SAIL FACILITIES

SAIL includes in its fold five integrated and four special steel plants and other service divisions. A map showing the location of the different steel plants/units of SAIL is given in Figure-2.

Production Unit

Bhilai Steel Plant (BSP). BSP is located in the state of Madhya Pradesh. It was set up with an initial capacity of 1 MT crude steel per annum and thereafter augmented to 4.0 MT. The plant was the first in India to produce wide (3600 mm) & heavy plates for domestic and international markets. It is also a major exporter of heavy rails, heavy structurals, and wire rods.The current product-mix of BSP is given below :-

Product-Mix	**Tonnes Per Annum**
Semis and Squares	5,53,000
Heavy Rails	5,00,000
Heavy Structurals	2,50,000
Merchant Sections	5,00,000
Wire Rods	4,00,000
Heavy Plates	9,50,000
Total Saleable Steel	**31,53,000**

Rupees One Crore = Rupees Ten Million

@ One US Dollar = Rs.25.40

Durgapur Steel Plant (DSP). DSP is located in the state of West Bengal. It is a major producer of railway materials like wheel & axles, fish plates and railway sleepers. It was set up with an initial capacity of 1 MT crude steel per annum which is now being augmented to 1.88 MT through large scale modernisation, establishment of new and sophisticated technologies, and a customer oriented product mix. The current product-mix of DSP is given below :-

Product-Mix	**Tonnes Per Annum**
Billet and Blooms	1,75,000
Merchant Sections	2,40,000
Medium Structurals	1,60,000
Skelp	1,50,000
Wheel and Axles	20,000
Sleepers	50,000
Fish Plates	5,000
Total Saleable Steel	**8,00,000**

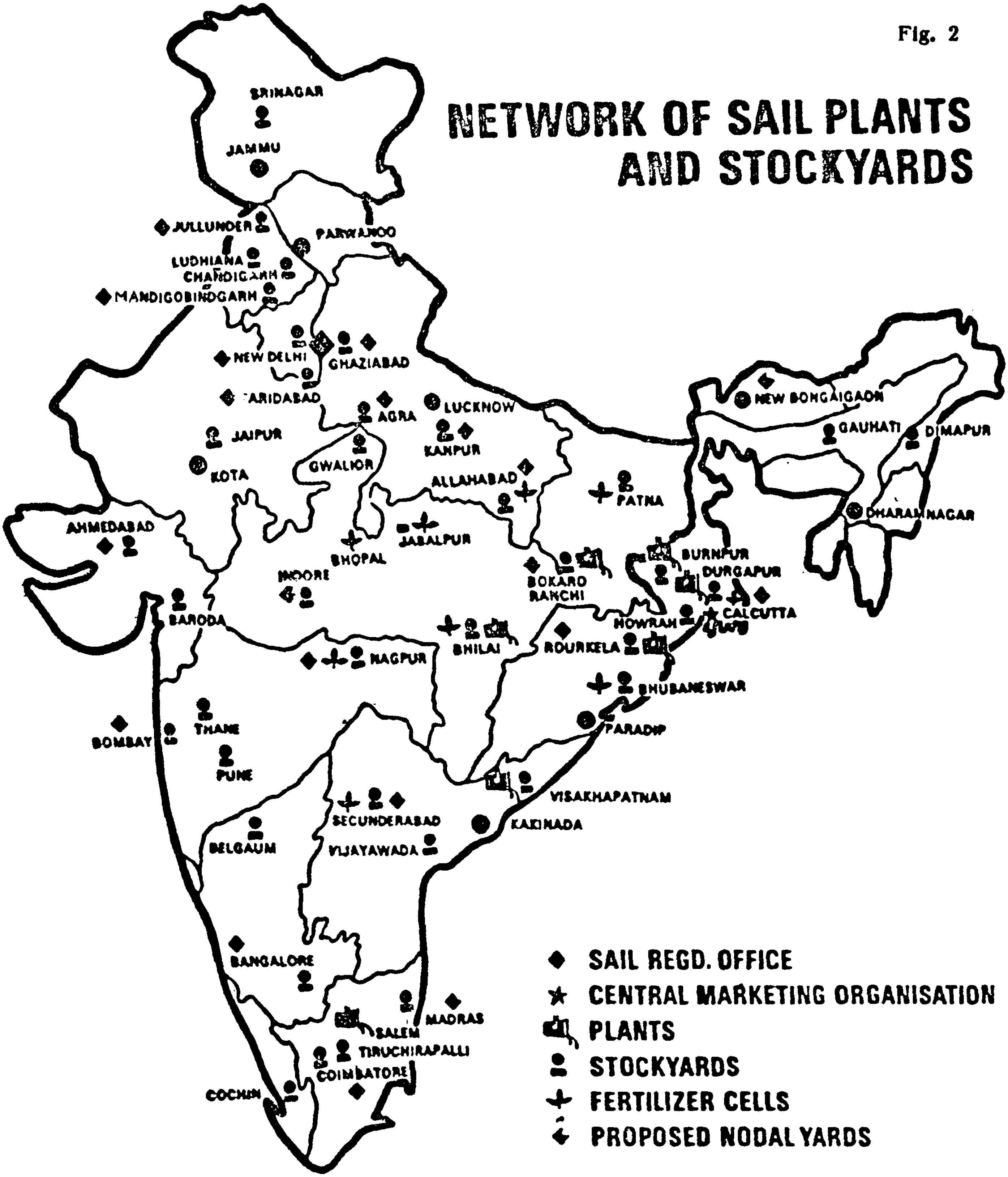
Rourkela Steel Plant (RSP). RSP is located in the state of Orissa. It was set up with an initial capacity of 1.0 MT and later expanded to 1.8 MT. Rourkela produces spirally welded and electric resistance welded pipes for the vital oil sector. Rourkela's sophisticated silicon steel mill produces Cold Rolled Grain Oriented (CRGO) and Cold Rolled Non-Oriented (CRNO) electrical steel sheets, which are vital import substitution items. The current product-mix of RSP is as follows :-

Product-Mix	**Tonnes Per Annum**
Wide and Heavy Plates	2,80,000
Hot Rolled Sheets, Narrow plates & Coils	1,75,000
Cold Rolled Sheets/Coils	2,40,000
Galvanised Sheets/ Coils(GP/GC)	1,60,000
Electrolytic Tin Plates	1,50,000
Electrical Steel Sheets Hot Rolled & CRNO/CRGO	90,000
ERW Pipes	75,000
Spirally Welded Pipes	55,000
Total Saleable Steel	**12,25,000**

Bokaro Steel Plant (BSL). BSL is located in the state of Bihar. It heralds India's accomplishment in the design, engineering and construction of steel plants, making it the first indigenous steel plant in India. It was set up with an initial capacity of 1.7 MT crude steel per annum and later augmented to 4.0 MT. It specialises in a wide range of Hot and Cold Rolled products. The current product-mix of BSL is given :-

Fig. 2

NETWORK OF SAIL PLANTS AND STOCKYARDS



Product-Mix	Tonnes Per Annum
Hot Rolled Coils,Narrow Plates and Sheets	14,96,000
CR Sheets/Coils	13,90,000
GP/GC Sheets	1,70,000
Tin Plates Gauge/TMBP Coils	1,00,000
Total Saleable Steel	**31,56,000**

Indian Iron & Steel Company (IISCO). IISCO is located at Burnpur in West Bengal. It was set up in 1918 and later become a subsidiary of SAIL in 1978. It has an annual capacity of 1.0 MT of crude steel.Cast Iron Spun Pipes,from 80 mm to 1050 mm diameter, are produced in its units at Kulti and Ujjain. Efforts are on to modernise and reorient the plant by upgrading obsolete facilities. The current product-mix of IISCO is given below :-

Product-Mix	Tonnes Per Annum
Semis for sale	1,50,000
Heavy rails	1,00,000
Structurals	2,20,000
Bars and Rods	1,60,000
Hot Rolled and Galvanised Sheets	1,20,000
Total Saleable Steel	**8,00,000**

Alloy Steels Plant (ASP). ASP is located at Durgapur in West Bengal. It is the largest alloy steel producing unit in India. The plant initially had a capacity of 1,00,000 T, which was subsequently augmented to 2,60,000 T. Its wide range of alloy and special steel products include Armour plate grade and special grade alloys, including stainless steel, to meet vital and strategic needs of the country. Besides ingots,the plant produces forged products,bars and sheets. It is equipped with VAD,VOD and RH Degassing facilities,complemented by continuous casting facility.

Salem Steel Plant (SSP). SSP is located in the state of Tamil Nadu. It has a capacity of 70,000 tonnes of Cold Rolled Stainless steel strips and wide sheets per annum. The plant meets the requirement of domestic stainless steel untensils and other industrial applications in a big way. It has established itself as a symbol of excellence within the country and also abroad.

Visvesvaraya Iron & Steel Co.(VISL). VISL is located in the state of Karnataka. It became a subsidary of SAIL in 1989. It has an installed capacity of 77,000 tonnes of alloy and special steels, and 23,800 T of ferro alloys. The plant will undergo an upgradation shortly. The facilities include both LD and EAF,complemented by vacuum degassing (VD) & continuous casting. A ladle furnace has also been installed.

Maharashtra Electrosmelt Ltd (MEL). MEL is located in the state of Maharashtra. It is the largest producer of High Carbon Ferro Manganese (HC-Fe-Mn) in India, with a capacity of 100,000 tonnes per year. It also has a capacity to produce 75,000 tonnes of several grades of saleable steel.

Service Units/Divisions

Raw Materials Division (RMD). RMD is located at Calcutta in West Bengal. It ensures size, quality and assured availability of raw materials for SAIL Plants. It controls 9 Iron ore, 5 Limestone, 3 Dolomite and 3 coal mines which annually produce approximately 21 MT of Iron ore, 6 MT of Limestone, 1 MT of Dolomite and 2.5 MT of Coal respectively. It has geared itself to meet SAIL's requirement of 31 MT of Iron ore, over 6.5 MT of Limestone and 3 MT of Dolomite by the turn of the century.

Research & Development Centre (RDCIS). RDCIS is located at Ranchi in the state of Bihar. It was established with the basic objectives of developing new processes and products, and provision of technological services to the Indian Steel Industry. It has well equipped technical and diagnostic including pilot scale facilities. It collaborates with scientific institutions in India as well as abroad for rendering technical assistance to the steel Industry.

Centre for Engineering & Technology (CET). CET is located at Ranchi. It is an in-house design, engineering and consultancy organisation of SAIL. It's range of services include project consultancy, design and engineering, project management, technology upgradation and export of project and services.

Management Training Institute (MTI). MTI is located at Ranchi. It forms the nucleus of the in-house management training in SAIL. It caters to the training, consultancy and management research requirement of the senior executives of the Company.

Central Growth Division. It is located at Calcutta. It overseas the facilities of the engineering shops in different SAIL Plants and units, which produce standard and special value added items. Many of these items are import substitutes. Items in its scope include rolls for Cold Rolling Mills, rolls for continuous casting etc.

Central Marketing Organisation (CMO). CMO is located at Calcutta. It handles the marketing front of SAIL in both domestic and foreign markets.CMO operates an extensive marketing setup of stockyards, dockyards, branch sales offices, consignment agents and extension counters linked by an elaborate computer network.

CURRENT LEVELS OF SAIL OPERATION

The details of Hot Metal, crude steel and saleable steel production for 89-90, 90-91 and 91-92, along with plan for 92-93 are given in Table-1 :-

Table - 1

Unit '000T

ITEM	89-90	90-91	91-92	92-93 Plan
HOT METAL	9685.6	9824.8	10611.0	10807
CRUDE STEEL	8269.0	8761.8	9631.1	9976
SAL.STEEL	7063.0	7364.6	8028.5	8292

The details of production of Alloy and special steels for 89-90, 90-91 and 91-92, and plan for 92-93 are given in Table-2 :-

Table - 2

Unit '000T

ITEM	89-90	90-91	91-92	92-93 Plan
CRUDE STEEL	197.4	202.1	225.0	240.0
SAL.STEEL	135.1	145.4	160.5	175.0

SAIL TRACK RECORD

Between 1985 and 1992, the Company has recorded a net profit of about Rs.1400 crores (550 Million US Dollar). In 1991-92, SAIL has recorded a profit of Rs.280 crores (110 Million US Dollar). It is for the 8th successive year that SAIL has recorded the profit.

The performance of SAIL is all the more impressive considering the fact that SAIL does not have any budgetary support from the Government since 1985-86. The financial performance of SAIL in respect of gross margin has progressively improved over the last few years (Table-3 & Figure-3).

Table - 3

(Rs. in Million)

ITEM	86-87	87-88	88-89	89-90	90-91	91-92	92-93 Plan
Turnover	42823	50362	66249	74202	81841	93050	102820
Gross Margin	5807	6453	11124	10629	12102	13720	15620
Net Profit	528.1	632.7	3024	1905	2447	2800	1520

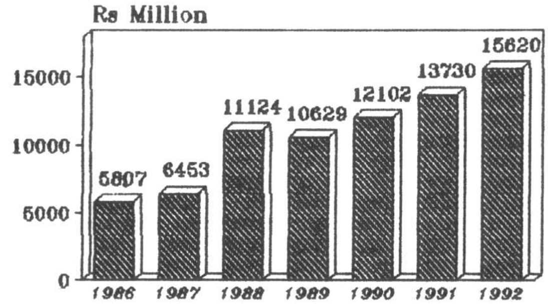


Fig. 3 : Gross Margin performance – SAIL
(Financial year starts 1st April)*

Capacity utilisation of SAIL, in terms of crude steel, has increased from 63 % in 1986-87 to 88 % in 1991-92. The year wise growth for the capacity utilisation of SAIL Plants is reflected in Figure-4.

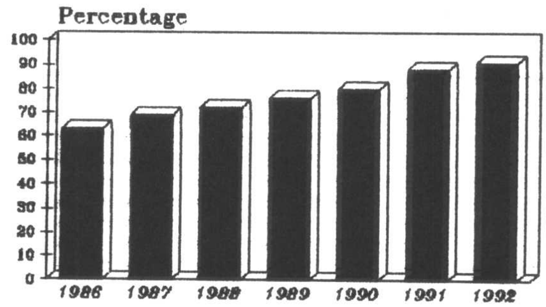


Fig. 4 : Capacity Utilisation – SAIL
(Year period is April – March)*

The technology indices of SAIL Plants reflect a marked degree of optimism. The average coke rate has dropped from 775 Kg in 1986-87 to 698 Kg in 1991-92 (Figure-5). This reduction in coke rate has to be viewed in light of the adverse coking coal quality parameters of indigenous coal, having an ash percentage of about 20 per cent. Of the SAIL Plants, BSP achieved an all time low coke rate of 666 Kg. in 1991-92. It is envisaged that a significantly low coke rate of 575 Kg. would be achieved at BSP by 2000 AD.

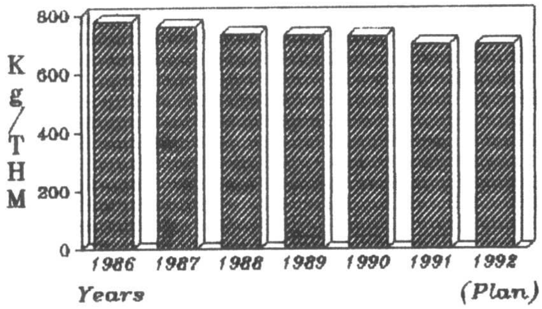


Fig 5 : Coke rate in SAIL
(Year period is April-March)*

The energy consumption of SAIL Plants has declined from 11.2 G.Cal per tonne of crude steel in 1986-87 to 9.17 G.Cal per tonne of crude steel in 1991-92 (Figure-6). Amongst the SAIL Plants, Bhilai Steel Plant achieved an all time low energy consumption of 8.36 G.Cal per tonne of crude steel in 1991-92. With stress on energy optimisation and increased capacity utilisation, it is targetted to achieve a level of 7.4 G.Cal per tonne of crude steel by 2000 AD at BSP.

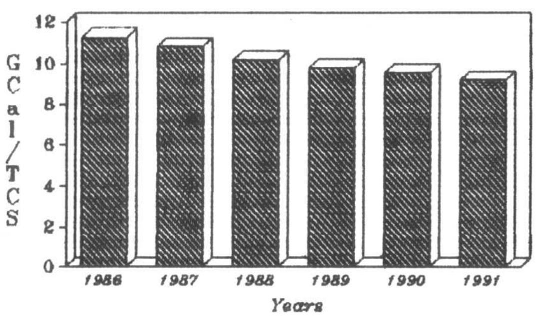


Fig 6 : Energy consumption in SAIL
(Year period is April-MArch)*

The quantum of standard tested quality in saleable steel has gone up from 71 per cent in 1984-85 to 88 per cent in 1991-92.

PLANNING STRATEGY FOR FUTURE GROWTH

Technology planning has become the nucleus of SAIL's growth strategy. The growth opportunities have been identified and suitable strategies evolved to exploit them for achieving the Company goals.

The technology plan of SAIL upto 2005 has been finalised after a detailed review. It is based on the following premise:

(a) State-of-the art-technology of iron and steel on the International front.
b) The level of existing technology in SAIL Steel Plants vis-a-vis above.
c) The specific constraints being faced by the SAIL steel plants in general and also individuallly.
d) The possibilities of bridging the technology gap and bringing about an improvement in view of the nature of constraints and the realities of the environment.
e) The future changes anticipated in technologies which may influence the iron and steel industry in a big way.This includes measures to be adopted to take advantage of these developments in the overall growth strategy.
f) Experience gained by each steel plant/unit of SAIL since 1986-87 towards selection and introduction of newer technologies.
g) Development of new sources of better quality raw materials and their exploitation.
h) Present status of pollution control in plants and mines and aiming towards evolving a logical and compatible environment management plan.

Besides above, the additional factors considered while formulating the technology plan are:

i) Maximum possible reduction in the specific consumption rates of raw materials through quality upgradation and improvement in yield.
ii) Full exploitation of existing facilities to minimise the investments on new facilities.
iii)Selective conversion of relatively obsolete facilities into modern efficient units.
iv) Provision of flexibility in the process of manufacture to cater to the changing customer needs of quality and variety.
v) Selection of proven systems and technologies for introduction during modernisation.

PRESENT STATUS OF TECHNOLOGY IN SAIL

Indian Steel Industry has emerged from a negative average growth rate of 0.6 percent during 1979-84 to a positive growth rate of 6.6 per cent per year during 1986-90, and a further 7 per cent growth thereafter. SAIL presently has a growth rate close to 10 per cent. The turn around in SAIL was possible mainly due to various measures taken for technology updating and upgradation, improved maintenance practices, better energy management and work culture.

The technology plan has detailed the implementation schedules for introduction of new technologies, updating the existing ones, replacement of obsolete equipment & processes through modernisation/ revamping/ refurbishing schemes. The plan revolves around internal generation of resources as a major means of raising the needed funds for these schemes.

Significant headway has been made since evolution of the technology plan in raising the level of technology in SAIL Plants. There is an improvement in the technology indices of SAIL Steel Plants as a result of several technology revamp and upgradation programmes that have been implemented in different SAIL Steel Plants.

Present status of technology in SAIL Plants in some of the important areas is as follows :-

Coal, Coke and Chemicals

- Use of imported coals in coking coal blends to the extent of 10-30 per cent (M10 index of coke has shown an improvement from the earlier 12-16 to the present 9.0 to 13.5).
- Introduction of PBCC technology - M 10 values of 8.5 to 9.0 have been attained at Bhilai, an improvement of 2-2.5 points.
- Groupwise crushing of coal resulted in improvement of crushing index of coal to 75-80 per cent (-3mm) and M 10 index by 1-2 points.
- Bedding & blending has become a regular practice.
- Replacement of the instruments with computer compatible ones for improved control.
- Hydrojet cleaning has been taken up for oven doors
- Hot welding repair implemented for coke ovens; it is being horizontally transferred among the different plants; it has resulted in increased availability of ovens.
- Various by-product chemicals recovered from coke oven gas have become technologically and economically viable; efforts are on to improve their yield.

Sintering

Strenuous efforts in the field of sintering have resulted in a number of improvements. Some of the measures undertaken

- Proportioning and control systems introduction
- Automatic coke moisture controller
- Modification of ignition hood
- Improved flux and fuel crushing
- Spring loaded strand sealing
- Modification /replacement of side plates and exhausters to increase bed height
- Off-line computerisation
- Pre-heating of sinter mix
- Use of blue dust in sintering
- High pressure sintering and pellet sintering

These measures have lowered energy consumption in sintering upto 40 per cent, reduced leakages upto 35 per cent and improved sinter yield by 10 to 12 per cent.

Iron Making

- Stock house sinter screening and conveyorisation installed - 3 to 4 per cent increase in hot metal production and 2 to 3 per cent decrease in coke rate.
- Improved charging facilities like Moveable Throat Armour (MTA) and Bell Less Top (BLT) have been installed in some of the Blast Furnaces for better burden distribution and efficient furnace operation,resulting in increased productivity and decreased coke rate.
- Under-burden & Above-burden probes have been provided for better insight to furnace operation.
- High Blast Temperature through stove design modification resulting in increased blast furnace productivity and decreased coke rate.
- Other measures incorporated Twin Tap Holes, Humidification of blast, Rocking Runners and Cast House Slag Granulation have contributed greatly to improve productivity, availability and utilisation of blast furnaces.

Steel Making

Open Hearth process has begun to be replaced by the BOF process. As an intermediate measure, OH furnaces are being converted to twin hearth furnaces. KORF has also been introduced for improved operation of OH furnaces and reduction in specific energy consumption. Major measures in vogue are :

a) Deslagging of mixer metal - reduced metallurgical load on the converters
b) Hot metal desulphurisation - ultra low levels of sulphur
c) Slag arresters for LD - production of clean steels
d) Improved ladle heating burner - improved yield
e) Combined blowing in converters
f) Aluminium wire feeding
g) Argon rinsing of tapped steel
h) Vacuum degassing units for improved quality of steels
i) Tapered Lance - reduced lance jam and improved Converter availability.

Substantial improvements in furnace productivity, yield and quality of steels have been realised due to incorporation of above measures.

Rolling Mills

- Micro-processor control of heating regime,and ceramic fibre sealing of pits have resulted in lowering of specific fuel consumption by 10-15 per cent.
- Modifications of water cooled skids of reheating furnaces of mills, as well as computer compatible instrumentation for furnace control, have improved heating regime of the feed stock.

- Roll knurling in primary mill to reduce ingot twisting, and roll lubrication to reduce roll wear.
- Controlled rolling and accelerated cooling measures have been incorporated in the mill proper for better mechanical properties and eliminating heat treatment.
- Balancing facilities at the finishing end of the mill ensure proper quality of the product.

Secondary Steel Making

In the area of alloy and special steels, there is an ever increasing demand for quality by the steel user in order to optimise cost as well as improve the excellence of the end products. More and more customers are insisting on defect-free steel, improved analytical and dimensional tolerances, superior and homogenous chemical properties.

Keeping in view the demand for quality steel, SAIL has turned to economically attractive and technologically feasible routes for achieving the goals of high productivity, high purity and improved mechanical properties of steel.

A comprehensive action plan has been drawn by SAIL to incorporate the technologies of 'Secondary Refining or Ladle Metallurgy' for production of high quality and clean steels. SAIL's involvement in secondary refining is the most extensive of any Indian Steelmaker. It envisages secondary refining of 100% steel by the turn of this century, and increasing percentage of alloy and special steels. R&D efforts are being intensified for development of steel grades for critical applications.

SAIL today has emerged as the leader for a whole range of alloy and special steels like auto-bodies, LPG, Pipe line, boiler plates etc. It has turned to self-reliance for CRGO/CRNO sheets. In the strategic sector of Defence, SAIL retains a monopoly/most preferred supplier status on account of both quality and costs. In the area of Railways, CORTEN steel has been produced as an import substitution item. Import substitution stainless steel for critical items has been produced at Salem with high returns.

The status of Secondary Refining technologies in SAIL Integrated Steel Plants are :-

1.	Vacuum Arc Degassing/ Refining (VAD/VAR)	- Existing
2.	Powder Side Injection	- -do-
3.	Vacuum Oxygen Decarb-urising/Refining (VOD/VOR)	- -do-
4.	Ca/Al Wire Injection	- -do-
5.	Argon Rinsing	- -do-
6.	Ladle furnace	Under Implementation
7.	Composition Adjustment Through Argon Bubbling and Oxygen Blowing (CAS-OB)	- -do-

Status of Secondary Refining technologies for Alloy & Special Steels Plants at SAIL :

1.	RH/DH Degassing	- Existing
2.	Vacuum Arc Degassing (VAD)	- -do-
3.	Vacuum Oxygen Decarburising (VOD)	- -do-
4.	Argon Rinsing	- -do-
5.	Ladle Furnace	- -do-

DEVELOPMENT OF SPECIAL STEEL GRADES

The following special steels have been developed at different SAIL Plants in association with RDCIS.

1.	API X 60 Steels	- Oil & Natural Gas Sector Pipe Lines
2.	Weather Resistant Steel IRS M-41 to CORTEN Standard	- Import substitute for Railways,Agriculture
3.	LPG Sheets	- Import Substitute for Gas cylinders
4.	High Strength 90 UTS steel	- To international quality for rails
5.	Micro-Alloyed Plates/ sheets	- Ship Building, Hydel projects, earth moving equipment
6.	Deep Drawing/Extra Deep Drawing Steels	- Automobile industry
7.	Copper bearing steel	- Sugar & beverages industry
8.	Duplex stainless steel	- Petrochemical and Chemicals industry
9.	Spade, Jackal steel	- Armour steel for Defence Sector
10.	BP 30 & BP 25 steel	- Missile programme for Defence sector
11.	CRGO/CRNO grade	- Import substitute for electrical sheets
12.	ASTM-A537 stee	- Pressure vessel quality
13.	Tin Mill Black Plate (TMBP)	- Import substitute for Container industry.

The list of products which are to be developed through R&D efforts in association with steel plants during 1992-93 is enumerated below ;-

1. API X-60 grade steel - Sour Gas Line Pipe.
2. ASTM A-204 grade B-Pressure Vessel Steel Plates.
3. API X-42 Steel - ERW Pipes with Guaranteed Fracture Toughness (FTT) for Gas Authority of India Ltd.(GAIL)
4. HSLA-80 Steel - Indian Navy.
5. Ferritic Stainless Steel - Import Substitute item.
6. Ball Bearing Steel - Import Substitute item.
7. ME-10 grade steel - manufacture of Cartridge casing for Defence.

SAIL MODERNISATION PROGRAMMES

Market study shows a gap in demand and supply of steel in India. Table-4 shows the demand and availability of finished steel for India in 1990-91, 1991-92 and 1992-93, along with details of future forecast upto 2004-2005. SAIL is gearing up to cut down on the these market gaps.

Most of the SAIL Steel Plants were commissioned in late 50s and expanded in 60s. IISCO is a much older plant. The need for modernisation and technology upgradation has been accepted for the last 10 years, but significant changes could not be undertaken earlier.

Substantial scope exists for expanding the capacity of SAIL Plants along with their modernisation. The choice of introducing a new technology has been such that optimum capacity is attained, to take advantage of the capital injection. It has been ensured that the backlog of maintenance is taken care of during modernisation.

SAIL's modernisation programmes are a part of its overall strategy to make SAIL a primary steel Company of the world. It aims at ensuring optimal utilisation of the workforce and its existing assets. The volume of production of SAIL Steel Plants is targetted to expand from the current production of 10.0 MT of crude steel to 12.0 MT by 1994-95, 17.0 MT by the end of the century and 20.0 MT by 2004-2005.

Modernisation of the Integrated Steel Plants

SAIL's modernisation drive at BSP consists of switching over entirely to BOF process for steel making coupled with continuous casting, which will permit optimum utilisation of the plant capacity. It is planned to increase production from the current level of 3.7 MT crude steel to 5.0 MT crude steel by the year 2000 AD.

Modern technologies are envisaged to be implemented upstream for achieving the crude steel targets. These include Partial Briquetting of Coal Charge (PBCC) in Coke Oven Batteries, Coal Dust Injection (CDI) and Bell Less Top (BLT) in all Blast Furnaces. Composition Adjustment Technology through inert gas purging and oxygen blowing (CAS-OB) is under implementation for clean steel making. Downstream, besides the modernisation of its existing finishing mills, a new modern Hot Strip Mill is planned to be installed.

The modernisaton programme of DSP is aimed to replace the obsolete OH process by the BOF process. After modernisaton, it is set to produce 2.5 MT crude steel by the turn of the century from the present level of 0.9 MT crude steel.

PBCC/Stamp Charging technology is planned for introduction in Coke Oven Batteries for improved coke quality. Modernisation of the Sinter Plant for better and increased charge of sinter in BF burden, coupled with CDI and BLT, is planned for better operation and productivity. 98 per cent of crude steel would be continuously cast in tandem with BOF steel making. Downstream, modernisation of all mills with state of the art technology would also take place.

Rourkela's modernisation aims at augmentation of existing sinter capacity, replacement of the OH process by addition of a new steelmaking shop with continuous casting, and revamping of rolling mills. PBCC and Stamp Charging in coke ovens are thrust areas for improved coke quality, while CDI in blast furnaces would help to reduce coke rate and improve productivity. BOF process of steel making would be the established process. Upto 90 per cent of crude steel would be continuously cast. Downstream, Multi-purpose Coating and Electro-Galvanising of steel strips is also envisaged. The modernisation packages would see RSP achieving a production level of 2.6 MT crude steel by the year 2000 AD from the presently achieved 1.2 MT.

BSL is targetted to achieve a production of 4.85 MT crude steel by the turn of the century as against the present production of 3.4 MT crude steel.The technologies to be adopted for achieving this target include PBCC and Stamp Charging in coke oven batteries, BLT and CDI in blast furnaces, and 100 per cent continuous casting of crude steel with BOF process of steel making. Downstream, besides modernisation of the mills, it is planned to install Galvalume Coating and Organic Coating lines.

The modernisation plan of IISCO at Burnpur envisages increasing its production from the present level of 0.36 MT crude steel to 2.0 MT crude steel by the year 2000 AD. Stamp Charging and PBCC are planned with new coke oven batteries. A new modern sinter plant would come up to facilitate sinter charging upto 80% in blast furnaces. CDI is planned for introduction in new blast furnaces. Steel would be made entirely through the BOF route in contrast to the present OH route, and complemented by continuous casting. Downstream, a modern Hot Strip mill would be added to the finishing facilities.

Besides augmentation of the capacities of SAIL Plants,a number of new technologies are to be introduced in a time bound manner. This will help in augmenting hot metal,crude steel and saleable steel production, and improvement in the techno-economic indices.

DEMAND - AVAILIBILITY OF FINISHED STEEL — INDIA

('000 T)

	ITEMS		90-91	91-92	92-93	96-97	2001-02	2004-05
			(Actuals)		(Plan)	(FORECAST)		
NON FLATS	BARS & RODS	*DEMAND*	5955	6330	6725	9570	14130	15600
		AVAIL.	*6703*	*7499*	*7637*	*9088*	*12893*	*13598*
	STRUCTURALS	*DEMAND*	2670	2305	2345	2985	4535	5300
		AVAIL.	*2093*	*2429*	*2528*	*3344*	*4154*	*5507*
	RAILWAY MAT.	*DEMAND*	810	810	810	795	985	1035
		AVAIL.	*653*	*688*	*688*	*651*	*771*	*736*
	TOTAL	*DEMAND*	9435	9445	9880	13350	19650	21935
		AVAIL.	*9449*	*10616*	*10853*	*13083*	*17818*	*19841*
FLATS	PLATES	*DEMAND*	1550	1655	1770	2625	4190	4290
		AVAIL.	*1682*	*1726*	*1746*	*2109*	*2469*	*2719*
	HR COILS / SHEETS / SKELP	*DEMAND*	2625	2810	3010	4435	7280	8100
		AVAIL.	*2134*	*2154*	*2618*	*4193*	*7800*	*11913*
	CR COILS / SHEETS	*DEMAND*	1505	1615	1735	2725	4145	4650
		AVAIL.	*1555*	*1607*	*1818*	*3417*	*3944*	*4245*
	GP / GC SHEETS) ELECTR. SHEETS) TIN PLATE)	*DEMAND*	975	1035	1100	1515	2260	2375
		AVAIL.	*855*	*894*	*924*	*1250*	*1730*	*1830*
	TOTAL	*DEMAND*	6655	7115	7615	11300	17875	19415
		AVAIL.	*6226*	*6381*	*7106*	*10969*	*15943*	*20707*
TOTAL FINISHED STEEL		*DEMAND*	16090	16560	17495	24650	37525	41350
		AVAIL.	*15675*	*16997*	*17959*	*24052*	*33761*	*40548*

Table – 4

Benefits of Modernisation

The modernisation schemes of DSP, RSP and IISCO, which are presently on the anvil, are expected to give several benefits. The schemes are likely to be completed by 1995-96. The major benefits expected are:-

- Crude Steel production of more than 30 per cent above the current level of production.
- More than 80 per cent of the steel will be produced by BOF as compared to 60 per cent today.
- The ratio of continuously cast steel will increase from 15 per cent to 70 per cent of the total crude steel production.
- The specific energy consumption per tonne of crude steel will reduce from the current level of 9.17 G.Cal to 7.9 G.Cal.

These improvements in productivity will result in about 20 per cent reduction in the works cost of saleable steel production. The major benefit envisaged after the modernisation and technological upgradation programmes is that SAIL will become a modern and successful corporate entity in the area of steel making.

MARKET ORIENTATION OF SAIL

Currently out of the total 840,000 T of steel imports of the country, share of flat products is predominant. This is mainly on account of the special qualities like DD/EDD, CORTEN etc. In case of plates, the special grades like boiler quality, ship building and corrosion resistant are being imported. There are significant imports of special grades such as CRGO, CRNO due to shortfall in their availability. Pipes in seamless and spirally welded grades are imported for the oil and gas sector.Railways also imported a large tonnage of 90 UTS rails.

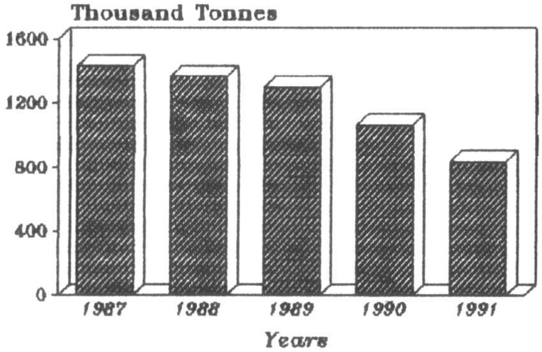


Fig 7 : Trend of steel imports – India

With strenuous efforts by it's R&D Wing and considerable technological inputs to its steel plants, SAIL has been able to cater to the needs of the priority sector for various grades of special steels which were hitherto imported. Figure-7 shows the downard trend in steel imports by India as a result of SAIL's efforts.

There has been a thrust for development of import substitutes, which has resulted in saving of vital foreign exchange for the country. It is also imperative that SAIL earns hard currency in the form of foreign exchange to finance it's raw material imports as well as finance the import of capital goods and technology.

In accordance with these priorities, SAIL is in the process of expanding its horizons beyond Indian shores. It has registered its presence in many developed countries for over two decades and has been recognised as a maker of quality steel. With this track record, it is now setting export targets consistent with the aim of enhancing India's reputation as a maker of quality steel. SAIL is aware of the changing needs of the world market, and has constantly striven to ensure quality products at competitive rates. Figure-8 shows SAIL's thrust to its export drive from its current levels to 3.5 million tonnes by 2005.

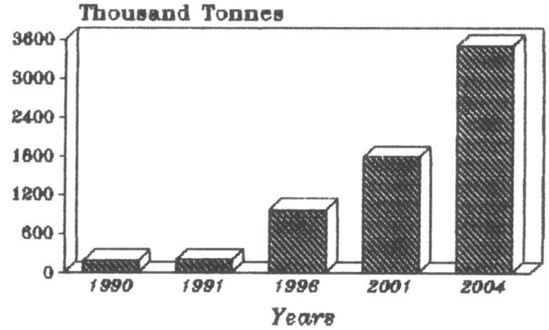


Fig 8 : Export trend and plan – SAIL
(Year period is April-March)*

SAIL as a steel maker is now well known, but SAIL's vital contribution to the nerve of the Indian economy viz. Agriculture sector, in the form of fertilizers produced at Bhilai and Rourkela, is significant. It also produces vital coal chemicals viz. Benzol products, Tar products etc. SAIL's granulated slag provides ample support to Indian cement manufacturers. SAIL thus reaches out to all sectors of the Indian economy, lending a hand to one and all,and contributing critically to the country's developmental strides.

SAIL ON INTERNATIONAL SCENE

In its efforts to cross newer frontiers, SAIL is diversifying its activities by bringing together its special technical and professional expertise, based on three decades of experience in steel making.

SAIL now offers the international steel companies with services in the following areas:

Projects & Engineering Services

- Preparation of study reports/Feasibility and detailed project report
- Project Engineering and Management
- Contracts and commercial assistance

Technical & Management Services

- Operation, Maintenance and Technical services
- Marketing and Distribution of Products

Technology and Know-how Services

- Process Modelling for optimisation of resources, process and output.
- Environment and Pollution control
- Waste Utilisation
- Development of new products
- Technology Transfer

Human Resource Development

- Training in operation and maintenance.
- Management Division programmes for different levels.
- Action leadership programme
- Customer specific training modules.

SAIL VISION

SAIL's activities are diverse and all pervasive, having within its fold different technologies and disciplines. SAIL plants and associated units give it the cutting edge to become one of the world's largest conglemerates in steel. Its expertise, honed by the latest state of the art technology, is based on several years of experience. What crowns its effort is the huge reservoir of human talent awaiting new challenges within the country and seeking fresh pastures across the seas.

SAIL has the potential to become not only one of the least expensive steel producer in the world, but possibly the third largest steel producing company next to Nippon Steel, Japan and Pohang Steel of Korea by 2004-2005.

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Optimization of the Steel Industry in Developing Countries

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Abstract

Optimization of the Steel Industry invokes multiple parameters and determining factors in different regions and countries - developing and developed. There are few standard yardsticks for defining and measuring optimisation on a universally acceptable basis. Formulation of different parameters covering optimisation such as steel production and productivity, energy consumption and availability, yield figures and quality characteristics, capital and operational costs, environmental protection measures, market acceptance and profitability, management and training etc., presents diverse rationale and performance patterns.

Steel industry in developing countries tends to follow optimisation criteria and performance results that could be significantly different from optimisation of the steel industry in advanced countries even though the two may have common objectives.

Optimisation of the steel industry in developing countries is necessarily tied to its technological status, its updating and upgraded operations. In some developing countries, the steel industry has been set up with foreign technical aid and financial assistance, thereby tied to donor technology for iron and steel production. Such donor technology has not necessarily been the most modern or optimum since it was based on donor technical aid package which thereby restricted the choice of steel plant design and equipment and limitations on the applied technology. In effect, the entire turnkey steel plant operations were affected by such bilateral aid requirments which in turn greatly influenced the optimisation characteristics and operational parameters. Such spectra heavily characterized the establishment, operations and optimisation of the steel industry in some of the developing countries such as India, Pakistan, Iran, Egypt, etc., etc.

On the other hand, the establishment of the steel industry in developing countries such as South Korea, Malaysia, Indonesia and Taiwan (ROC) followed relatively much more modern and updated technology which in turn yielded optimisation characteristics and performance results qualitatively and quantitatively distinctly superior.

Then there are the developing countries of Latin America such as Brazil which followed technological routes and upgraded technology that yielded another set of optimization spectra. And lastly covered is the steel industry in the centrally planned economy developing countries.

The example of the steel industry's growth in China in recent decades and years stands as a classic illustration of self-reliance aided by judicious selective collaboration untied to foreign aid limitations and characteristics and this in turn yields another optimization spectrum.

The paper concludes with the stipulation that there are no universal standardized optimization characteristics and parameters that can be globally applied to the burgeoning steel industry in the developing countries.

THE SUBJECT OF OPTIMIZATION connotes albeit empirically co-ordination of various parameters and their standardization but in effect and practice invokes multiple interpretations. A steel man when asked how his wife was replied "compared to what". So the subject of optimization also entails the comment "compared to what". This then is the dilemma which any discussion of optimization presents itself. Optimization of capital costs, productivity and production costs, technology applied and process employed, quality of product-mix obtained and the sale price it commands, each of these variants affects, links and inter-links the overall subject of optimization which is considered by some to be sensitive for any unified evaluation of an industry. The iron and steel industry with its high capital costs and low profitability brings forth the comment - go for cosmetic industry if you want to make money.

The year was 1966/67 when the writer undertook his first UNIDO technical consultancy mission to South Korea for establishing its integrated steel industry, preceded by a mission of persuasion to the World Bank which opposed any assistance or talk of any integrated steel industry in South Korea.

The World Bank as also some others had in those years warned against setting up any integrated iron and steel industry in South Korea since the latter had no raw materials resources of optimum quality such as iron ore, coal, gas or oil as also of Korean domestic markets. When the writer quoted the Japanese steel industry to the high and mighty, the pitch reply was "Everybody is not Japanese". And yet to-day, the state-sponsored Pohang Steelworks (POSCO) in the Republic of Korea is adjudged to be the world's lowest cost integrated steel producer and the same POSCO is now join hands with U.S. Steel to help modernize its Pittsburgh, California facility. Let us elaborate on this subject of optimization of the capital costs for integrated steel industry.

At the current prices, the capital investment costs per ton of installed steel capacity is reportedly of the order of US $2000. However, much depends upon the ingenuity and negotiation skill of the steel equipment buyer and he takes into account the fact that capital equipment/good industry in the advanced countries is depressed as much as their steel industry is and that they need capital goods in order to keep their capital goods industry at economic capacity operating levels. And look at the case of South Korea which shows the figure reportedly as low as $700-$800 per ton installed steel capacity vide the following:

"POHANG IRON AND STEEL CO., said construction began end 1985 on South Korea second integrated steel mill on the Bay of Kwangyang on the southern coast. Posco said the mill, with an initial crude steel production capacity of 2.7 million tons a year, is scheduled for completion in June 1987 at a total cost of $1,465 billion won ($1.7 billion), including $498 million in foreign loans. For the project, Mitsubishi Corp., of Japan, Voest-Alpine AG of Austria, Mannesmann Demag AG of West Germany, Davy McKee PLC of Great Britain and several other foreign makers have formed consortia with Korean makers to supply plants, Posco official said. (AP-DJ)".

The Kwangyang Bay works is the cheapest steelworks anywhere in the world in recent history. Posco estimates that it cost as little as $637 per tonne of annual raw steel capacity. Considering that this total construction cost also included costs of the site and land reclamation work, that per-tonne cost is very low when a comparable world figure is close to $1500 per tonne.

Posco adds that the unit construction cost of Kwangyang second phase expansion will be as little as $370 making a two-phase average of $504 per tonne. The company compares this with the per-tonne construction cost of Brazil Tubarao works of about $700, and China Steel second phase expansion cost of $857. Posco says its low construction cost will strengthen its international competitiveness. (Metal Bulletin, 15 May 1987).

From the actual analysis of the bids received in 1985 for establishing a 50,000 tpy capacity steel re-rolling mill (only rolling imported steel billets), the capital equipment costs quoted by well established equipment suppliers range from over US $25 million to as low as US $2.4 million. And here comes the catch, catch as you catch can. These are not hypothetical estimates; these are based on actual bids received and under scrutiny/study. These illustrations can be multiplied, the multiplier effect is multiplied depending upon who is bidding for whom. Identical criteria will apply when a developing country is "buying" the capital investment funds; the rate of interest levied for such capital investment loan have been as low as 2.5% with loan payments covering 25 years and with 10 years of grace period.

One has to keep an alert and roving eye on the current developments. Capital costs for a four-million tons/year capacity pelletizing plant which has gone into operation during 1985 has been of the order 50-55 US $/tonne installed capacity whilst there are examples where this figure has been multiplied by three, the infra-structure and supporting facilities being the same in two cases.

Optimization and Growth of Steel Industry in Developing Countries

Many in developed/industrialized countries have questioned the logic and wisdom of establishing and of expanding steel industry capacity in developing countries in the face of world-wide over-capacity particularly in developed and industrialized countries; this indeed is a critical/crucial question based on the implication that the growth of the steel industry in the developing countries is misguided owing to over-capacity in advanced countries. The counter question posed would be why and how did the advanced countries set-up such over-capacity in steel production in the first place when their domestic steel consumption was much less than their installed/burgeoning capacity and equally so in the face of cost competitiveness, shrinking home markets and aging/obsolete steel facilities? The answer to both these questions lies in the pruning and establishing optimized steel capacity in the advanced countries through scrapping of old steel facilities/plants, reducing manpower and increasing productivity whilst introducing newer innovative technologies. The optimization of steel capacity in developing countries is also being pragmatically realized, based on rising domestic markets/demands, objectives of self-reliance and self-sufficiency, reducing foreign exchange/import costs and last but not the least in establishing a sound steel cored technological base to promote the catalytic in-tandem growth of engineering industries and technical manpower and in other words accelerated industrialization.

Now pose these questions to a developing or a developed country bereft/devoid of raw materials and natural resources for setting up the steel industry - raw materials of iron ores, coal/coke etc., and natural resources of oil and gas. The Republics of Korea and Japan provide the practical answers. The lesson learned is from the Japanese example in 1960s and 1970s that a steel industry dependent upon the imports of raw materials can be competitive domestically and in the world markets only if the capital costs are kept optimally low and the facilities are technologically highly advanced and productive in terms of tons of steel produced per man year such as of: Japan 391 tons, USA 349 tons, FRG 381 tons and Brazil 141 tons - all in 1987 and these figures are being continuously upgraded.

POSCO in the Republic of Korea produces internationally cost competitive steel despite imports of almost 100% of the raw material requirements (95% of its iron ore and 100% metallurgical coal) as shown in Table 1. The production cost of steel at POSCO is even lower than that of Brazil even whilst Brazil's production cost is one of the lowest in the world considering Brazil's modern steel plants, high grade supplies of domestic iron ores etc..

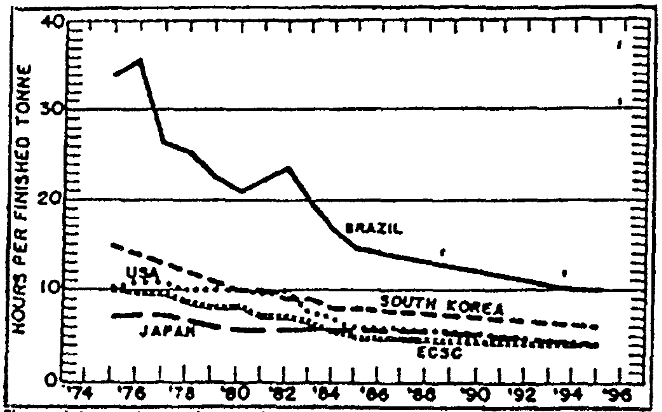

Figure 1 Labour productivity in some selected countries. 1/

POSCO's achievements growing from an underdeveloped farmland with mostly unskilled manpower to modern industrial complexes of efficient steel industry and shipbuilding yards with highly skilled force represents optimisation at its best - a model for developing countries to follow. Taiwan (ROC) is another good example. Low production costs coupled with high quality of steel output are the target for these countries. Brazil for example could produce flat products at US $270 per tonne and so could Taiwan at US $280 per tonne compared to US $342/tonne in Japan and US $492/tonne in USA to roll out flat products. Pohang's figure was around US $282/tonne in 1982 and this has been further lowered and improved upon.

U.S. steel industry has also to-day rebounded to high productivity, an essential requirement of high wages and labour costs. U.S. steel industry required in 1987 4.5 man hours to produce one net-ton of steel, the West Germans needed 5.8 man hours to do so and the Japanese required 5.5 man hours for the same one net-ton of steel made in 1987/88.

Labour productivity measured in terms of tonnes per man year has been reported in 1989 to be the highest for Pohang (South Korea) at 612 tonnes, NSC-Japan 392 tonnes, Kawasaki-Japan 371 tonnes, Sumitomo-Japan 363 tonnes, NKK-Japan 331 tonnes, China Steel-Taiwan (ROC) 352 tonnes, Usiminas-Brazil 109 tonnes, TISCO-India 74 tonnes, SAIL-India 45 tonnes, U.S. Steel 527 tonnes, Bhilai and Bokaro Steel-India 71-72 tonnes.

The latest figures released for 1989/90 indicate the following man hours per short ton of steel produced in the UK and USA:

UK-British Steel Corporation - 5
USA-National Steel - 6
USA-Great Lakes Steel - 5.1
US-LTV Indiana Harbour Steel - 3.5
US-Bethlehem Steel - Burns Harbour - 3.3
US-Inland Steel - Chicago - 3.2
US-US-X - Gary Works - 3.1

Figure 1 depicts labour productivity in some selected countries.

Brazil

To-day the Brazilian steel industry is the sixth largest in the world with an installed capacity of about 27 million tons of steel/year. Brazilian steel industry produces full range of steel product-mix - covering, flat, non-flat, carbon steels, stainless steels and special alloy steels to meet the domestic needs of a growing economy and sophisticated industrial base as also for export markets. The prospects of Brazilian steel industry's growth are among the best in the world. Despite having one of the highest capital costs per ton of installed steel capacity in the world, no major steel producer with the possible exception of South Korea has lower steel production costs than Brazil. This ensures the Brazilian steel industry to compete internationally. With low labor cost per ton of major steel producers and continued improved productivity per man hour, Brazil steel producers can maintain their competitive cost edge even whilst wages increase by upgrading productivity, employing sophisticated management techniques and applying proved newer emerging technologies.

Brazil's raw steel output has been 25.5 million tonnes in 1990 rising from 24.7 million tonnes in 1988. Exports are meanwhile expected to be steady at about 11 million tonnes of semis and finished steel in 1989 rising from 10.9 million tonnes in 1988. Out of this figure, slab exports would be about

Table 1 2/

Class I Cold Rolled Steel
Cost Breakdown by Process for Steel Mills in U.S. and Abroad

USS PER SHORT TON	TYPICAL US MAJOR	LTV BEFORE	LTV AFTER	U.S. MILL	WEST GERMAN MILL @ 1.85DM/S	JAPANESE MILL @ 155/C/S	CANADIAN MILL @ 0.73C/S	S.KOREAN MILL @ 850 WON/S	BRAZILIAN MILL @ 10,000 CR/S	MINI MILL C.R. COIL	MINI MILL MERCHANT BAR
Iron Ore	36	38	31	39	26	25	35	25	11	0	0
Met Coal	50	55	45	41	57	58	55	58	67	0	0
Hot Metal	140	148	123	140	127	115	130	109	103	0	0
Liquid Steel	180	188	164	172	175	165	170	153	145	0	0
Slab	215	220	187	200	209	190	205	173	172	155	140
H.R. Coil	285	254	254	270	280	245	275	213	222	175	155 (billet)
C.R. Coal	365	377	327	345	352	310	345	256	275	215	200 (bar)
S.G.&A	32	32	24	22	27	35	26	18	25	285	N.A.
Financial	46	56	29	28	55	130	34	86	111	20	10
Total Pretax	443	461	380	395	434	475	405	360	411	80	20
Before										385	230
Financial	397	405	351	367	379	345	371	274	300	305	210

5 million tonnes in 1989. Brazil's large producer of slabs, Cia Siderurgica de Tubarao (CST) would have exported three million tonnes of slabs in 1989. Usiminas would have exported about 0.4 million tonnes of slabs during the same period including exports to USA - Lone Star Steel and California Steel. The impact of 1977-79 oil shock, rising interest rates on international borrowings and debts has been severe. Between 1980-1983 per capita steel consumption dropped by 30% and total domestic apparent consumption by 40% as a result of domestic economic problems and depression. Whilst total domestic apparent consumption in 1987 showed recovery surpassing the 1980 level, per capita steel consumption still remained 20% below 1980 levels at about 25% of U.S. per capita steel consumption. Brazilian steel industry was thus confronted with debt crisis and negative growth particularly when its expansion was fructifying to meet the projected increased domestic steel demand forecast earlier. Thus the Brazilian steel industry had no choice except to export thereby achieving a share of world export market consistent with its share of world steel production.

The drop in the domestic steel market and poor recovery led to revision in the further growth of the Brazilian steel industry faced as the latter was with half-completed projects which could not be cancelled nor equipment already delivered to be discarded, including completion of the two new greenfield plants of ACOMINAS and CST. Whilst the second National Plan called for the establishment of 50 million tonnes annual capacity by the year 2000, the projected expansion had to be curtailed to 30% increase of the installed capacity in the same period.

Thus the Brazilian steel industry proceeded more on fulfilling optimisation plans rather than direct growth. SIDERBRAS-state owned steel group is now engaged in raising the productivity of the completed integrated plants of COSIPA, USIMINAS and CSR, further optimising the steel product-mix and applying environmental control measures.

Private sector steel plants such as Grupo Gerdan and Belgo Mineira, likewise, will be engaged in optimising productivity and quality of steel product-mix, improving environmental conditions and production costs. No additional investment and increased capacity are planned.

India

The crude steel production in India during 1988 was 14.2 million tonnes; of this about 11 million tonnes were produced in the major integrated steel plants and the balance 3.2 million tonnes in the Mini steel plants based on electric arc furnace route using steel scrap and DRI sponge.

The first major integrated steel plant in India was set up in 1910/11 by the Tata Iron and Steel Co. Ltd.; it has currently a capacity of 2.2 million tonnes of crude steel/year which is being raised to 3 million tonnes in the current expansion plans. TISCO is the only major integrated steel plant in the private sector whilst there are some semi-integrated steel plants also in the private sector; the Mini steel industry wholly belongs to the private sector in India. All the other major integrated steel plants are state owned including the new complex at Visakhapatnam nearing completion.

The technologies employed in the integrated steel plants vary widely mainly because the sources of donor technologies from overseas technical collaborators and financial aid agencies were different and the plants werre set up at different times. Most of the plants utilize low proportion of sinter in the blast furnace burden ranging from 30-40% and only one plant going up to 62% sinter burden. Owing to high ash coke and adverse Al_2O_3/SiO_2 ratio of the Indian iron ores, the coke rate ranges from 680-880 kgs/tonne of iron. The average blast furnace productivity is also low ranging from 0.6 to 1.1 tonnes/cu.m/day in different plants. The steel productivity is also very low ranging from 30 tonnes to 75 tonnes per man year in different steel plants. The average energy consumed per tonne of crude steel is also very high ranging from 10 to 15.5 (G cal) million kilo calories in different plants. 42% of the total crude steel capacity is still based on basic OH process. The LD oxygen steel making process is being expanded - average no. of heats ranges from 5000 to 7000 heats/year. The proportion of continuously cast steel in the integrated steel plants is a mere 12% and 27% if the Mini steel plants are taken into account.

Table 2 . 3/ **U.S.A.: Share in domestic apparent consumption of steel imports by countries and regions of origin**

Years	Japan		E.E.C.		Latin America		Others		Total %	Apparent consumption
	Import. (1000 t)	%	Import. (1000 t)	%	Import. (1000 t)	%	Import. (1000 t)	%		
1979	6.336	5,5	5.405	4,7	647	0,5	5.130	4,5	15,2	114.962
1980	6.005	6,3	3.887	4,1	630	0,7	4.969	5,2	16,3	95.247
1981	6.220	5,9	6.482	6,1	782	0,7	6.414	6,1	18,8	106.444
1982	5.185	6,8	5.597	7,3	974	1,3	4.907	6,4	21,8	76.338
1983	4.237	5,1	4.114	4,9	2.415	2,9	6.304	7,6	20,5	83.455
1984	6.630	6,7	6.334	6,4	3.132	3,2	10.067	10,1	26,4	98.922
1985	5.975	6,3	6.977	7,2	2.625	2,7	8.678	9,0	25,2	95.495
1986	4.425	4,9	6.613	7,4	1.963	2,2	7.692	8,5	23,0	89.969
1987	4.288	4,5	5.782	6,1	2.144	2,3	7.710	8,1	20,9	95.330
1988	4.290	4,2	6.226	6,0	2.602	2,5	7.773	7,6	20,3	102.915

Table 2 shows the U.S. steel imports from different regions/countries from 1979 to 1988 with Latin American exports to USA to be 2.6 million tons in 1988, chiefly from Brazil.

It will thus be seen that the Indian steel industry has poor productivity, high energy consumption and low yield figures which leads to high steel production costs. The integrated steel plants have therefore started a massive modernization program to upgrade the production technologies and productivity and lower the operational/ production costs although the current situation and scenario is dismal and the overall optimization is one of the lowest. What exactly are the reasons for these poor characteristics. One basic reason is that Indian steel industry has continued to operate outmoded technologies of the 50s. The Indian steel industry owes its growth to "tied" technical and financial packages from overseas such as from Soviet Union, UK and FRG. Such donor technologies of the 50s have not necessarily been the most modern or up-to-date which has thereby restricted the choice of the most optimum steel plant design and equipment and severe limitations on the applied technologies. On the other hand, the establishment of the steel industry in South Korea, Taiwan (ROC), Malaysia followed much more modern and updated technologies such as for example from Japan which has thereby yielded optimization characteristics and performance results qualitatively and quantitatively distinctly superior to those of Indian steel industry.

The steel industry's growth in China in recent decades and years stands as a classic example of self-reliance aided by judicious selective foreign collaboration untied to foreign aid limitations. Starting almost from scratch after World War II, the Chinese steel industry has grown from 8 million tonnes/year output in 1958 to about 60 million tonnes in 1988/89.

The result of multiple aid donors of Indian steel industry has been that the facilities of each steel plant have been different from one another and do not incorporate the latest design or technologies; in some cases the technology applied in the 60's has been the most obsolete, a glaring example of which has been the installation of a jumbo slabbing mill at Bokaro steel plant by the Russians in the 70s instead of a modern continuous slab caster; the installation of the latter will now take place at Bokaro in the 90s, almost a quarter century later. Furthermore, the Cold Strip mill supplied by the Russians is reportedly unable to cold roll strip below 0.3 to 0.4 mm in thickness at Bokaro steel plant with the result that Bokero had to install separate cold-rolling mill stands from Wean-United (U.S.) to achieve 0.15 to 0.2 mm thickness needed for tin plate production. Bhilai steel plant had put up jumbo basic open hearth steel making furnaces of up to 500 tons capacity of Soviet design when in Japan and elsewhere, LD oxygen steelmaking/BOF furnaces were correspondingly set up. Labor productivity in the Indian steel industry has thereby been one of the lowest in the world as shown below: Table 3

The norms of performance of some of the integrated steel plants in India compared with international practice are very low. Bhilai and Bokaro steel plants were set up with Soviet collaboration whilst Durgapur and Rourkela were set up with British and FRG collaboration respectively. The new steel plant under completion now, Visakhapatnam steel plant is based on Soviet collaboration. 4/

Energy consumption in the steel industry

The current energy consumption in the Indian steel industry is of the order of 10.8 to 15.5 G cal (million kilo cal) per tonne of crude steel compared to the international levels of 4.5 to 5 G cal. Table 4 depicts the Indian scenario.

Table 4 4/

Specific Energy Consumption per tonne of crude steel in Indian steel plants (G cal/tonne crude steel)

	1982/83	1983/84	1984/85	1985/86
Bhilai	9.005	8.926	8.985	8.830
Bokaro	10.789	10.962	10.537	10.815
Durgapur	10.813	11.756	12.497	11.456
Rourkela	13.464	12.919	11.834	11.122
IISCO	16.313	16.414	19.662	15.469
TISCO	10.554	9.994	9.760	9.681

The International Iron and Steel Institute postulates good steelmaking practice at about 4.6 G cal/tonne of steel. In Japan the consumption has been brought down in 1988/89 to 4.15, in USA to 5.8, in the UK to 4.579 and FRG to 5.164 to 5.5 G cal per tonne of steel. The much higher energy consumption per tonne of steel made in India has been attributed to obsolete technology, high ash contents of Indian coals, low yields, very limited waste heat recovery, inadequate preparation of raw materials and low percentage of agglomerated sinter in the blast furnace burden.

Mini steel plants in India likewise have a very high energy consumption per tonne of steel made in electric arc furnace practice at over 700 kwH compared to 420 KwH in advanced overseas practice.

Table 3 4/

Steel plant productivity in tonnes of steel ingot produced per man year

Years	Bhilai	Bokaro	Durgapur	Rourkela	IISCO	TISCO
1982-83	72	71	39	44	34	64
1983-84	63	63	34	42	28	64
1984-85	69	60	31	43	22	68
1985-86	68	65	37	46	30	68
1986-87	68	61	39	48	29	74

Table 5 depicts the recent energy consumption data of some steel plants in Europe.

Table 5

Net Energy Requirements of the Steel Industry

Country	1985 G cal/tonne crude steel	1985/1980 % change	Process Pattern 1985 % BF/BOF	Process Pattern 1985 % EAF	Remarks
Spain	3.875	17.8	39	61	Steelmaking based
Italy	4.55	3.9	48	52	largely on EAF
Sweden	4.25	25.6	48	52	Route
Netherlands	4.4	9.6	100	0	Steelmaking based
Japan	4.425	9.3	71	29	on 70/75 BOF and
UK	5.3	9.4	72	28	30/25 EAF Routes
Brazil	5.75	NA	72	25	(— IISI)

Past, present and the future

In May 1941, the "A" Blast Furnace of Tata Steel in India created a world monthly production record of 37,721 tons of hot metal, the highest production from a single blast furnace in the world in 1941; this was despite the fact that this blast furnace of Tata Steel was not the largest installation in the world at that time. The overall rate output of Indian blast furnaces during the pre-independence era was 1.14 tons/ cu.m./day. It is regretable that owing to continuously rising ash contents of Indian coal/coke, this figure has droppped to less than 1 ton/cu.m/day whilst in other countries, it has risen to 2 and even 2.5 tons/cu.m/day.

China adopted BOF/LD oxygen steelmaking practice soon after Rourkela steel plant in India put up 40 tons BOF/LD vessels in the fifties. The first BOF/LD oxygen steelmaking shop set up at Shouda Iron and Steel co., consisted of three 30-ton converters rated to produce 0.6 million tons of steel per annum. To-day, the same shop in China with the same converters is producing 1.88 million tons of steel annually. Compared to this, the three 40-ton BOF/LD oxygen steelmaking converters shop at Rourkela designed to produce 750 ,000 tons of steel per year, is currently producing 500,000 tons of steel/year and the maximum achieved was 811,00 tons during 1965-66.

The situation in Eastern Block countries is no different from that in India where most of the steel plants were put up with Soviet collaboration. Thus there are no universal optimisation characteristics and parameters that can be globally applied to the burgeoning steel industry in developing countries in which the Japanese steel industry has played a very valuable role particularly in the case of South Korean, Brazilian and Chinese steel industries.

It is appropriately stressed that the iron and steel industry's establishment and sustanined growth in developing countries should not be left to the vagaries of bilateral financing and technical collaboration but should be subjected to critical techn-economic evaluation by independent experts/sources. Examples of foisting obsolete and unmatching technologies are not rare but abound in the case of developing countries; a typical illustration is the installation of a large continuous bloom caster and the c.c. bloom to be rolled in a billet steel rolling mill and the final end-products are R.C.C. rods, bars and rounds to be rolled in a merchant mill from the steel billets. A continuous billet caster would have been ideal eliminating thereby the capital cost of Bloom and billet steel rolling mill as also the heavier capital cost of a continuous bloom caster. The bi-lateral donor/technical collaborator, in this particular case, did not posses the continuous billet caster technology. Such illustrations can be multiplied in actual cases/practice. The choice of technological processes and the economic consideraitons often tend to be based on non-technical factors in the case of developing countries where the selection of process technology and the related plant equipment, are inevitably linked with the particular supply of iron and steelmaking plant and equipment by the country which furnishes the financial and technical aid package. For example,in one leading developing country, the BOF/LD oxygen steelmaking plant was installed in the late eighties instead of the early sixties when basic open hearth steel melting furnaces were wrongly preferred owing to above considerations/requirements. The history of steel industry in developing countries is replete with such examples of empirical rather than optimised growth.

The optimisation of steel industry in developing countries has to be carried out all the way centering around the most optimum technology and appropriate equipment and layout; that this has not been universally the experience in the past should not mean that such trends and history should repeat themselves in the future also.

The VSZ-SLovak steel plant at Kosice in Czechoslovakia operates an integrated facility producing mostly flat products; this plant was set up with Soviet collaboration as was done in the case of Bokaro steel plant in India. The VSZ-Slovak steel plant's cold strip mill is reportedly unable to produce cold rolled strip below 0.35 to 0.4 mm, a situation which was rectified by Bokaro in India by putting additional cold rolling stands from Wean United (USA). The Galatz steel plant in Romania has fared better with western supplied equipment and so has the Skopje steel plant in Yugoslavia. The Smederov steel plant in Yugoslavia uses domestic low-grade iron ore with resultant poor results all the way instead of using high-grade imported iron ores. South Korea on the other hand rightly keeps exporting its highly siliceous iron ores from Yang Yang mines to Japan for blending with high alumina iron ores imported by Japan from India. For its integrated steel plants, South Korea wholly imports high grade iron ores. Helwan Steel plant in Egypt on the other hand keeps smelting its high phosphorous Asswan iron ores and lately Bahariya iron ores with high alkali contents. Paz Del Rio steel plant in Colombia prefers to use high phosphorus domestic iron ores; it could well barter its abundant high-grade coal resources for high-grade iron ore from Venezuela which imports coal from overseas. Acepar of Paraguay rightly uses high-grade Brazilian iron ores for its small blast furnace using charcoal for iron smelting. Piratini in Brazil uses 30-35% ash coal for its SL/RN rotary kiln operations to produce directly reduced sponge iron.

India has started importing low ash coking coals only recently for blending with domestic high ash metallurgical coking coals. Skopje steel plant in Yugoslavia continues to use its low grade chamostitic iron ores containing 35-40% Fe for iron smelting in submerged arc electric pig iron furnaces with or without prior pre-reduction with dried lignite; prior costly beneficitation of chamosite iron ore to raise its Fe content to 43% is not of much help. Siderperu at its Chimbote steel plant uses coke breeze, anthracite and plenty of costly imported oil for directly reducing its high-grade iron ore from Nazca (South Peru) in rotary kilns. The Danube steel plant in Hungary set up with Soviet collaboration continued to use stationary open hearth furnaces for steelmaking until recently when it switched over to BOF steelmaking operations; the opening phosphorus of the scrap and hot metal charge in their stationary open hearth furnaces was reportedly 0.045-0.05% and it had to have a tap-to-tap time of about 11 hours merely to oxidize and refine the silicaon, manganese and carbon contents. The Sendzimier steel works in Poland still labors with its open hearth steelmaking shop containing some twin-open hearth furnaces; this plant was set up with Soviet collaboration and the Soviet steel industry even to-day produces almost 50% of its steel output by the obsolete basic open hearth route even whilst the latter has practically disappeared in most steel producing countries of the world.

The scrapping of the Purofer direct reduction process in Brazil and FRG, the INCHON direct reduction plant disaster in South Korea, disappearance of the Strategic-Udy Dr-rotary kiln process, etc., are other milestones of the global steel industry. And to-day, the march of combined blowing technologies in converter steelmaking, secondary steelmaking and ladle metallurgy-steel refining rule in advanced countries and are catching the limelight albeit slowly in developing countries.

The optimization of the process routes coupled with the optimization of the steel plant equipment, has to be synchronized with the growth of the steel industry in the developing countries. The developments in thin slab casting (developed by SMS-CSP) of FRG and industrially implemented at Nucor in USA followed by Koahsiung in Taiwan and other pioneering developments by Mannesmann-Demag, Voest-Alpine, DVAI, Danieli, Kawasaki-Hitachi in their slab casting are there to watch and follow on appropriate optimization basis particularly in developing countries with their scanty resources of trained manpower and capital funds.

In conclusion, it is stressed that the development of steel industry in the developing countries should be based on sound techno-economic optimization characteristics instead of on techno-political considerations, considering that the steel industry is highly capital intensive.

Acknowledgments

Technical data presented in these pages has been evaluated by the writer after consulting scores of references in current technical literature (journals and publications) to whom due acknowledgment is thankfully made. Most of the views offered herewith are of the writer himself. Individual references/sources are indicated wherever possible.

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The System of Consultations of UNIDO for the Development of the Iron and Steel Industry in the Developing Countries

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I. The System of Consultations of UNIDO

The System of Consultations is an instrument through which the United Nations Industrial Development Organization (UNIDO) serves as a forum for high level policy makers from Governments and business for discussions on sectoral issues directed towards a viable industrialization with the aim of assisting developing countries to increase their share in world industrial impact.

Participation in the consultation meetings is reserved mainly for private industry and policy-makers from Governments and enterprises. Such selected participation ensures a multidisciplinary and broad coverage of the issues to be discussed and in the formulation of policies and strategies for the development of a selected industrial sector or sub-sector.

The consultations can be organized at global (worldwide) level or at regional or sub-regional level. The System of Consultations has held numerous meetings covering sectors and topics such as:

- agricultural machinery
- building materials
- capital goods
- electronics
- fertilizers
- fisheries
- food processing
- industrial financing
- training of industrial manpower
- leather and leather products
- petrochemicals
- wood and wood products
- non-ferrous metals
- iron and steel

Part of the consultation process consists of preparing studies and analyses of the sector or sub-sector and convening preparatory expert group meetings. They examine the relevant trends including the constraints to enter the industry and policy recommendation to overcome the identified constraints. Expert group meetings are aimed at identifying the major issues to be discussed during consultations. In these EGMs specialists well known for their experience in the particular sector or brand of industry are invited on their own capacity to participate with UNIDO experts in the identification of such issues.

II. Consultations in the Iron and Steel Industry

Four global consultations have been organized since 1977, two in Austria, one in India and one in Venezuela. A number of expert group meetings were organized at the regional level in preparation for those Consultations. A detailed list of meetings can be found in the Annex to this paper.

The First Consultation on the Iron and Steel Industry, has convened in Austria from 7 to 11 February 1977. It gathered over 150 representatives from more than 65 countries. The Consultation concentrated itself on issues related to the long-term prospects for the development of the steel industry and its requirements in terms of raw materials, fuel, technology and financing. UNIDO was requested to actively promote a continuous exchange of information on the sector and to identify obstacles hampering the development of the world steel industry and ways to overcome them; as well as means and strategies for securing the price competitive availability and supply of steel making raw materials.

The Second Consultation was held in New Delhi, India from 15 to 19 January 1979. The Consultation focused on the changing pattern of world steel production and constraints connected with financing. The Consultation called for a medium-term development programme; international cooperation on supply/contractual procedures of iron ore and coking coal; assistance to developing countries in establishing a steel industry, particularly in relation to technical and economic consultancy as well as human resources development activities; and the analysis of social and human aspects of the development of the iron and steel industry. UNIDO organized the Third Consultation in Caracas, Venezuela from 13 to 17 September 1982. It discussed issues related to manpower training, financing iron and steel projects and the entry of newcomers into the steel sector. The meeting recommended increasing the exchange of information and cooperation between developing countries on training activities. The necessity for development of universal guidelines for training methodologies was underlined. Special emphasis was placed on the evaluation of existing systems for financing infrastructure and training as well as measures to be introduced to assist newcomers in the commissioning of new projects, particularly those using mini mill technologies.

Austria was the host of the Fourth Consultation held in Vienna, from 9 to 13 June 1986. The Consultation put special emphasis to the analysis of the iron and steel situation and the restructuring process experienced by the world steel sector. Alternative development strategies for the iron and steel industry in developing countries were analysed. The importance for the developing countries to develop an integrated approach between the iron and steel industry and the capital goods sector as a basis for more independent, cost-effective and self-reliant economic and social development was stressed.

Impact of the Consultations on the Iron and Steel Industry. The conclusions and recommendations stemming from the deliberations of these meetings have a multi-disciplinary nature. They appeal to all the actors involved in the steel industry: governmental policy-makers, regional institutions, steel managers and industrialists, as well as international financing and industrial institutions. They have served as valuable and practical tools for decision-makers of the steel community both from developed and developing countries in the formulation of sustainable and sound strategies and policies for the development of the steel industry in their respective countries.

Furthermore, the outcome of the consultations has enabled UNIDO to design more efficiently its technical assistance activities in the field of iron and steel thus enlarging the benefit of the developing countries from international industrial cooperation.

One illustrative example of UNIDO's response to the consultation process is the establishment of the Industrial and Technological Information Bank (INTIB). INTIB is the hub of a worldwide network of information centres -"Focal Points"- which have lines with local sources of specialized know-how and expertise. INTIB coordinates and maintains data bases with information including:

- -technology offers and requests, and joint venture opportunites;
- -industrial development: abstracts of reports, studies, etc. and directories of R&D centres and other information sources;
- -tecnology transfer agreements;
- -industrial energy saving;
- -clean technology;
- -materials technology.

Another important follow-up of the process of consultations has been the development of comprehensive training programmes to assist in the development of human resources in the field ofiron and steel in developing countries. A set of normative guidelines for the mastering of technology in iron and steel through training has been prepared.

These normative guidelines cover broad issues related to the commissioning operation and managing of steel plants. They help to evaluate and select the most appropriate technology and plant structure relevant to the domestic environment. Furthermore, a methodology for the evaluation of performance of key positions in the iron and steel plant has also been developed.

The industrial operations branches of UNIDO have been using and implementing these normative guidelines in their technical assistance projects around the world.

Additionally, the consultations process has served as an effective instrument for the identification of concrete and punctual needs of technical assistance in developing countries. A series of technical assistance projects have been rendered in the establishment, management and operation of new plants, including national planning of the metallurgical industry through master plans, techno-economic studies, feasibility studies and marketing studies. Practical expertise for rehabilitation, restructuring, modernization and efficient operation of existing plants has been rendered to countries in Africa, Asia and Latin America. Some examples: establishment of a scrap processing plant in Angola; establishment of the National Technical Consultancy and Training

Centre (NTCTC) in Czechoslovakia; establishment of a pilot and demonstration plant for the production of sponge iron, India; assistance in the introduction of computerized management maintenance system ao AHMSA and SICARTSA, Mexico; assistance to improve the quality control of Zisco Steel in Zimbabwe.

Last but not least, it is worth mentioning that the consensual and normative character of the Consultations has revealed itself as an efficient vehicle for fostering North-South as well as the South-South technical cooperation.

Moreover, through the discussions, the owners of technology and financial means required for development acquire clear and precise ideas of the specific needs of developing countries and, very often, use the event to arrange contacts aiming at establishing cooperation programmes/projects either on a multilateral, bilateral or enterprise-to-enterprise basis. The African Iron And Steel Association (AISA) has been established in December 1991 in Algeria as a direct result of a recommendation from the Fourth Consultation. UNIDO provided the necessary support in terms of expertise and technical assistance required for a successful launching of their activities. Other regional associations such as the Latin American Iron and Steel Association (ILAFA) and the Arab Iron and Steel Union (AISU) have been long-term partners of the System of Consultations. The conclusions and recommendations of the Consultations have provided an excellent framework for their operations.

III. Future Programme and Activities

The last years of the 80s and the beginning of the 90s have represented for the iron and steel sector a period of profound structural changes. The active entrance into the steel market of the former European centrally planned economies as well as the growing internationalization of the market, the increasing environmental awareness all over the world and the higher expectations on performance and reliability have set new requirements for steel producers in terms of quality and productivity.

In the developing countries the steel scenario is even less homogeneous. While the restructuring of the sector in Latin America, the Middle East and the developing Asia enabled some improvements in production and consumption figures and gave some prospects for optimism, the iron and steel sector in Africa has not followed the same pattern.

Despite a number of rehabilitation projects and commissioning of new plants during the 80s, the disparity between local production and consumption in Africa has increased by the end of 1991. At this year the share of Africa of the world steel production represented 1.3 per cent while the consumption was about 3.3 per cent. Given the prevailing shortage of foreign exchange, it is not surprising that steel imports have been declining which concomitant adverse effects on general industrial activity and development.

In the context of the above, the System of Consultations is determined to continue playing an active role in the iron and steel industry. We have planned our forthcoming activities in areas of interest for the whole sector, like application of total quality and environmental management in the iron and steel and coverage like in the case of the regional consultation in Africa.

(i) **Seminar ILAFA-UNIDO-IAS on Total Quality in the Iron and Steel Industry, 24-27 August, 1992, Buenos Aires, Argentina**

The seminar organized in cooperation by the Latin American Iron and Steel Association (ILAFA), the Argentinean Iron and Steel Institute (IAS) and the Pan American Standards Commission (COPANT). It will have as main topic the implementation of total quality management systems in iron and steel plants. Special consideration will be given to regional experiences and strategies that have been applied, difficulties encountered and how they have been overcomed; results and future developments. As to iron and steel technologies is concerned, it will be of interest the main means for securing quality regarding procedures, equipment, input and raw materials.

(ii) Regional Consultation on the Iron and Steel Industry in Africa, Lagos, Nigeria 1994 (tentatively)

The Regional Consultation in Africa will be organized in cooperation with the African Association of Iron and Steel (AISA). The expected growth of Africa's iron and steel industry in the 1990's and beyond will require the development of strategies and methodologies aimed at the identification and implementation of appropriate measures for the rehabilitation of the African Steel industry, the diversification of the product mix, the establishment of an adequate cascade programme for manpower training as well as the introduction of adequate techniques for improving the use of available natural resources.

One of the main objectives of the Consultation will be to provide a regional forum for all the main actors involved in the African iron and steel industry, including regional financial organizations, for in-depth discussion and analysis of suitable strategies for rehabilitating the industry, taking into consideration the local constraints.

A series of preparatory activities are being organized in order to ensure a higher impact from the Consultation for participating countries. Rehabilitation programmes for steel plants from the Preferential Trade Agreement Countries have been prepared and programmes for training in introduction of environmental management techniques are being developed. Technical assistance in preventive maintenance to countries from the Maghreb region has also been provided.

Furthermore, a series of meetings with selected experts from the African iron and steel community will be organized to discuss additional issues of concern to the region.

(iii) Global Consultation on Environmental Management in the Metallurgical Industries, 1995

The increasing interconnections between environmental management, cleaner technologies, waste minimization and competitiveness as well as the required legislative framework and its impact on industry profitability in the framework of market globalization will be one of the central issues of the Global Consultation on

Environmental Management in the Metallurgical Industries in 1995. Financial instruments for the introduction and application of enviromentally sound technologies will be analyzed.

This Consultation is of paramount interest, especially for developing countries where the environmental problems generated by the sector are a matter of increasingly concern.
Limitation of financial resources reduce, in most cases, the ability of plants to improve efficiency of raw materials utilization and upgrade environmental management techniques. Consequently, a large number of plants in developing countries operate with obsolete technologies and equipment, thus wasting valuable human and natural resources and energy and thus increasing the environmental load.

Preparatory activities for the Consultation have already been initiated in Africa, Asia, Latin America and Europe. In cooperation with other international organizations, such as the International Labour Organisation (ILO), the United Nations Economic Commission for Europe (UNECE), and regional iron and steel associations (ILAFA in Latin America, South East Asian Iron and Steel Institute (SEAISI), Arab Iron and Steel Union (AISU)), the System of Consultations has been establishing regional Advisory Environmental Committees. These Committees have as a major objective to follow-up and coordinate environmental-related activities of the steel industry in their respective regions.

In addition, it is foreseen that the Committees will establish working groups which will be expected to formulate and recommend concrete action in the following sub-sectors at the subregional or regional level:

(i) Environmental Management
- environmental auditing/monitoring
- pollution prevention programmes
- cleaner technologies
- standards/regulations
- cost benefit analysis of environmental projects

(ii) Metallurgical liquid waste management/ prevention

(iii) Metallurgical solid waste management
- dust minimization/ recovery
- slag/sludge minimization/recovery

(iv) Thermal pollution prevention/reduction

Aditionally, the working groups will:
- provide consultancy services in the region's iron and steel sector aimed at solving/organizing their environmental constraints/ activities;
- prepare comprehensive joint training programmes;
- develop and design regional research programmes in common problem areas;
- establish an environmental Iron and steel Data Base system using UNIDO's Data base system on energy and environment "REED".

Regular meetings between the advisory committees are planned for 1993 and 1994.

IV. Conclusions

Since its inception the System of Consultations has been a mechanism to help design and identify schemes of international industrial cooperation for assisting the developing countries in selected industrial sectors including iron and steel industry.

The globalization of the economy, the worldwide greater trade liberalization and the growing internationalization of the steel market have set new challenges to the steel community and therefore also to the System of Consultations.

We are fully aware of these emerging challenges and we are actively working in order to be able to continue providing our assistance to the iron and steel sector in developing countries. Our main goal is to assist them to attain better benefits from the new dimension of international industrial cooperation on the basis of the respect of the interest of all concerned parties.

"Appendix"

LIST OF CONSULTATIONS ON THE IRON AND STEEL INDUSTRY

-Preparatory Meeting for the First Consultation on the Iron and Steel Industry, Vienna Austria, 7-11 December 1976

-**First Consultation on the Iron and Steel Industry**
Vienna, Austria, 7-11 February 1977

-Expert Meeting of Research and Development Institutions on Adaptation of Iron and Steel Technology for Developing Countries, Jamshedpur, India 28 November-2 December 1977

-Preparatory Expert Group Meeting on Training in the Iron and Steel Industry, Vienna, Austria, 9-11 January 1978

-Working Group Meeting on Iron Ore, Vienna, Austria, 3-5 April 1978

-Working Group Meeting on Coking Coal, Vienna, Austria,
6-8 April 1978

-Expert Group Meeting on Training Problems in the Iron and Steel Industry, Vienna, Austria 24-26 April 1978

-**Second Consultation on the Iron and Steel Industry**, New Delhi, India, 15-19 January 1979

-Small Expert Group Meeting on Scenarios of the Iron and Steel Industry's Development, Vienna, Austria, 3-5 September 1980

-Second Small Expert Group Meeting on Scenarios of the Iron and Steel Industry's Development, Vienna, Austria, 12-13 March 1981

-Third Small Expert Group Meeting on Scenarios of the Iron and Steel Industry's Development, Vienna, Austria, 3-4 December 1981

-Second Working Group on Scenarios of the Iron and Steel Industry's Development, Estoril, Portugal, 3-5 February 1982

-Working Group Meeting on the Long-Term Contracts for Purchase/Supply of Iron Ore and Coking Coal, Bratislava, CFSR, 16-18 March 1982

-**Third Consultation on the Iron and Steel Industry**, Caracas, Venezuela, 13-17 September 1982

-Ad-hoc Expert Group Meeting on Strategies for more integrated Development between the Iron and Steel and the Capital Goods Sectors, Vienna, Austria, 16-18 October 1985

-Expert Group Meeting on the Preparation of Guidelines for the Establishment of Mini-Plants in Africa, Vienna, Austria, 2-4 December 1985, Vienna, Austria

-**Fourth Consultation on the Iron and Steel Industry**, Vienna, Austria, 9-13 June 1986

-Latin American Meeting on Total Quality Management in the Iron and steel Industry, Buenos Aires, Argentina, August 24-28, 1992

Future Activities

-Regional Consultation on Iron and Steel, 1994, Lagos, Nigeria (to be confirmed)

-Consultation on Environmental Management for the Metallurgical Industries, 1995, venue to be determined.

Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

Technological Innovative Restructuring of the Steel Industry in Central and Eastern Europe Including the Former USSR

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Abstract

The paper introduces UNIDO's technical co-operation projects in the iron and steel sector. Many eastern European countries have turned to UNIDO for technical co-operation and advice. The iron and steel sector is characterized by obsolete technology, overmanning and poor performance. It is an area of particular concern. Based on imminent needs special emphasis will be placed on improving management skills; improving plant profitability; preparing industries for privatization; advising on marketing/sales of products; reducing air and water pollution and utilizing wastes; as well as introducing cleaner technologies and energy conservation measures. Examples of completed, ongoing and pipeline (planning stage) projects are provided. Though UNIDO is certainly in a position to provide unbiased independent advice which is required by these countries, technical co-operation is restricted by the scarce available funds and donor financing is often the only solution to project approval to help metallurgical industries in central and eastern Europe to survive and become "clean".

UNIDO, like many other organizations and industrialized countries is following the developments in eastern Europe with great attention. The radical political and economic changes and the move from centrally planned economies to open market economies require adjustment by all concerned and improvements in all aspects, including technology, manpower, equipment and quality of output. Industries, including metallurgical plants are looking for Western partners and rationalization and modernization; after years of stagnation, investment is mandatory. Privatization of industries to increase efficiency and competitiveness has already started to take place with progress made by Hungary and Poland, followed by the CSFR and other countries.

Many disruptions in long-established centralized market outlets caused declines in sales of steel and other metal products as the companies have to cater for their own sales and product promotion and will have to establish, for this purpose, their own marketing departments.

Under the new political and economic environment in Eastern European countries, a major emphasis is being placed on converting industries to become competitive in a market economy. Some countries already stopped the operation of outdated and polluting production units and are trying to retrofit others. In this rationalization process, steel output of the industry in the region decreased substantially. The restructuring/ modernization and upgrading of the iron and steel industries in the former Eastern bloc countries, being a prerequisite for privatization, will require massive multilateral and bilateral assistance from the free market economies in grants, investments, training and technical assistance.

In the first place it will be necessary for the management to become market oriented, absolutely needed under conditions of a market/profit driven economy. The free market system will be the leading and decisive criterion of the restructuring processes. The product range of metallurgical plants, like steel mills will need to be reviewed/modified to cater to local/international demand.

The drive to democracy and market oriented economy in Central and Eastern Europe brings along the necessity for rehabilitation of uncompetitive plants. Eastern Europe faces the challenge of making its steel plants profitable and clean.

Basic Characteristics of the Steel Industry

The technology gap between eastern and western European metallurgical and steel plants is sizable, e.g. less than 20 % of the region's steel industry is continuously cast whilst some 40 % is produced in open hearth furnaces. The basic characteristics of the eastern European steel industry are (1):

- technical backwardness of the industry compared with world best practice;
- poor operating performance relative to the available technology (often based on poor initial design);
- poor levels of plant availability symptomatic of poor maintenance standards;
- inability to adapt new processes and make new products in local conditions;
- shortages of management and intermediate skills (in spite of the long tradition of the industries);
- characteristics of management skills for restructured environment;
- low level of automation and computer application;
- excess of low cost labour;
- excess of work force per ton of steel produced;
- excessive consumption of energy and raw materials;
- underdeveloped marketing and sales standards (protected market policies);
- neglect of environmental standards and lack of clean technologies;
- likely receptiveness to foreign aid and managerial assistance.

UNIDO's Assistance to the Iron and Steel Industry in Developing Countries

Projects in this sector aim at:

- Choice, selection and adaptation of technologies and processes, including testing of raw materials
- Pilot scale production;
- Introduction of maintenance systems;
- Environmental monitoring and control;
- Energy auditing and conservation;
- Rationalization of production, including computer application;
- Quality control, increase in performance.

Technology transfer relates to all aspects of

- Conventional, appropriate technologies;
- Computer aided systems for process control and energy conservation and plant maintenance;
- Direct reduction of iron ores and sponge iron production;
- Modern production processes, e.g. ladle-refining, vacuum treatment, rolling in controlled atmosphere, continuous casting and thin slab casting and advanced heat treatment techniques;
- Production of HSLA steels, microalloyed steels, ultraclean steels, metal matrix composites and ferrites;
- low waste/non-waste technologies, e.g. near net shape castings.

The activities concentrate mainly on

(a) Establishment, management and operation of new plants at all scales, through preparation of master plans, techno-economic studies, feasibility studies and marketing studies;

(b) Provision of expertise for rehabilitation, restructuring, modernization and efficient operation of existing plants covering application of appropriate technologies and equipment, including technological consulting, product development, and introduction of managed and computerized systems; improvement of product-mix, harmonized to the national, regional and international demand, consulting on management and cost accounting of metallurgical and metal transformation plants;

(c) Development, organization and implementation of specific training programmes, in-plant group training or study tours and individual fellowship placements.

Complementarity. The programme by UNIDO is aimed at complementing many other ongoing programmes such as the EC co-operation pacts (PHARES programme) with Hungary, Poland and the CSFR, or under negotiation with Bulgaria and Romania. Also, due account will be paid to the programme by the United Nations Development Programme (UNDP), the World Bank (e.g. the study now under implementation for Poland) and the assistance by the European Bank for Reconstruction and Development.

The studies by international organizations/ communities are usually of a general nature dealing with the whole aspect of industry rehabilitation/ restructuring. Individual studies/concrete projects and remedial measures will have to follow in individual industrial sectors, whereby UNIDO can play an important role in providing unbiased technical assistance services and advice.

Technical Co-operation for eastern Europe

Given the requirements in eastern Europe apart from "traditional" technical assistance, projects will be oriented towards

1. Improvement of management skills; advice to plant management in the investment decision stages; preparation of techno-economic studies;
2. Improving plant profitability;
3. Preparing industries for privatization;
4. Advising on marketing/sales organization of products; export promotion and business planning; application of computer simulation models;
5. Adherence to environmental standards; reduction of air and water pollution; profitable utilization of "wastes" from metallurgical plants; regional co-operation;
6. Conversion of military enterprises to civil production.

As regards technical assistance, the following activities are under implementation or in the planning stage:

Improvement of management skills. Consultancy services for a study of three steel plants in the CSFR (East Slovak Iron and Steel Works, Trinec Iron and Steelworks and Poldi United Steel Works) are being undertaken on a bilateral basis by a US company (based on a US grant), for the Federal Ministry of Economy, Prague. UNIDO plans to complement the consultancy by arranging a three weeks study tour for steel industry officials to highly industrialized countries to study operations and management philosophies of steel plants.

UNIDO assistance to CSFR was also decisive in establishing a National Technical Consultancy and Training Center (NTCTC) in Prague. Experts from NTCTC transfer their technology within CSFR and to other developing countries, e.g. in the field of industrial software development and application, such as computerized managed maintenance systems.

Improving plant profitability through rehabilitation, market oriented production, enhanced maintenance practices and decreased energy consumption. Under this heading UNIDO proposes to assist eastern European countries in:

- Cost reduction (material and energy conservation, manpower cost);
- Pricing policies;
- Rehabilitation/restructuring of plants;
- Choice/selection and recommendation of new equipment and processes with particular emphasis on cleaner technologies;
- Quality control, improvements of operating performance and plant availability (e.g. through enhanced plant maintenance);
- Introduction of automation and operating control systems.

Rehabilitation/restructuring. In any rehabilitation study the following basic economic considerations should feature

- a list of existing facilities which are candidates for retrofitting of automation technologies, including estimated costs and benefits;
- a list of facilities which should be replaced including estimated cost and benefits;
- a list of facilities which should be abandoned including estimated benefits;
- an evaluation of crew assignment and crew sizes in specific key areas;
- an evaluation of management structure and information flow;
- recommendations relative to business and management information systems.In Bulgaria two UNIDO consultants recently surveyed the mini metallurgical plant "Kamet", Pernik and confirmed the technical feasibility and economic viability of plant modernization. It was recommended to instal the already delivered equipment and to go ahead with

EAF, CC, ladle metallurgy, vacuum degassing and rolling of high quality alloy steels with an annual capacity of 200,000 tons, based on market demand.

During UNIDO staff member missions to Bulgaria the need for high-level advisory services for restructuring and privatizing the metallurgical industries at Kremikovtsi, Pernik, Srednogorye, Plovdiv , etc. was confirmed.

In Poland UNIDO consultants advised on the modernization of the stainless steel tube production line of Huta Buczek Steelworks. Assistance was requested for introducing controlled accelerated cooling of plates in the Czestochowa Steel Works and for modernization of the foundry plant at the Ostrowiec Steel Mills
Interest was also expressed for improvement of steel quality and extension of product mix in Zygmunt Works; Development and implementation of Quality Assurance System (OAS) in Baildon Works; and a local market analysis for steel products.

Requests from CSFR include techno-economic appraisal for rehabilitation of the heat plant in POLDI Steelworks, Kladno; fly ash and steelmaking slag utilization and assistance to POLDI Steelworks Waste Disposal Plant. The need for improvement in quality control was expressed in a Conference held at Ostrava.

Five projects for the modernization of metallurgical units (steelmaking, foundry, rolling mill areas) of SKODA Pilsen Heavy Engineering Group which are under formulation will expectedly lead to large scale investment projects.

UNIDO expects and is prepared to assist the former Soviet republics in their transition period towards màrket economy conditions for metallurgical industries with the final objective to evaluate and justify investment opportunities and provide a basis to potential investors to take investment decisions based on new conditions for business. Some initial steps were made in this direction, e.g. the organization of an Expert Group Meeting on International Industrial Joint Ventures, held in Tallinn in 1988, or the Interregional Symposium on the Role of the Industrial Co-operative Movement in Economic and Industrial Development, held in Moscow, in 1990.

Initial contacts have also been established with some companies e.g. Elektrostal, the Magnitogorsk Iron and Steel Works and the Serov Iron and Steel Works and these companies have indicated interest in diagnostic and fact-finding missions which, depending on the results, would be followed by direct technical assistance and consultancy advice, covering also environmental and pre-investment studies.

Computerized plant maintenance. In the CSFR, with the help of a UNDP/UNIDO financed project, local staff guided by a project contractor developed and introduced a computerized managed maintenance system (CMMS) in the East Slovakian Steelworks of Kosice. Thereby concrete annual savings of about 63 million crowns were achieved. Assistance for introduction of CMMS was also carried out for the Dunai Iron and Steel Plant, Hungary. Under another small-scale project the Jesenice Steelplant in Yugoslavia was supplied with a CMMS package and staff trained at the premises of the Italian supplier.

Energy conservation. Energy efficiency in eastern Europe is very low, mainly because of obsolete technology, equipment, and lack of process control and instrumentation. High energy consumption is also causing higher pollution levels, e.g. 40 % of steel production in the region still comes from open hearth furnaces, only 20 % is continuously cast. Therefore, the identification and choice of optimum technologies and selection of energy-saving equipment is of utmost priority. Projects towards this aim will be pursued, e.g. energy auditing and evaluation as well as introduction of new, energy saving technologies such as thin slab casting. Poland and CSFR (Nova Hut, Ostrava) will introduce thin slab continuous casting during the modernization process.

Preparing industries for privatization. The restructuring process is being also supported by privatization projects through which it is envisaged to provide high level advisory services in these new areas for Eastern and Central European countries. Project proposals for Bulgaria, the CSFR, Hungary and Poland have been prepared and are being pursued. Initially, these projects will bring about increased awareness at the level of the Office or Ministry of Privatization on the opportunities (advantages and constraints) for privatization of metallurgical industries in the respective countries. Large metallurgical plants will be slow to privatize. The effects of the restructuring and rationalization programmes must be firmly defined and under way before values can be established and near- and medium-term new capital requirements determined. With assistance and support from interested western industrial associations and companies, and bilateral institutions, UNIDO would arrange for seminars and study tours, assist in market surveys, identification of technologies and related facilities requirements, feasibility studies. UNIDO may also investigate direct foreign investment and joint-venture potential.

Retraining. During any restructuring and rationalization process excessive labour force is reduced to correspond to the actual requirements. Thereby staff will be released for redeployment to other industries in a given area. Proper retraining of employees and workers is necessary and such retraining capacity (including training of trainers) needs to be established/strengthened. A typical project of this type is presently under implementation in the CSFR with the aim of upgrading the Poldi Steelworks Retraining Centre at Kladno. This is a pilot project and it is envisaged to establish a network of retraining centres in similarly affected regions such as Kosice and Ostrava and in other eastern European countries.

Advice on marketing/sales organization of products. Under the new political and economic environment in central and eastern European countries, a major emphasis is being placed on converting industries to become competitive in a market economy. The speed of political change in eastern Europe was so dramatic and so recent that the countries' strategy to adjust its industries, including steel, to a market economy is still evolving.

Steel trading in eastern European countries undergoes major reorganization and many mills can no longer rely on a state-owned sales organization but have to establish own agencies or departments. Until recently the steel plants were centrally controlled by an iron and steel headquarters/ trading company which provided centralized marketing and sales services. Due to the restructuring process this service is no longer available, and the steel plants themselves have been entrusted to organize both local market and export sales. Proper establishment of sales policy by each steel plant and increased marketing measures will be prerequisites for the steel plants to keep their market share and to cater to the actual demand. This will require proper choice of product mix, according to market requirements and minimum investment needs, modernization and process control to meet EEC European standards and proper business planning to become competitive on the European and overseas markets.

This entails the necessity for key management people to acquire an in-depth understanding of application of marketing and other new management techniques for planning, monitoring and controlling activities using various technologies and procedures to successfully implement short-term and long-term strategy to adapt their plants to a market/profit-driven economy and to keep or increase the levels of sales/exports.

CSFR requested UNIDO to provide high-level advisory services in sales policy and steel servicing in selected steel plants and reorienting the CSFR metallurgical industry in the area of marketing.

Adherence to environmental standards, introduction of clean technologies and profitable utilization of wastes. The EC and other European countries are spending billions of dollars to meet stringent environmental regulations whilst the eastern European countries, in close proximity to the "clean" countries keep on polluting air and water and produce solid wastes, constituting a health hazard to local and foreign inhabitants. It is of regional, if not international concern, to create awareness in these countries on the importance of introducing environmentally sound technologies and on the available technological alternatives, e.g. profitable utilization of wastes (such as recovery of valuable metals from flue dust, or utilization of slag).

It is reported that environmental improvements are at the top of priority lists of the metals and mining industry in eastern Europe including former Soviet republics. However, there will be a chronic lack of funds to cope with these requirements. Studies are proposed to:

- Identify areas of pollution that can be improved by changes in practices with minimum investment;
- Identify pollution abatement required to bring the plant(s) to acceptable environmental levels including estimated investment and operating costs.

As a first regional approach by CSFR and UNIDO, a Workshop on Environmental Protection in Highly Industrialized Regions and Utilization of low-waste/ non-waste technologies in metallurgical and basic industries, was held in Ostrava, CSFR, in December 1990, with participation from CSFR, Hungary and Poland. As a follow-up and based on discussions with the competent ministerial and industrial bodies in the CSFR, Hungary, and Poland, a UNIDO consultant prepared a project document for Reduction of Environmental Impact of Metallurgical Operations. The objective of the sub-regional large-scale project is to abate industrial pollution and to promote industrial co-operation between the Czech and Slovak Federal Republic, Hungary and Poland by diminishing mutual environmental impact and risks connected with metallurgical operations, concentrated on both sides of the border region of Slovakia with Hungary and of the Czech Republic with Poland.

Projects aimed at introduction of environmentally sound technologies have been undertaken for Hungary for

(a) Improvement and rehabilitation of the steel plant at Miskolc, DIMAG Stock Corporation and

(b) Investigation and Improvement of Environmental Impact of Iron and Steel Industry in the Sajo River Valley Area.

Follow-up projects were requested and it is expected that other eastern European countries will follow suit and request UNIDO assistance; programmes are under consideration and will have to be worked out for Bulgaria, the CSFR and Poland (mainly in the iron and steel sector) and other European countries of the former "Eastern bloc", facing similar environmental problems.

Advisory services on dust catching, recycling and environment protection in the metallurgical combine of Elbasan in Albania were provided.

There is a large priority list for projects identified during staff member missions, e.g. for Bulgaria related to profitable utilization of metallurgical wastes, with special emphasis on metallurgical slag (for Kremikovtsi, Pernik, Srednogorye and others); and advisory services in energy conservation and environmental protection and pollution control at metallurgical plants.

The UNIDO/IAEA environmental assessment expert mission to Copsa Mica, Romania, in May 1991 confirmed the urgent need for environmental auditing and protection measures at the SOMETRA plant, whilst SIDEX requested assistance in updating technology and management, also including water purification; improved dust collection from BF, coking and sinter plants; energy conservation, etc.

Conversion of military enterprises. Another subject of considerable interest mainly to the former Soviet republics is the conversion of defense and military industries (closely connected with metallurgy) into the civilian sector for production of domestic/household goods, etc. UNIDO and the ATM (Association of Machine-building Technologists) co-organized the International Conference on Conversion, held in Moscow in December 1991. The major thrust of the conference was conversion of former USSR defence industries into the civilian sector, which would also involve the metallurgical and other basic industries. The situation of the sector is characterized by huge scientific and technical potential and infrastructure, a highly qualified workforce, large quantities of semi-processed and new materials. However, financing to use the large unutilized capacities and for retraining is not available. Studies/projects will need to be undertaken on the most promising alternatives for production of consumer and other goods with minimum investment.

New materials. Following up activities of the World Materials Congress (Chicago, September 1988) UNIDO has been trying to apply existing knowledge in the development of advanced materials in a qualified, organized and professional way. This has led to increased confidence by the governments of developing countries requesting technical assistance from UNIDO in this emerging field.

In developing the programme of activities for new materials two types of materials were distinguished. Firstly, new structural materials - HSLA steels, high temperature strength aluminium and copper-cobalt-iron alloys which have been developed and produced thanks to the achievements in steel refining techniques, the development of new near-net-shape forming and rapid solidification techniques. The second type of new materials are new functional materials which have been developed to perform essential and specific functions in the electronic industry. Examples of UNIDO's technical assistance in this field are e.g. assistance in pilot production of gallium arsenide and permanent magnets.

UNIDO is actively pursuing a series of supporting activities aimed at dissemination of information on new trends and developments in the metallurgical field to most advanced developing countries, such as preparation of state-of-the-art papers on HSLA steel production, emerging technologies in steel production, awareness on metal-matrix composites, solidification of cast composites, clean materials technologies, advances in superplasticity and superplastic forming, image analysis, NDT, hard and soft magnetic materials, aging materials, surface modification technology, powder metallurgy, etc., as well as organization of workshops in the field of new materials.

Furthermore, it is planned to establish permanent contacts with institutions and universities that assist industries and develop new materials activities like the Max-Planck Institute and the Aachen Technical University (Germany), the North Carolina State University Advanced Materials Center (USA), the Korean Institute of Advanced Technology (Rep. of Korea), Institute of Advanced Materials and New Technologies in Triest (Italy), and similar institutions in CSFR, Poland, Belarus, Ukraine and the Russian Federation, to build up a reliable network that would ensure the successful implementation of future technical assistance projects related to the development/production of advanced materials in developing countries.

Supporting activities - Seminars. UNIDO is developing a series of seminars/study tours for former eastern bloc countries to acquaint them with western management/sales/ marketing techniques and technology and to establish industrial contacts. This would be accomplished by using related industrial associations in industrialized countries as organizers and sponsors. The seminars/study tours would include presentations of western technology by industry, discussions of applying technology in the specific situations in eastern Europe and the scoping of possible projects by the UNIDO selected participants. Possible areas of interest are:

- Environment;
- Solid waste treatment/utilization;
- Air/water treatment;
- Restructuring;
- Operations management training;
- Energy auditing;
- Energy conservation;
- Military conversion to domestic industry.

Along these lines UNIDO has proposed restructuring workshops with senior management representatives of metallurgical companies/institutions to be organized in the capitals and metallurgical industries centres of selected republics, such as Russian Federation, Ukraine, Belarus, Armenia, Khazakhstan, Georgia, etc. Those would be oriented towards senior managers, engineers and economists of major plants which are facing restructuring problems (including modernization of production processes, improvement of quality, domestic and export marketing and sales network organization, management upgrading, business planning, environment and energy improvements, re-training and re-qualification, etc.). A Russian steelplant has already expressed willingness to participate in UNIDO activities and a workshop on restructuring and privatization is envisaged. The costs could be covered by a Trust Fund contribution by the plant (in roubles), complemented by funds from supporting donor countries.

Project Financing

A major source of financing available to UNIDO are the funds allocated by the United Nations Development Programme on a country-by country basis, in cycles of five years and up to a predetermined amount. A number of industrial projects are entrusted to UNIDO as executing agency for UNDP. Co-financing by the recipient country is often invited. The allocation by UNDP for all types of projects for the programming cycle 1992-96 for Eastern European countries is restricted. Just to mention some figures (in million US dollars): Albania 5.98, Bulgaria 2.84, CSFR 1.5, Hungary 1.77, Poland, Romania and Yugoslavia each 3.55.

Other funding possibilities are the United Nations Industrial Development Fund, pledged by UNIDO member Governments and Trust Funds provided by either the recipient country or company (self-financed) or from a third party donor (e.g. a development finance institution).

Conclusion

It is clear that such enormous tasks as plant rehabilitation or pollution abatement cannot be handled by the concerned countries themselves or by international organizations alone. It will need the efforts of the international community to help eastern European countries to properly manage their plants and make them cleaner, thereby improving the living conditions of the whole region. In a number of cases the donor/investor will be able to obtain an immediate return on "investment"on environment related projects. Whilst gaseous air pollution and water pollution will require additional mobilization of non-profit oriented financial sources, solid wastes, such as slag, sludge and particles from flue dust can profitably be processed by various technologies to marketable metal and other products. It is within UNIDO's portfolio to handle such projects and to carry out the necessary studies and arrange for test work.

UNIDO is also assisting in organizing restructuring studies for metallurgical plants in eastern Europe which will take into consideration the overall view of the modernization process including raw materials, energy, production facilities and technologies, product mix, quality assurance, workforce, management, domestic and export market and investment policies and strategies. Such restructuring studies are indispensable for the governments to take the right course of action in the rehabilitation of individual companies. It is expected that restructuring studies undertaken by international bodies like UNIDO would guarantee the success of modernization efforts, including environmental considerations, and would encourage investments. In central end eastern European countries which have a strong engineering and capital goods industry or comparative advantages on the raw material side, the iron and steel industry may be considered the backbone of the industrial sector, being the supplier of raw materials to many other downstream industries. Thus, restructuring and modernization of this core industry is of particular importance.

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Restoring Treatments of Nickel-Base Superalloys and Their Importance in Recovering Turbine Components

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Abstract

From an exposition about most critical components in gas turbines, superalloy products, ie. blades, vanes. housings, discs, etc., it is treated the role of chemical composition and termomechanical history on their properties. Later, it is considered their systematic loss of properties by temperature, time and stress effects (common operating parameters), when microstructure is transformed and internal microdiscontinuities are generated. Finally, it is presented an overview about treatments and processes that can recover loss properties in base of microstructural restoration and internal deffects elimination. Previous topics are graphically showed for several components treated at COMIMSA and comments about general experience restorating superalloys.

THE MOST CRITICAL COMPONENTS IN GAS TURBINE, those that work in hot zones and are exposed to greater stresses extent (blades, vanes, housings, etc.), are mainly manufactured from nickel and cobalt base superalloys.

According to the way they acquire their properties, superalloys are divided in three big groups: solid solution, carbide precipitation hardening and intermetallics precipitation hardening.

Solid solution alloys are those which require high heat resistance and dilatation properties. Examples: HASTELLOY X and INCONEL 625. They are mainly employed in combustion chambers, injectors, etc. Their properties are supported by nickel and cobalt elements, diluted in molibdenum and iron.

Superalloys hardenned by carbide precipitation are characterized by their superior mechanical and corrosion resistance. Typical examples are Hastelloy C, MM-509, etc. They are used in housings and static support systems. Their properties are contributed by tungsten, chromium, titanium and molibdenum carbides.

Superalloys hardenned by intermetallic precipitation require more technological development. There are many superalloys of this type, for instance: IN 738, HAYNES 25, WASPALOY, UDIMET, etc. They work under high temperature and complex mechanical and thermal stresses on their components: blades, vanes, discs, etc. They are based on a phase called γ', composed by alluminium, titanium, nobium and nickel. Fig. 1 is an example of superalloys types and components described above.

Alloy elements effect and their relation to composition and phases. Superalloys contain an elements combination that produces excellent properties at high temperature. Those elements finally integrate solid solution or precipitates.

Fig. 2 shows a table of different elements effects and influence on phases formation in superalloys.

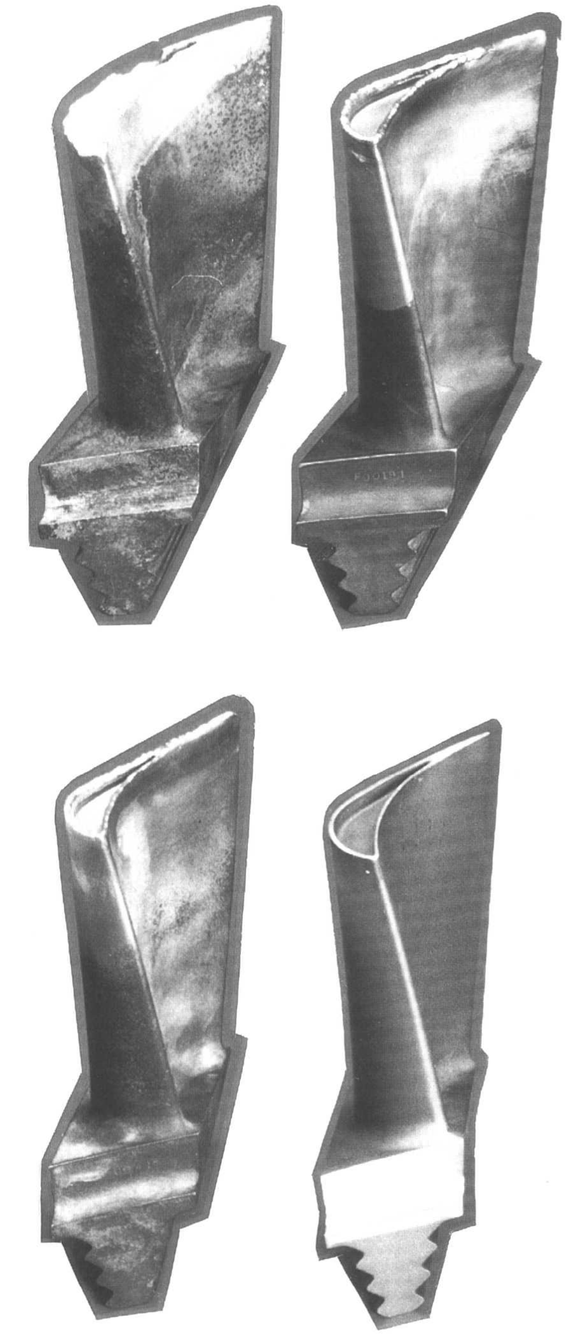

fig. 1.- Hot zone blades from power turbine.
MATERIAL : IN 738 base nickel superalloy hardenable by precipitation.

Solid solution is modified by chemical elements as follows: Mo, Ta and W increase resistance, Cr and Al improve heat oxidation resistance; Ni stabilizes γ phase, and Co favours secondary precipitation.

Precipitation is generated according to the following: Al and Ti are γ' originators, a precipitate which produces excellent properties at high temperature. Nb is γ'' originator; C and B produce carbides and borides, which act as hardenners and grain growth inhibitors.

In this way, superalloys chemical composition together with thermal and thermomechanical treatments and solidification system determines optimal operating metallurgical properties. Then, it is very important to stablish composition ranges within specified limits, since said ranges are narrow in order to achieve optimal properties.

Superalloys properties and their deterioration. Main superalloy components properties for gas turbines are: mechanical resistance at high and atmosphere temperatures, hot resistance corrosion, impact resistance, thermofluence and hardness. Properties are obtained at intersection levels sets, being function of several phases generated by chemical composition. Only superalloys possess so wide properties gamut as compared to other materials, to be able to operate in present turbogeneration machines. That is, we could say that efficiency, power and turbines evolution depend on technological development extent in superalloys.

Fig 3. shows micrstructure of a nickel base superalloy, hardenable by the intermetallic γ' precipitation (IN 738), over which blades properties are based on.

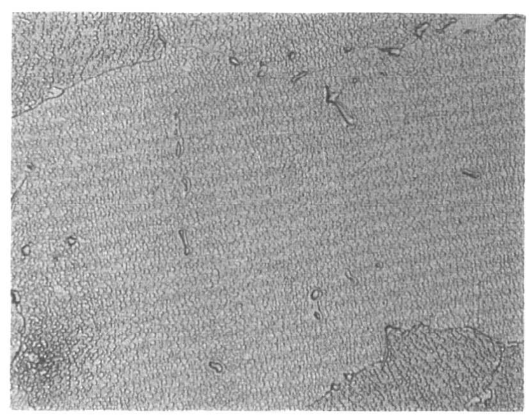

fig. 3.- IN 738 superalloy microstructure. Note the prescence of small γ' intermetallic precipitates homogeneosly spreaded in γ matrix.

EFFECT	BASE Fe	BASE Co	BASE Ni
Hardenning by solid solution	Cr, Mo	Nb, Cr, MO Ni, W, Ti	Co, Cr, Fe Mo, W, Ta
FCC matrix stabilizer	C, W, Ni	NI	-
Carbides originators:			
type MC	Ti	Ti	W, Ta, Ti Mo, Nb
type M_7C_3	-	Cr	Cr
type $M_{23}C_6$	Cr	Cr	Cr, Mo, W
type M_6C	Mo	Mo, W	Mo, W
M (CN) type carbonitrides	C, N	C, N	C, N
General promoter of carbide precipitates	P	-	-
γ' originator Ni_3 (Al, Ti)	Al, Ni, Ti	-	Al, Ti
Delays formation of hexagonal phases (Ni_3 Ti)	Al, Zr	-	-
Increases solvus temperature of handenners precipitates and/or intermetallics	Al, Mo Al, Ti, Nb	Ti, W, Ta	Al, Ti, Nb
Oxidation resistance	Cr	Al, Cr	Al, Cr
Developes hot corrosione resistance	La, Y	La, Y, Th	La, Th
Sulphidization resistance	Cr	Cr	Cr
Developes thermofluence properties	B	-	B
Causes seggregation	-	-	B, C, Zr
Facilitates mechining	-	Ni, Ti	-

fig.2.- Effect of several chemical elements respect to properties generator phases in superalloys.

These intermetallics growth in operation is due to high temperature (fig. 4), causing loss of chemical composition homogenity and stabilizer phases loss. By the same reason, it is generated phenomena known as thermofluence. This causes material aging, which finally produces piece fracture or replacement.

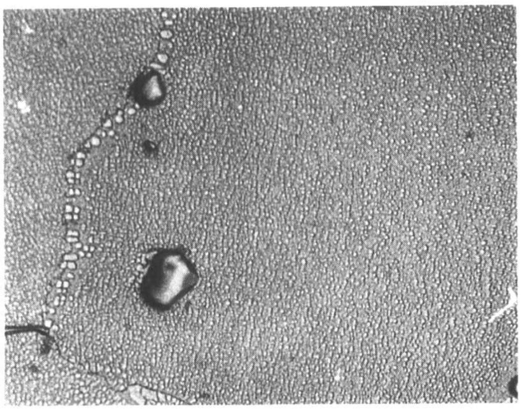

fig. 4.- IN 738 superalloy microstructure in which γ' precipitates have growth as a function of high temperature time in operation causing properties deterioration.

On fig. 5 it can be seen microstructure of a superalloy hardannable by carbides, HASTELLOY C, with carbides growth, originating said phenomena; besides, dendrites limits are appreciated. In those dendrites, thermofluence phenomena is generated by microvoids "widening". This phenomena was detected in stators housings when normally operating at high temperatures during aprox. 40,000 hours. Properties lowered at levels near 50% of original properties.

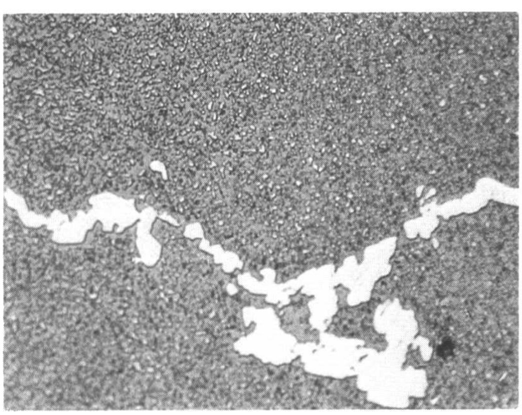

fig. 5.- Hastelloy C superalloy micrestructure hardenable by carbide precipitation. It can be seen carbides, distribute in grain limits and matrix.

Properties restoration. Many lossed properties in operation, as mentioned in the former chapter, can be recovered through mechanical-metallurgical treatments.

Basis for restoration depends on two mechanisms: first, phases transformation alteration by new phases nucleation which through controlled thermal treatments convert them to original phases as in new pieces, supplying a matrix with properties very near to originals when pieces were new. Second, cancellation of microcavities induced by thermofluence. Utilized tool is the process known as HIP (Hot Isostatic Pressing).

Thermal treatments consist of temperature increasing up to altered intermetallic disolution, practically causing their dissapearance. After it, other treatments are carried out for their nucleation, growth and stabilization, to achieve required dimensions for desired properties.

HIP is a thermomechanical process with pieces temperature increasing within an isostatic pressurized chamber by inert gases. High temperature at easy strain levels in solubilized materials together with high pressure (15-30 Ksi), causes material fluence into "cavities" : pores and inter-dendritic spaces, closing them and welding them by diffusion.

Conclusions

According to previous exposition, to accumulated experience by COMIMSA, and to continuous exchange among research and development intitutions respect to superalloy components restoration properties for gas turbines, next conclussions are obtained:

- It is possible to restorate numerous components, ie. blades, vanes, housings, etc., reutilizing them once again with previous properties verification.
- It is advisable a deterioration properties evaluation of turbine components after average life period finishing, order to stablish restoration extent. On the contrary, the contrary, there is a danger to cause irreversible damages in said components.
- It is advisable that all turbine components sent for recovering be also sent for properties restoration.
- HIP (Hot Isostatic Pressing) is a valuable tool for hot zone blades superalloys to restorate loss properties by thermofluence.
- It is very useful for gas turbine operating and maintenance personnel, their constant upgrade about general superalloy technology and aging phenomena, as a tool to optimize decision-making.

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Recent Developments in Iron and Steel Powder Production for High Performance P/M Components

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Abstract

This paper describes the developments of major commercial methods of production of iron and steel powders with exceptional improvements in powder properties which make them ideal materials for high performance P/M and powder forging applications.

THE APPLICATION RANGE OF P/M PARTS has been greatly expanded recently. Most of the new parts are being developed for high performance applications. Increased complex shape, higher stress levels and demanding applications have required technical innovations and improvements in P/M manufacturing processes and in powder production methods (1). This has led powder producers to develop iron and steel powders with significant improvements in raw materials, uniformity and consistency of powder from batch to batch, cleaner powders, finer powders and alloying methods. These developments demanded advanced powder production technologies such as mechanical alloying and rapid solidification processing for both the attainment of new alloying possibilities and the preparation of highly engineered materials (2-4). The main requirements of sintered products made from alloy steel powders for high performance structural P/M components are: high strength, ductility, fatigue resistance, dimensional accuracy and machinability (5). The major requirements of powder produced by a certain method for such applications are: (i) high apparent density to reduce filling height and increased flow rate, (ii) *superior compressibility* to produce higher green density at commercially compacting pressure, and (iii) a suitable and consistent chemical analysis to obtain compacts from iron powders and from iron powders with alloying additions which would exhibit minimum dimensional change during sintering and consistent sintered properties (6-8).

This paper is concerned with the development of various commercial production methods of iron and steel powders and their properties which have resulted in the increased performance of structural P/M components.

Plain Iron Powder Production

The commercial production methods of iron powder are:

(i) Direct reduction of iron ore or iron oxide by carbon or hydrogen. This is a convenient, economical, extremely flexible and traditional method for controlling the properties of iron powder regarding size, shape and porosity over a wide range. This process yields very fine powders with irregularly shaped particles and considerable pores within each particle and are called sponge powders. Proprietary trade names of this process

are Hoeganaes and Pyron processes.

(ii) Atomization. Atomization processes are widely used for making both iron and steel powders. Atomization consists of mechanical disintegration of molten metal stream into small droplets which are rapidly cooled by means of conductive or/and convective heat transfer. The disintegration of a liquid stream by the impingement of high pressure jets of water, gas or oil is called *water-, gas-, or oil atomization,* respectively. Other modified versions of atomization are *centrifugal, vacuum, ultrasonic, rotating electrode process, plasma rotating electrode process, electron beam rotating process, rotating disk atomization, etc.* (9).

The important features of (inert) gas atomized powders that make them suited for a number of applications are: (a) spherical shape, (b) cleanliness, (c) rapidly solidified structures, particularly at small particle size, and (d) high production rates to achieve acceptable production costs (10). Advantages of water atomization include: (a) increased production rate due to high cooling rate that would meet the price demands of, for example the automotive industry, (b) limited segregation of an alloying element, (c) availability of finer particle sizes by using higher water pressure jets, and (d) irregularly shaped powder particles of -100 mesh (< 15 µm) for providing better green strength.

(iii) A combination of both reduction and atomization process (such as Domfer process).

(iv)Thermal decomposition of iron carbonyl. Fine sized, pure and extremely spherical iron powders are prepared by thermal decomposition of iron carbonyl, $Fe(CO)_5$. Finer (1-5 µm) iron powders are produced when the process is conducted at high temperature. The reduction of decomposed iron in hydrogen atmosphere at 400° C (752° F) completely eliminates C, O and N and produces a pure and soft (VHN = 100) iron (11,12). They find applications in metal injection molding (MIM), special electronic core, P/M blending and electromagnetic radiation absorption and magnetic recording processes (13,14).

Other methods of limited applications are:

(i) fluidized bed reduction of iron ore or mill scale by hydrogen or carbon monoxide, (ii) hydrogen reduction of ferrous chloride precipitates, (iii) electrolytic deposition followed by hydrogen annealing, (iv) comminution of wrought mild steel, followed by hydrogen annealing, and (v) ball milling and decarburization of high purity pig iron shots.

Some of the commercially used methods are discussed here.

Hoeganaes Process. Hoeganaes process consists of: (i) reducing pure magnetite (Fe_3O_4) ore with a 85-15 mixture of coke and limestone to make into sponge iron cake, (ii) pulverization and milling to powder and annealing the resultant product in hydrogen. The outstanding advantages of Hoeganaes process are: (i) flexibility in controlling the sponge iron products (Fig. 1) (15) over a wide

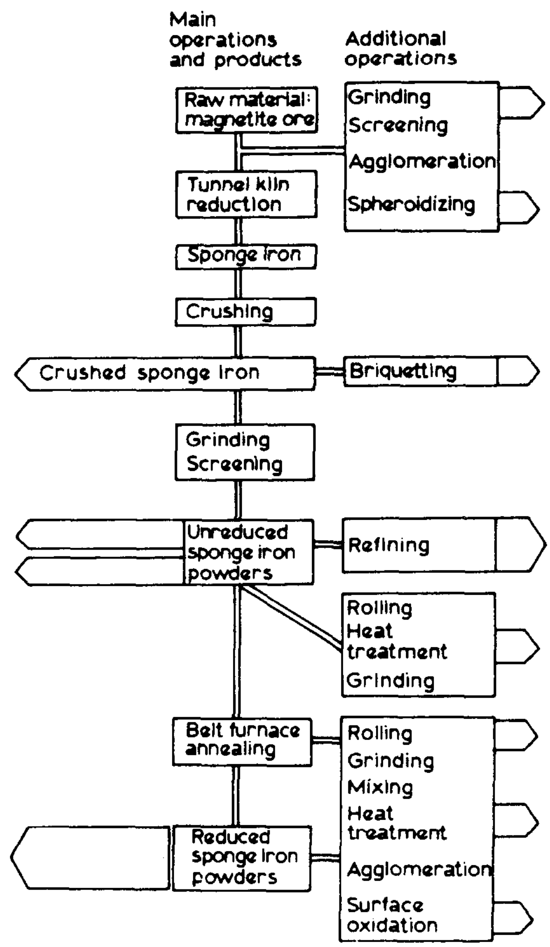

Fig. 1. Flexibility of Sponge Iron Process.

range of particle size between < 50 µm and 3 mm, apparent density between 1.7 and 3.7 g/cm^3 and carbon content between 0.01 and 0.25% (13) and (ii) steady improvement in powder properties for P/M applications with regard to consistency and improved compressibility (6,16,17). Although sponge powder exhibits unsurpassed green strength, growth and development of P/M parts based on atomized iron powder have been faster than that of P/M parts using sponge powders (18).

Hoeganaes has also introduced a new high purity water atomized iron powder such as ABC 100.30 grade with supercompressibility (7.3 to 7.4 g/cm^3 density in a single pressing operation) by carefully selecting the raw material, modern steel refining and improvements in the reducing annealing process to attain lower levels of carbon and reducible oxygen. This powder is increasingly being used for high density structural P/M parts, including those where subsequent surface hardening or plating operations are needed, and for soft magnetic iron - based materials (19).

Pyron Process. Pyron process is another method of reduction of iron oxide where a carefully selected mill scale from steel mill is reduced in hydrogen at about 980°C (1800°F). The resulting sinter cake is converted into powder by a simple milling operation. Pyron iron powders are spongy with finer pore structure (than those in the Hoeganaes powder particles) because of higher rate of reduction and sintering. As a result compacts made from Pyron powders sinter faster than those from Hoeganaes iron powders (20).

Quebec Metal Powder (QMP) Process. QMP process consists of disintegration of freshly refined high purity molten iron as the raw material into granulated iron by high-pressure horizontal water jets, dewatering and drying, passing through a ball mill to reduce the powder, feeding into a reducing (or decarburization and annealing) furnace, crushing and grinding of resulting cake to powder, and final blending to homogenize into individual batches and packaging for shipment (Fig. 2) (15,21). Table 1 shows the chemical,physical and metallurgical properties of ATOMET 28, 29, 29M and 30 iron powders for P/M applications (21,22). Although ATOMET 28, 29 and 29M are used for medium density (6.4 - 6.8 g/cm^3) P/M application, only ATOMET 29M provides superior machining properties and increased machining tool life. ATOMET 30 is used for high density (6.7 - 6.9 g/cm^3) P/M applications with high green strength and chemical purity. QMP has also introduced phosphorus-bearing iron powder for applications requiring superior magnetic and high impact strength.

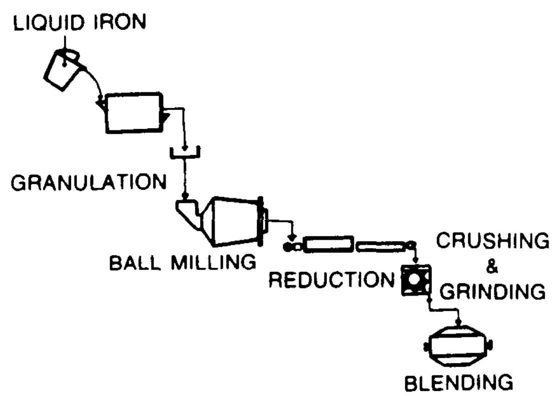

Fig. 2. Schematic QMP's iron powder process.

Kobe/Kobelco Process. Kobe Steel Company has produced water atomized iron powder grades such as 300M offering high compressibility (6.9 g/cm^3 at 5 t/cm^2), 300MH offering slightly higher purity and compressibility level (7.0 g/cm^3 at the same compacting pressure) and 300NH achieving 7.1 g/cm^3 green density after extended reduction/annealing treatment (23). Kobelco's 300 MS grade offers reduced compressibility and green density (6.7 g/cm^3 at 30 tsi), but improved cleanliness, i.e., low inclusion level (size: 50 µm max and area ratio: 0.03% max) which finds successful applications in hot powder forging of connecting rods and other automotive parts (24,25).

Kawasaki Process: Kawasaki Steel Corporation has produced a new water atomized KIP 304AS grade iron powder with high compressibility (7.05 g/cm^3 green density at 1% zinc stearate at 490 MPa), higher purity, improved compactibility, lower inclusion content, high green strength, and low ejection force by the stricter selection of scrap, more rigorous refining in the electric arc furnace, extended high temperature first annealing and the incorporation of a second annealing. This powder is designed to meet current requirements of high performance P/M parts (26).

Table 1. Typical Chemical, Physical, and Metallurgical Properties of ATOMET Iron Powders.

TYPICAL PROPERTIES	ATOMET 28	ATOMET 29	ATOMET 29M	ATOMET 30
CHEMICAL ANALYSIS, %				
Carbon	0.05	0.05	0.05	0.01
Oxygen	0.17	0.17	0.16	0.14
Iron	99+	99+	99+	99+
Manganese	0.008	0.008	0.008	0.008
Sulfur	0.005	0.005	0.005	0.004
Phosphorus	0.025	0.025	0.025	0.025
Silicon	0.03	0.03	0.03	0.03
Copper	0.02	0.02	0.02	0.02
PHYSICAL PR0PERTIES				
Apparent density, g/cm^3	2.84	2.93	2.95	2.93
Flow rate, s/50g	27	26	26	26
SCREEN ANALYSIS (U.S. mesh), %				
+ 70	trace	trace	trace	trace
-70/+100	5	5	5	8
-100/+140	28	28	28	28
-140/+200	23	23	23	24
-200/+325	22	22	22	22
-325	22	22	22	18
GREEN PRPERTIES[1]				
Green Density, g/cm^3	6.7	6.7	6.7	6.8
Compaction Pressure, MPa(tsi)	510(33.0)	510(33.0)	494(32.0)	502(32.5)
Green Strength,, MPa(ksi)	13.8(2)	13.8(2)	2.1(1.75)	12.4(1.8)
SINTERED PROPERTIES[2, 3]				
Transverse Rupture Strength, MPa(ksi)	897(130)	897(130)	862(125)	1000(145)
Hardness, HRB	84	84	81	85
Tensile Strength, MPa(ksi)	483(70)	483(70)	469(68)	498(72.2)
Dimensional Change, % from die size	+0.17	+0.17	+0.34	+0.25

1. Mix: 0.75% Zn Stearate. 2. Mix: 0.9% C + 2.0% Cu + 0.75% Zn Stearate.
3. Sintered in Rich Endothermic Gas at 1120° C (2050° F) for 30 minutes.

Domfer Process consists of high pressure water atomization of liquid iron containing high carbon content to a granular 'shot', grinding the high carbon ground shot in ball mill to produce desired powder size, mixing the ground powder with ground mill scale and heating in belt furnace at sintering temperature to form a pure iron cake and carbon monoxide. The cake is then attrition milled back to powder (27). Domfer iron powder is, therefore, an improved alternative for sponge iron powders in the medium density range (28). The widely used Domfer plain iron powder grades are MP 32 and MP35 with good compressibility (7.08 g/cm^3 at 50 tsi or 770 MPa) and better compressibility (7.18 g/cm^3 at 50 tsi or 770 MPa), respectively (29).

Steel Powder Production

Alloying addition affects the response to compacting and sintering behavior. Elements that go into intersitial solid solution in the iron reduce the compressibility of the powder to the greatest extent. This is followed by substitutional elements such as Mn, Ni, Mo and Cr (Fig. 3) (30,31). For this reason C is normally added separately as graphite. Among the impurities, N exerts the most detrimental effect on green density: this is followed by S, P, and O to a maximum 0.3% (Fig. 3) (18,30,31). Among the

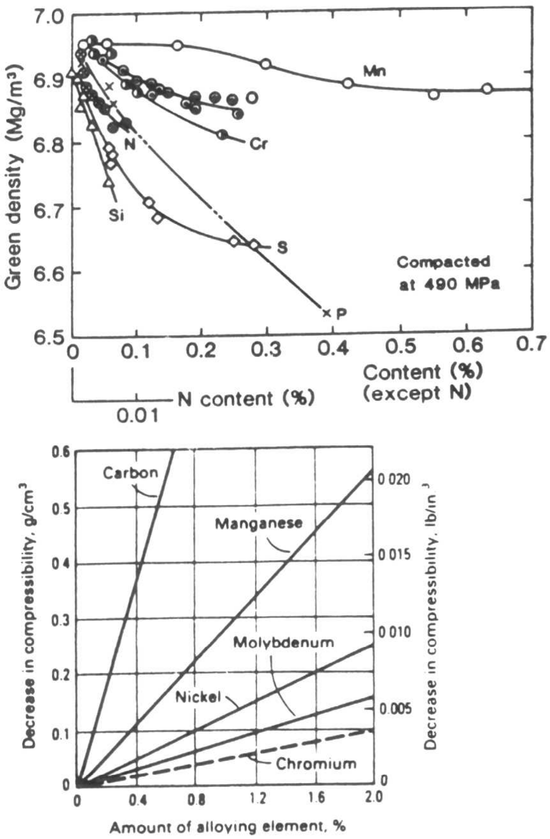

Fig. 3. The effect of alloying elements on compressibility.

dissolved alloying elements, Si has the worst effect on green density, followed by Cr, and Mn.

The main alloying methods for steel powder production can be divided into the following categories: (a) fully or prealloyed steel powder, (b) partially prealloyed or diffusion bonded steel powder, and (c) admixed or blended (very fine) elemental powders (2,18). Fig 4 is a schematic illustration of alloying method (2,18). Mechanical alloying is a non-conventional alloying method.

PREALLOYED STEEL POWDERS

Fully prealloyed steel powders were made by several manufacturers starting from late sixties. Since the alloying elements are homogeneously distributed throughout these powders particles, the overall compressibility is usually moderate-poor due to increased strength of the powder particles (32). This is a drawback when powders are pressed at

Fig. 4. Schematic main alloying methods.

room temperature as in traditional P/M process, but this characteristic becomes irrelevant for hot PF applications (2,18). That is why, fully prealloyed powders are widely used in PF applications (15).

Both gas and water atomization processes are available to produce low alloy steel, tool steel, Fe-P, astaloy, 12% Cr steel, high speed steel and stainless steel powders (20,33). These atomized powders must be softened by reducing annealing at 900°C (1652°F) in dry, purified hydrogen, to facilitate pressing and to achieve the required green density and strength necessary for subsequent processing (33).

Low Alloy Steel Powder: In 1970's, a host of grades were introduced by Hoeganaes, notably Fe-P alloyed steel powders for high performance P/M parts and soft magnets and Astaloy range of prealloyed water atomized steel powders for powder forging and wear resistant applications (20).

Prealloyed low alloy steel powders containing Ni, Mo and Cu have now captured a permanent place in the manufacture of high strength structural P/M parts. Si and Mn as well as Mn and Cr are considered to have great potential as cheap alloying elements in the production of high strength P/M steel components.

Hoeganaes has produced several water atomized low alloy steel powders and designated them "Ancorsteel" grades such as 1000, 1000B, 1000C, 4600V, 85HP,150 HP, etc. for high performance applications (34). Table 2 lists the typical analysis and properties of base powder Ancorsteel 1000, 1000B and 1000C grades. Ancorsteel 4600V has been shown to have a combination of high tensile and fatigue strengths. Table 3 illustrates the typical properties of Ancorsteel base powders 85 HP, 150 HP and 4600V. Controlled additions of Cu, Ni, and graphite into these Ancorsteel prealloy powders produce high sintered density and ultimate tensile strength. Accelerated cooling from sintering temperature can be used to develop high strength martensitic structures (34). Single pressing of Ancorsteel 85 HP to a density of 7.14 g/cm^3 has resulted in as-sintered tensile strength of 58.63 ksi and an endurance limit of 21.5 ksi. Increasing the density to 7.51 g/cm^3 by double pressing/double sintering has produced a tensile strength of 85.4 ksi and the endurance limit of 35.5 ksi. Heat treatment of double pressed/double sintered Ancorsteel 85HP has provided the highest tensile and fatigue strengths of 182.67 and 63.34 ksi, respectively. Materials based on Ancorsteel 150 HP are more hardenable than those based on Ancorsteel 85 HP (35).These data are compared with Ancorsteel 4600V in Fig. 5 (36).

Table 2. Typical analysis and properties.

	Ancorsteel 1000	Ancorsteel 1000B	Ancorsteel 1000C
Composition, %			
C	<0.01	<0.01	<0.01
O	0.14	0.09	0.07
N	0.002	0.001	0.001
S	0.018	0.009	0.007
P	0.009	0.005	0.004
Si	<0.01	<0.01	<0.01
Mn	0.20	0.10	0.07
Cr	0.07	0.03	0.02
Cu	0.10	0.05	0.03
Ni	0.08	0.05	0.04
A. D., g/cm^3	2.94	2.92	2.92
Flow rate,s/50g	26	26	25
Sieve analysis, %			
+60	trace	trace	trace
-60/+100	10	12	17
-100/+325	68	67	70
-325	22	21	13

Table 3. Typical properties of prealloyed base powders Ancorsteel 85HP, 150HP and 4600V.

(Wt %)	Ancorsteel grades 85 HP	150 HP	4600V
Ni	-	-	1.82
Mo	0.85	1.50	0.54
Mn	0.14	0.14	0.17
C	<0.01	<0.01	<0.01
O	0.07	0.07	0.16
N	0.014	0.014	0.005
S	0.01	0.01	0.002
A. D. (g/cm^3)	2.90	2.90	2.96
F. R. (s/50g)	24.0	24.0	23.8
Sieve Analysis, %			
+100	10	10	11
-100/ +325	70	70	68
-325	20	20	21

Various water atomized low alloy steel grades, such as ATOMET 1001, 1001 HP, 4201, 4401, and 4601 with superior compressibility are now available from QMP. High chemical purity, exceptional cleanliness, good apparent density and flow rate, high hardenability and superior compressibility make them ideal material for high performance P/M and powder forging applications (1,35-37).

Mannesmann Demag has introduced water atomized "MSP4' prealloyed powder containing 4% Ni, 0.5% Mo, 0.01% C, and 0.15% O. Advantages of this powder are: (i) its competitive price with heat treatable diffusion alloyed steel powders and prealloyed water atomized steel powders based on Cr - Mn - Mo using vacuum annealing and (ii) the use of traditional conveyor belt sintering at 1120°C (2050° F) together with rapid cooling to produce a homogeneous martensitic structure with close dimensional tolerance and without the need for sizing. Mixing of 0.3 - 0.6% C as graphite and Cu powder (up to 2%) with 'MSP4' compensates for shrinkage during sintering and volume increase during martensitic transformation. This powder is

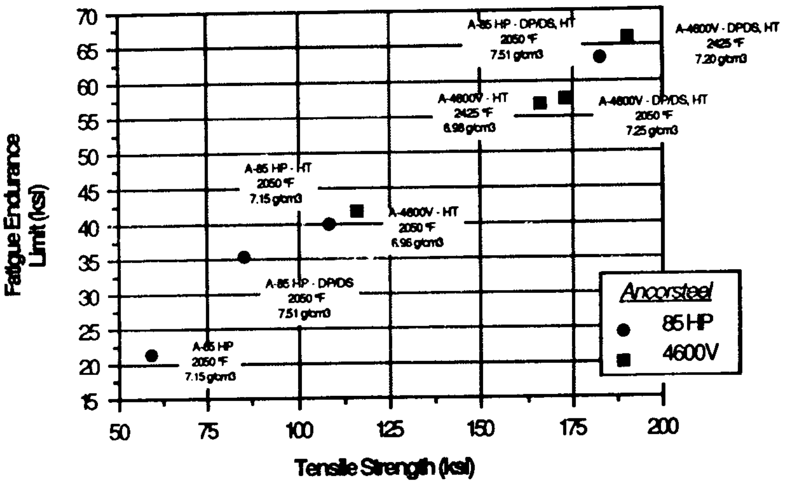

Fig.5. Fatigue endurance limit vs. tensile strength for Ancorsteel 85HP and Ancorsteel 4600V.

finding applications as high performance automotive cams and synchronizer hubs (40).

Table 4. Compositions of KIP prealloy steel powders.

	Chemical composition (%)										
	C	Si	Mn	P	S	Ni	Cu	Mo	Cr	N	O
4600 ES	0.001	0.01	0.08	0.017	0.007	1.12	0.42	0.23	-	0.001	0.09
4600 AS	0.003	0.01	0.08	0.009	0.004	1.45	0.53	0.47	-	0.001	0.12
4100 VS	0.02	0.04	0.83	0.021	0.015	-	-	0.29	1.05	0.001	0.10
SIGMALOY 415S	0.004	0.01	0.05	0.005	0.005	4.31	1.60	0.48	-	0.001	0.11
SIGMALOY 2010	0.001	0.01	0.05	0.005	0.003	1.93	-	1.03	-	-	0.07

A high quality of Kobelco's ultra high pressure water atomized steel powders with high purity, consistent high quality, excellent compressibility and superior compactibility are available for a wide range of industrial applications. Notable among them are 300MC, 300ME, 300MS, 4600A, etc (24).

Kawasaki facility has developed a new grade of low alloy steel powder 4600ES, which is suitable for the production of high density and high strength P/M components through double pressing/double sintering and heat treatment operations (5,23). KIP 4100VS powder with green density of 7.15 g/cm^3 at compaction pressure of 690 MPa is attributed to the low O, C and N contents, by including a vacuum reduction annealing method in this new process route which is considerably better than 6.91 g/cm^3 for an earlier grade of 4100 (39). This has solved the premix problem of the lack of high quality, low oxygen alloy steel powder (41). Table 4 lists the compositions of KIP alloy steel powders. Fig. 6 shows the density and strength levels achieved by double pressed and double sintered KIP 4600 ES, 4600 AS, 4100 VS and Sigmaloy 415 S alloy steel powders

High Alloy Steel Powder: The basic problem with high speed steels is their strong tendency for segregation which results in a fairly coarse and non-uniform structure; this, in turn, affects the safety in heat treatment, makes the grinding operation more difficult and limits the toughness. The use of proper P/M technique has solved this problem (42,43).

Powders Ltd, Davy Loewy and Edgar Allen

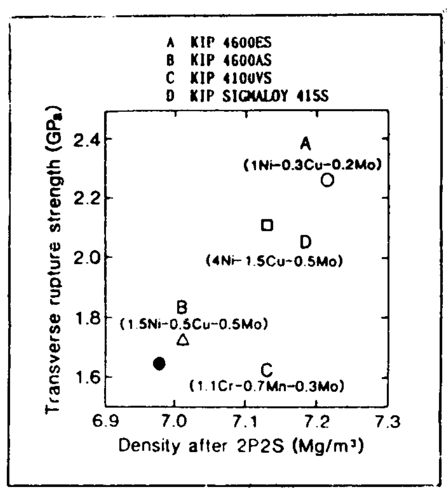

Fig. 6. Density and strength of double pressed and double sintered alloy steel powder compacts.

Tools Ltd. in the U.K., and CMI in the U.S.A. have developed high speed steel (HSS) powder production technology based on water atomization process (31,43,44). On the other hand, Uddeholm in Sweden, Crucible Inc. in the U.S. A., and Kobe Steel in Japan have produced HSS powders by inert gas atomization process (33).

Kobe's atomization process involves high purity, high pressure gas atomization of molten steel from the tundish into a rapidly solidified powder with a fine homogeneous carbide or carbonitride structures, heating in a nitriding furnace, and

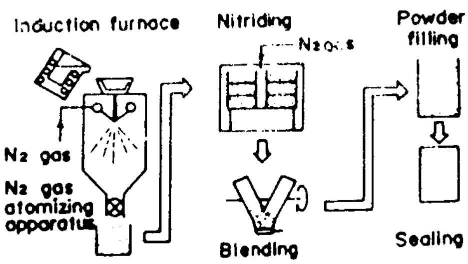

Fig. 7. Flowsheet of Kobe's high speed steel powder manufacturing process.

blending in order to homogenize contained nitrogen. It is then transformed to a mild steel can, evacuated and sealed (Fig. 7). This nitrogen containing HSS powder contains 0.6 - 1.4% C, 0 - 1% N, 4% Cr, 6% Mo, 6% W, and 3.5% V (45).

ASEA STORA process (ASP) for the high speed and tool steel powders was introduced in 1970's. This uses inert gas atomization of prealloyed melt to produce relatively coarse, essentially spherical metal powders. In the new horizontal design, the melt is disintegrated into very small drops by a gas jet. The droplets are flung horizontally where they cool and solidify very rapidly into spherical powder particles. The powder is then screened prior to leaving the atomization chamber and finally poured directly into a storage container (46).

A limiting factor for HSS material is the size of the fracture initiating defect to which the strength level can be directly related. The smaller the defect the higher the strength according to the equation:

$$\sigma = \text{constant} \times (K_{IC} / \sqrt{d})$$

where K_{IC} is the fracture toughness of the material and d is the size of the critical size defect. In the ASP processed material, the harmful effect of large carbide is non-existent (47).

Stainless Steel Powders: Like high speed steels, stainless steel powders are manufactured by both the gas and water atomization, using carefully controlled raw materials and processing parameters (46). Commercial available grades include AISI 410, 410L, 430L, 440C, 446, 304, 304L, 347, 316, 316L and 317.

Water atomization in an inert (nitrogen) gas purged atomization chamber with 140 MPa (2 ksi) water pressure produces - 80 mesh powder (46). Water atomized stainless steel powders are extensively used to produce corrosion resistant sintered parts, extruded tubes, and specialized components for turbine, oil country goods, and chemical process plant. A considerable amount of powder is produced by proprietary gas atomization process (48,49).

PARTIALLY ALLOYED OR DIFFUSION BONDED STEEL POWDER

The demand for making high strength, high ductility P/M parts through single pressing and sintering led to the development of several types of composite-type, partially prealloyed steel powder containing Cu, Ni and Mo, called by trade names of Distaloy SA, AB, SE, SH, AE, AG, 4600A and 4800A (by Hoeganaes) and Sigmaloy 415 and 2010 (by Kawasaki Steel Corporation). They exhibit high compressibility and are heat treatable for maximum properties. They represented a real breakthrough in iron based sintered alloys (18).

The production of these powders involves the heat treatment of a mixture of fine pure iron powder (in the form of their metal oxides) and fine metal alloy powders in reducing atmosphere during which two operations, viz., (i) iron oxide reduction and (ii) subsequent diffusion bonding of alloying elements into iron powder particles take place (2,20,32,41,50-53).

The Distaloy grades are produced using either sponge iron or atomized Ancorsteel 1000 B powders and varying amounts of Cu, Ni- Cu, Ni- Mo-Cu and Ni-Mo as alloying elements for bonding to the surface of the iron powder particles. Distaloy AG is based on the supercompressible ASC 100.29 atomized iron powder with 8% Ni and 1% Mo additions. Mixed with 0.5% graphite and lubricant it can produce parts, after single pressing at 600 MPa

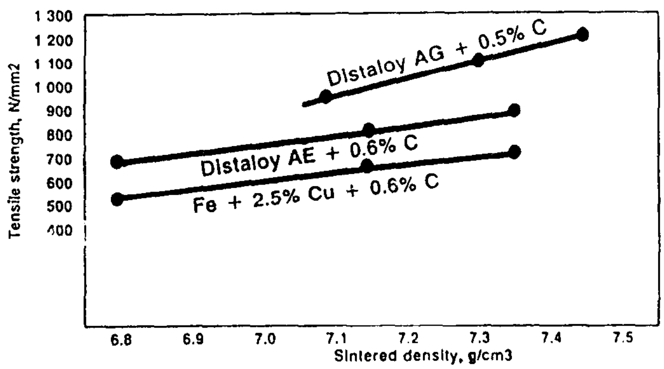

Fig. 8. Comparison of strength of Distaloy AG P/M steels with Distaloy AE and Fe-Cu-C alloy.

and single sintering at 1150°C (2100° F), with a sintered density of 7.32 g/cm^3, tensile strength in excess of 1000 N/mm^2, elongation of 4% and hardness of 320 HV20 without heat treatment. Fig. 8 shows a comparison of Distaloy AG P/M steels with Distaloy AE and Fe-Cu-C alloy (19).

Distaloy 4800A is a diffusion bonded steel powder with 4% Ni, 0.5% Mo and 1.5% Cu. Mixed with 2% Ni, 0.3 - 0.8% graphite and 0.75% Acrawax using Ancorbond process, it can produce column tilt levers by double pressing to a density of 7.3 g/cm^3 with impact and hardness values exceeding the specified minimum (27.2 J and 68 HR15N, respectively). Carburizing treatment, followed by *tempering* at 232°C (450°F) imparts a wear resistant surface.This P/M part only requires honing of the pivot hole to meet the specified tolerance (54).

The composite type alloyed Sigmaloy 415S and 2010 steel powders use water atomized pure iron powder as the base material (see Table 4 for composition). Sigmaloy 2010 can achieve ultrahigh tensile strength of 1500 MPa, an absorbed energy of 21 J, a rotating bend fatigue strength of 460 MPa and a contact fatigue strength of 2560 MPa after normal pressing, sintering and (case hardening) heat treatment and tensile strength of 1920 MPa with an absorbed energy of 53 J after double pressing/double sintering, bright quenching and tempering (52). The increased properties of sintered compacts made from Sigmaloy 2010 are attributed to the strain induced martensitic transformation of Ni - rich retained austenite in the sintered compact during tensile or fatigue tests. Since Ni - rich austenite generally decreases strength, it must be transformed into martensite (55,56). Table 5 lists the properties of sintered and heat treated parts made from Sigmaloy 2010 and 415S steel powder (52). They find applications in automobiles as valve guides, shock absorber parts, oil pump rotors, timing pulleys, etc. (2).

The advantages associated with this alloying approach are: (i) maintenance of high inherent compressibility of the base iron, (ii) increased green strength, (iii) reduced risk of alloy segregation and dusting during transportation of the powder mix, (iv) homogeneous distribution of alloying elements, (v) good sinterability, and (vi) outstanding stability of this composite type base

Table 5. Mechanical properties of sintered and heat treated parts made from A (2010) and B (415S) steel powders.

Powder	Tensile Strength (MPa)	Absorbed Energy (J)	Fatigue Endurance Limit (MPa) Rotating Bend	Contact
(a) Single-Pressing, Single Sintering, Carburizing and Tempering.				
A(2Ni-1Mo)	1500	21	460	2560
B(4Ni-0.5Mo-1.5Cu)	1380	20	410	2430
(b) Double-Pressing, Double-Sintering, Bright-Quenching and Tempering. (0.6% Gr., Sintered at 1523K)				
A(2Ni-1Mo)	1920	53	390	2710
B(4Ni-0.5Mo-1.5Cu)	1720	39	350	2330

powder (2). This material has also led to the elimination of double pressing/double sintering and sizing because of the high hardness obtained in the sintered condition (2).

Mannesmann Demag's new diffusion alloyed 'master alloy' grade ULTRAPAC-20 Cu gives a segregation free Cu distribution. The Cu content can be adjusted by mixing ULTRAPAC-20 Cu with plain iron powder (57).

ADMIXING

To prepare a uniform, press- ready mixes containing all the necessary alloying additions for powder users as well as to preserve premix uniformity against the natural tendency to demix during handling and subsequent processing, Hoeganaes has developed a proprietary mixing process, called ANCORBOND,

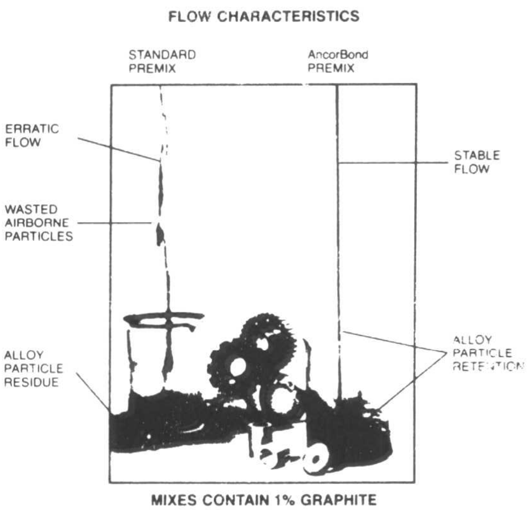

Fig. 9. Flow characteristics of regular premix and an ANCORBOND premix.

bondaloy or bondamix technology that uses patented binders to bond additions to the base powders (58-60). Fig. 9 shows the difference in flow behavior between a regular premix containing 1% graphite and an ANCORBOND processed mix. The erratic flow and dusting of regular premix compared with the more uniform flow or lamellar behavior of the the former is quite apparent.

Benefits of ANCORBOND processing: ANCORBOND processing results in: (i) improved (or uniform) flow rate and better die filling while retaining similar green strength, (ii) potential for improved productivity, (iii) reduced variability in the sintered properties, (iv) opportunities for new alloy development, (v) utilization of fine particle additives and (vi) potential for achieving increased P/M part densities and weight control without the need to resort to double pressing/double sintering techniques.

Like Hoeganaes, Kawasaki Steel Corp., has developed its own "segregation - free" pre-mixed powders called by the trade name 'clean - mix', by bonding graphite and other alloying additives to the surface of iron powder (61).

MECHANICAL ALLOYING

In mechanically alloying (MA) process, composite metallic (or ceramic) powders are produced by simultaneous and repeated sequence of extensive plastic deformation, cold welding, and fracturing of a mixture of metallic and alloying ingredient particles during a dry, high energy (attrition, vibratory or large diameter tumbler) ball milling process (62 -64).

The mechanically alloyed powders are characterized by dense, intimate mixing of constituent metals on a fine scale, homogeneous with a grain refined (submicron grain size) microstructure, extended solid solubility, and formation of nonequilibrium phases. These particles have irregular shape, suitable for high packing density during compaction, and, in addition, they are free of interdendritic microsegregation and pores which are occasionally encountered (65). This results in unique combination of high strength and corrosion resistance. Another advantage is the production of amorphous alloys where an extended range of compositions can be processed which is not possible by rapid solidification.

Mechanical alloying is the most successful method for the production of high temperature creep resistant fine (submicron) oxide dispersion strengthened (ODS) Fe-based superalloys(66), amorphous Fe-Ti and Fe-Ta alloy powders (67).

RAPID SOLIDIFICATION PROCESS

In rapid solidification process (RSP) the local solidification time is reduced with increasing cooling rate. Typically, the cooling rate of conduction processes range between 10^6 and 10^8 °C/s ($1.8x10^6$ and $1.8x10^8$ °F/s) whereas the convection processes may be limited to the range 10^4 and 10^6 °C/s ($1.8x10^4$ and 1.8×10^6 °F/s) (68).

Important attributes of RSP are: increased homogeneity, highly refined microstructure and second phase particles refinement, extended solid solubility limit (i.e., alloying flexibility), and formation of unique nonequilibrium crystalline and non-crystalline (amorphous or glassy) metastable phases which have significant influence on the properties and structural engineering applications of alloys (68-72).

Rapidly solidified low alloy steel powders with a fine homogeneous structure and dispersion of fine, stable sulfide and oxide inclusions such as MnS, VS, SiO_2, MgO and Al_2O_3 have been produced for hot consolidation processing to high strength and ultrahigh strength P/M parts. This enhancement of mechanical properties is attributed the retention of fine grain size during austenitizing at high temperatures because of effective pinning of grain boundaries by finely dispersed, stable inclusions. Production of stress corrosion resistant NiMoLa ultrahigh strength steel via RSP is another landmark in the development of high performance P/M parts (73). The composition of this steel is similar to 4340 NiCrMo steel where Cr is replaced by higher concentration of Mo (1.5% instead of 0.25%) and La (as $LaNi_5$) is introduced into the melt to balance P and S to promote stable fine $LaPo_4$ and La_2O_2S inclusions (74).

Other potentialities of RSP technology include the development of amorphous soft magnetic materials, amorphous ferromagnetic Fe-B-Si alloys for transformer applications, crystalline soft magnetic Fe-B-Si-Al alloy (75), hard magnetic alloys based on crystalline Fe-Nd-B alloy (39).

Conclusion

It is clear from this brief review that ferrous powder production technology has come a long way. The properties of ferrous powders available today, which include high chemical purity, chemical homogeneity, high cleanliness, consistent high quality, excellent compressibility and/or high hardenability fulfill a wide range of high performance P/M parts makers' and end users' (automobile producers) requirements. As a result, various high performance P/M parts were produced: for example, powder forged connecting rods, automotive transmission parts, automotive cams, and gears, steering column tilt lever, synchronizer hub rings, valve guides, shock absorber parts, oil pump rotors, timing pulleys, soft magnetic materials (with superior magnetic and impact strength) from low or medium alloy steel powders; valve seats, rocker arm tip and cam shaft from high speed steel powders; and flanges for exhaust system and fastener for the rear view mirror from stainless steel powders.

In the last few years, a wide variety of new class of materials - amorphous, crystalline and crystalline-amorphous metallic composites with fine microstructure and extended solid solubility limit have been obtained by mechanical alloying and rapid solidification processing for novel applications.

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Understanding Production Costs & Cost/Performance Tradeoffs: Key to Staying Competitive

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Abstract

The importance of understanding manufacturing costs at the design stage, cannot be overstated. One of the key forces that will dictate the success of future organizations is their ability to effectively understand the economic implications of processing changes. The competitiveness of future organizations will rely heavily on breaking down the barriers between design and manufacturing. The design stage in competitive organizations, must serve to fulfill two functions. Firstly, it must be the determinant of the most effective material and processing route for a given application. Secondly, it must work closely with manufacturing in ironing out the problems associated with manufacturing a cost-effective, quality product.

Bearing in mind the above, it stands to reason that efforts be directed towards developing techniques and refining methodologies that will help design engineers understand the cost implications of design changes. This paper will explain the use of one such technique, Technical Cost Modeling, applied towards understanding the competitive forces that dictate materials selection for automotive crankshafts. The identification of the optimal manufacturing process for an application relies not only on cost effective manufacturing, but also on the ability of the technology to deliver a quality product within the cost window. This paper will deal with assessing cost/performance tradeoffs, using an operations research based technique called Multi-Attribute Utility Analysis.

A system based, competitive assessment as applied in this paper, helps determine the feasibility of success for a new venture, at the early design stage. Apart from this, the approach offers the following:

1. Aids in long term strategic planning
2. Assesses the optimal processing technology prior to extensive capital investment
3. Defines a window of processing conditions within which technologies are competitive
4. Assesses the economic feasibility of pre-developmental technologies
5. Aids in obtaining a preliminary understanding of the manufacturing costs of quality

MAINTAINING COMPETITIVENESS requires an accurate assessment of manufacturing costs and the underlying cost/performance tradeoffs. While the industry has used a variety of techniques in the past to assess process costs, none of them have involved a bottoms up technique based on the "physics" of the process. Technical Cost Modeling (TCM), as described in this paper offers corporate personnel, manufacturing engineers and planners a tool by which they can assess the economic implications of process changes and can address issues of technology and process competition.

Advanced technology development is a time consuming process that involves extensive investment in terms of capital and human resources. Frequently the final outcome concerning the success of a particular design hinges on its cost effectiveness compared to existing designs. In spite of this, organizations spend far too little time and effort understanding production costs at the "Phase 0," or pre-development stage of an operation. The bulk of production cost analysis efforts is spent at a later stage at which time it may be too late to revert to an alternate design. This paper presents a systems based approach for addressing technology and materials selection, and elucidates its use in making strategic business decisions.

Scenario

The scenario under consideration one of technology selection for the automotive crankshaft. Changes in materials, driven by the production of high performance vehicles, has spurred an interest in microalloy steel grades for crankshafts. Microalloy steel grade is more expensive than conventional bar steel. However, the use of microalloy steel results in the elimination of heat treatment and provides some machining advantages. Given these conflicting conditions how can a corporation decide on whether microalloy steel offers a strategic advantage for the production of crankshafts? Techniques used to address this question are presented in this paper.

Figure 1 presents the task sequence that corporations need to follow, in order to be assured of a successful product in the marketplace. The existence of an innovative product or technology is no longer sufficient to justify acceptance by the market place. In order to succeed, an application has to satisfy one of two conditions:

1. It has to be cost competitive with existing options, or
2. It has to provide specific performance advantages for which consumers are willing to pay a premium.

The extent to which these two conditions are satisfied, has to be ascertained prior to high volume production.

Methodology

Two techniques are used to address cost competitiveness and cost/performance tradeoffs. These are Technical Cost Modeling (TCM) and Multi-Attribute Utility Analysis (MAUA).

Technical Cost Modeling. Technical Cost Modeling (TCM) is a "bottoms up" method for analyzing the economics of alternative materials systems. It is an extension of conventional process modeling, with particular emphasis on capturing the cost implications of process variables and economic parameters.

A TCM breaks total cost into the individual elements that make up the total, and estimates these elements separately. Thus, the complex task of cost estimation is reduced to a series of simpler estimating problems. Individual cost elements are estimated based on inputs from the model's user and on a series of predictive equations. These predictive equations are derived from information gathered from materials and equipment suppliers, original equipment manufacturers and the analyses of case studies.

The predictive nature of TCMs separates these models from other cost estimating tools. It assures that they can be used quickly and credibly by individuals who do not spend their full time either in cost analysis or embroiled in the details of the process being estimated. The models are built to be flexible since uncertainty surrounds all estimates, and a flexible architecture allows the user to analyze the sensitivity of costs to key variables. If desired, the predictive equations can be overridden by externally supplied values. A schematic of a TCM is shown in Figure 2.

The full value of Technical Cost Modeling is realized when the predictive equations are used to generate a first pass estimate, which is further refined and validated through expert review. In

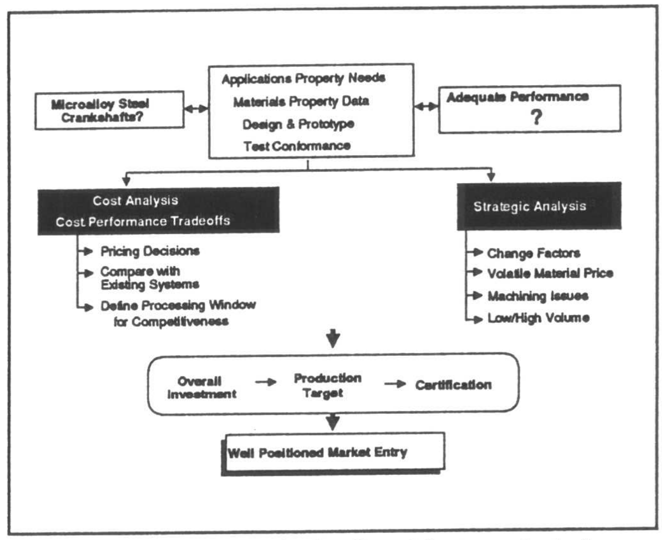

Fig 1 - Market Entry & Positioning-Use of Systems Analysis

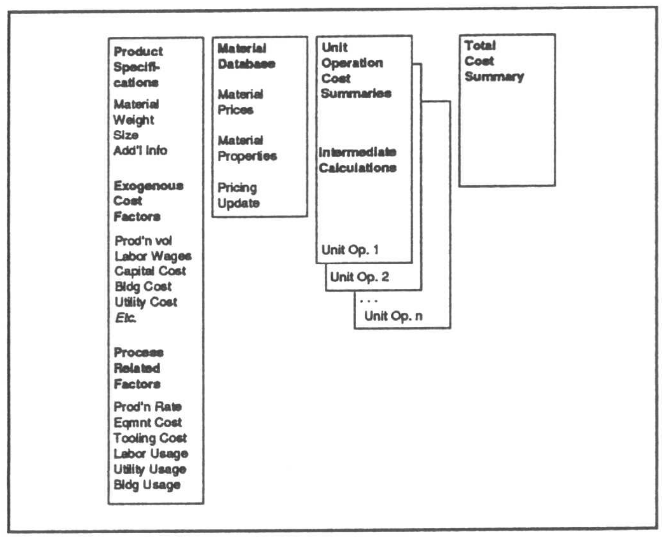

Fig 2 - Technical Cost Model Layout

this way, the models serve as a tool to guide the cost estimation process, and the early model results stimulate the review process and expedite the cost estimation.

Technical Cost Modeling can be used to accomplish the following:

- Simulate the costs of manufacturing products
- Establish direct comparisons between material, process, and design alternatives
- Investigate the effect of changes in manufacturing scenarios on overall cost
- Identify limiting process steps and parameters
- Determine the merits of specific process and design improvements

Multi-Attribute Utility Analysis (MAUA). MAUA, as a research technique has strategic applications ranging from R & D to marketing. It can be used to target critical technology or material properties and place a dollar value on each incremental improvement in performance. MAUA can also be used to structure the material selection procedure, provide the basis for demand analyses, and fine tune material pricing policies.

MAUA is a measurement technique, directed toward measuring the preference structure of a decision maker that is revealed in the course of a structured interview. The interview questions subtly evaluate the user's preferences while confronting the subject with situations drawn from their own experience in the area of materials selection. In materials selection, these questions take the form of a materials acceptance problem. Figure 3 shows the steps involved in performing MAUA.

The critical element of MAUA is the introduction of uncertainty, and the reaction of the subject to uncertainty. The key to a successful MAUA is the identification of individuals who actually make the decisions being studied, and to conduct an interview. These interviews frequently yield considerable information outside the strict scope of MAUA, which provides insight into the dynamics of the decisionmaking process within individual organizations.After the interview, the data is reduced to the form of a mathematical construct known as the utility function. This function transforms given levels of performance into a measure of preferability known as utility. Because the utility function is an analytical function, it is possible not only to calculate the utility of the specific combinations of performance each alternative under consideration represents, but also to identify all combinations of characteristics which may yield this level of utility.

Technology Screening - Crankshaft

Production costs for automotive crankshafts produced using four competing technologies, nodular casting, austempered ductile iron casting, steel forging and miocroalloy forging, were estimated based on the assumptions presented in Table 1. Figure 4 presents the cost breakdown by factor for the four alternatives.

Nodular casting is clearly less expensive than the other alternatives. The labor and capital costs are representative of the amount of machining required in the operation. A change in processing technology from nodular cast to steel forging results in a machining penalty leading to higher costs. Compared to the steel forgings, it can be seen that microalloy forgings are less expensive due to savings in machining and elimination of the quench and temper heat treatment. An analysis of this type helps ascertain answers to the following questions at the design stage:

- What are the cost intensive factors?
- How does microalloy steel compete with existing technologies?
- What are the tradeoffs between machining and forming costs for the various technologies?
- On what factors should I focus my efforts to bring down the cost?

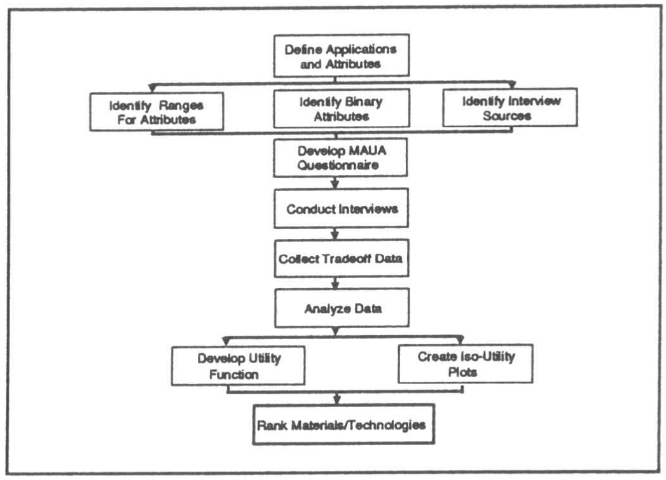

Fig 3 - Flowsheet for Utility Analysis

Table 1 - Cost Estimating Assumptions

	Sand Cast	Forged	ADI	Microalloy
Annual Vol (parts)	792,000	792,000	792,000	792,000
Final Part Weights (lbs)	32.6	32.6	32.6	32.6
Die Life (parts)	250,000	15,000	250,000	20,000
# ForgingImpressions	-	2	-	2
# Cavities/Impression	-	1	-	1
Material Cost	$0.28/lb	$0.22/lb	$0.25/lb	$0.25/lb
Dedicated Equipment	no	yes	no	yes
Maintenance	10%	4%	10%	4%
For All Alternatives				
Period Amortization	10 yrs			
Amortization Rate	12.0%			
Tax Burden(% invest)	1.2%			
No. Shifts/Day	2			
Working Hrs./Shift	8			
Working Days/Year	240			
Labor ($/man-hour)	24.0			
Cost of Bldg Space ($/sq ft)	$90.0			

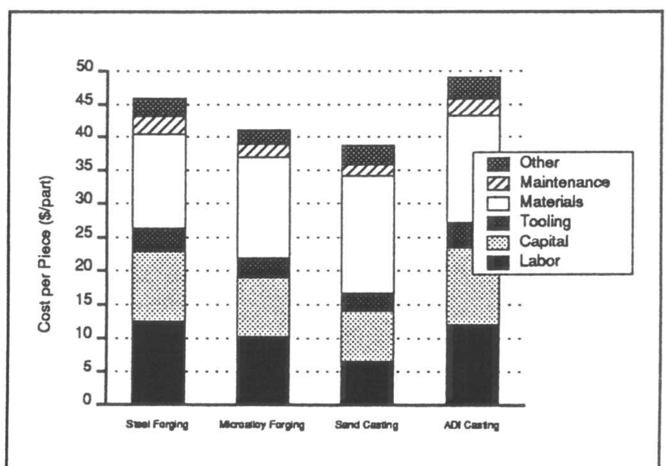

Fig 4 - Breakup of Cost by Factor for the Crankshaft

Strategic Planning

Long term planning rarely relies on static evaluations. The technique elucidated above can help assess production costs in a dynamic environment of changing factors. Thus, it is possible to assess the competitive implications of changing materials prices. Figure 5 presents the price variation of the microalloy forged crank with the price of microalloy steel. Implicit here is the assumption that all other materials prices and other factors remain constant.

Based on the scenario of a corporation wishing to enter the crankshaft market supplying microalloy steel cranks, dynamic analysis helps project materials prices at which microalloy forgings will compete with steel, ADI castings and nodular castings. It is evident that at prices below $0.21/lb for microalloy steel, microalloy forgings have an economic edge over nodular castings, and they maintain this advantage over steel forgings for microalloy prices up to $0.31/lb. An analysis of this type helps position the technology at specific market segments based on existing factor conditions.

Figure 6 presents the variation of cost with production volume. This analysis helps determine the production volume that needs to be met in order to compete with existing technologies. Using the above analysis, the business manager can determine the optimal market in which he should position his technology. Figure 7 graphically presents this positioning. Knowing à priori that microalloy steel competes only for higher performance vehicles at high production volumes (due to scale economies), helps focus development efforts, and significantly enhances a materials chance of success in the market .

Cost/Performance Tradeoffs

While it is true that a significant number of technology and materials selection decisions stem from economic considerations,

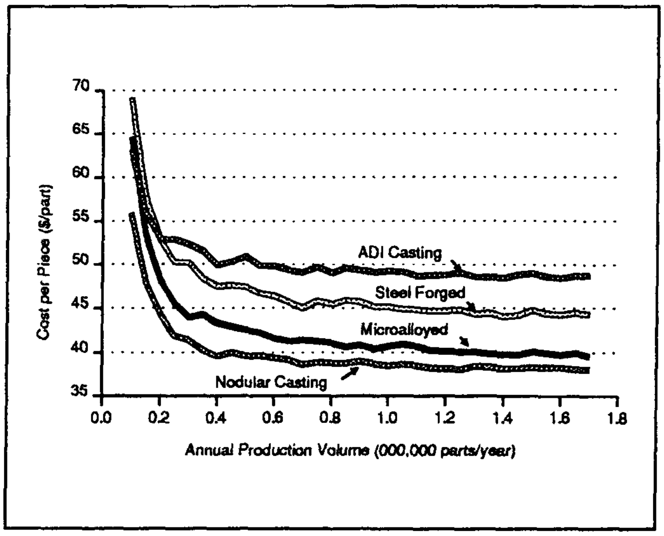

Fig 6 - Variation of Total Cost with Vol for the Crankshaft

performance considerations are also pivotal in determining which technology is utilized for a particular application. OEMs and other users are often inclined to pay a premium for the performance enhancements offered by certain materials and technologies. This may, for example, take the form of higher tensile and yield strengths or lower weight. The problem that needs addressing then translates to one of ranking the various material and technology alternatives available based on their relative degrees of acceptability. This, along with a detailed cost analysis, serves as a corporate planning tool and helps focus technology development and market entry.

The results of utility analysis, an operations research based interview technique explained before, are presented below to

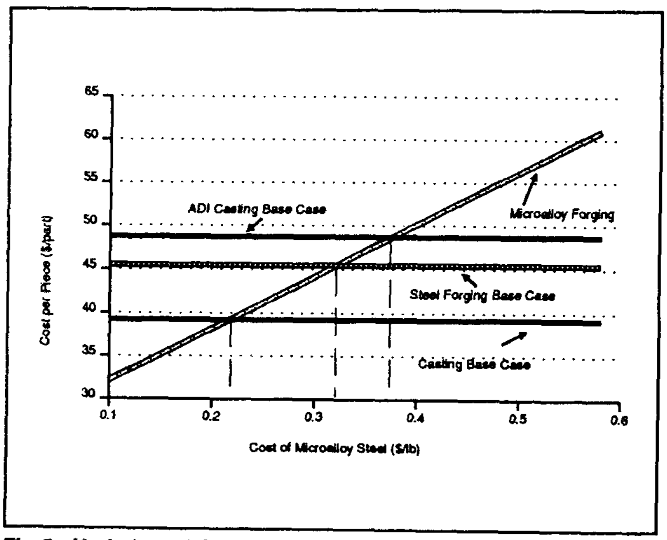

Fig 5 - Variation of Cost with Price of Microalloy Steel

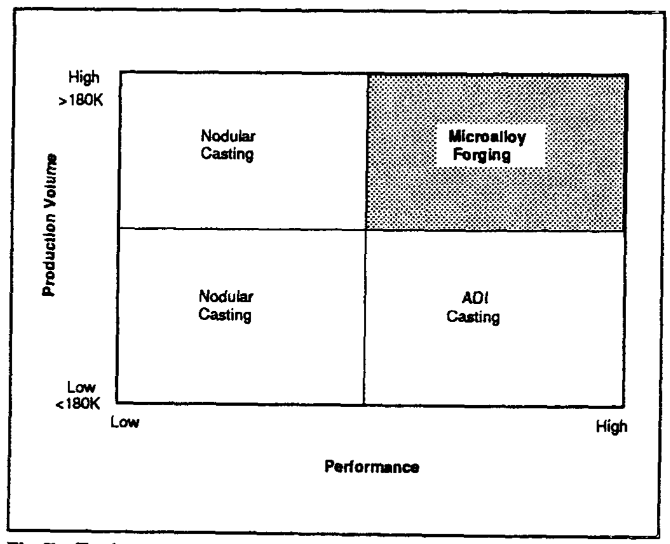

Fig 7 - Technology Positioning-Based on Economics

demonstrate the nature of information gathered and the way in which the information is assessed and utilized.

In assessing how a given material/technology is ranked vis a vis others in the market, it is necessary to identify those engineering attributes which are preferred by users, and which can be traded with cost. For example low weight is always preferred and traded off with cost. Similarly, engine manufacturers will pay for increases in modulus which is a measure of the stiffness of the application.

Table 2 presents a matrix of attributes, and the ranking of alternatives, obtained using the interview based MAUA technique. Implicit in this analysis is the assumption that for all cases except nodular castings, the application is redesigned to take advantage of the higher strength. This redesign results in a 20% weight reduction. This analysis helps the business planner conclude that based on the mix of cost, modulus and weight, his microalloy steel product has a unique play in the market place.

Akin to the case of cost analysis, dynamic analyses will help define thresholds that need to be satisfied for a new material or technology to perform on par with existing ones. Figure 8 presents the variation of total utility with production cost. Total utility is a function of the weighted mean of the three attributes listed as preferred. It is apparent that utility decreases with increasing cost. Of more interest is the situation when a new material, designated as 'B' is set to enter the market and compete with existing material 'A.' This analysis helps define the range by which the cost of 'B' can exceed that of 'A' while having the same level of acceptability in the marketplace.

Using the same information, one can assess the tradeoff between cost and any performance attribute. Figure 9 presents the tradeoff between cost and weight. The slope of the curves is

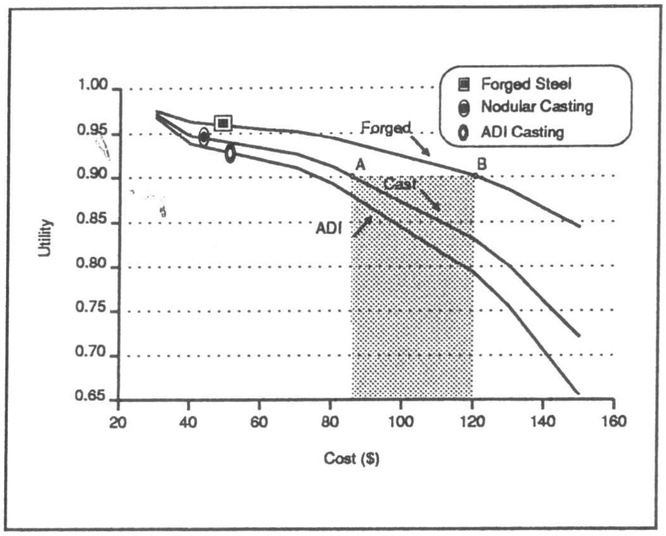

Fig 8 - Total Utility as a Function of Cost for Crankshaft

representative of the willingness to pay for added performance. Figure 9 demonstrates the use of the analysis in strategic Planning. Assuming that microalloy steel can be represented by point 'B' on the curve, and that point 'A' is representative of nodular casting, the dark shaded triangle represents the range by which either the cost or weight has to decrease by in order for microalloy steel to be as preferable as nodular casting. Using this window of performance threshold, the business planner can work with production, engineering and design personnel to devise a research and development plan that can meet these requirements.

Given the cost threshold, the business planner can, through the use of the cost models, determine the optimal matrix of processing variables that will yield the required cost target. These variables can then be reviewed by the engineering and manufacturing staff with regards to the feasibility of attainment.

Table 2 - Utility Analysis - Attributes & Ranking

	Finished Cost	Finished Weight	Modulus	Rank
Microalloy Forgings	$37.08	26.08 lbs	29,000 ksi	1
Steel Forgings	$41.21	26.08 lbs	29,000 ksi	2
Nodular Castings	$38.45	32.60 lbs	21,000 ksi	3
ADI Casting	$42.78	26.08 lbs	21,000 ksi	4

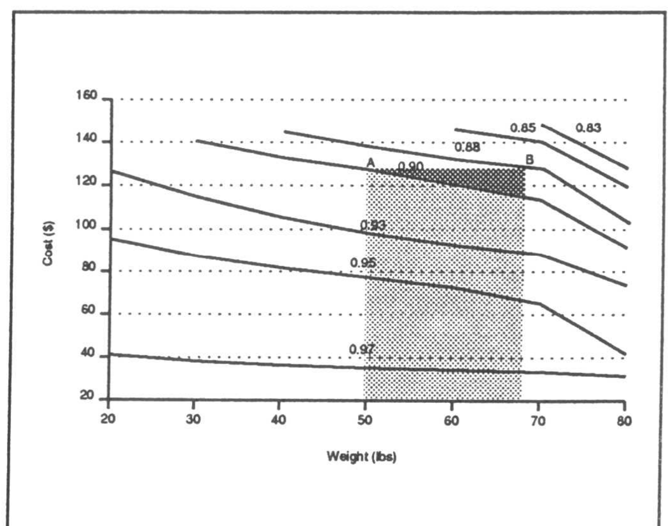

Fig 9 - Cost-Weight Tradeoff for the Crankshaft

Conclusions

While technological strides in processing and materials have yielded a competitive edge to many players, a fundamental understanding of the cost drivers, together with an analysis of the cost/performance tradeoffs remains critical to the success of most new ventures. This paper has elucidated two powerful techniques that form the backbone of detailed business and technology analyses. Use of these techniques through the design stage of technology and materials development efforts helps focus development and enhances the probability of success for new ventures.

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Expert System with Simulator for Billet Conditioning Line Control

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Abstract

Recently, due to the increasing variety of products in the manufacturing line, it has become difficult to attain high productivity using simple sequencer logic for line control. To overcome this problem, artificial intelligence approaches are considered to be useful. An expert system can be extremely useful because it easily accommodates heuristic rules. This paper introduces an expert system developed for deciding routes of the products on a billet conditioning line in steel-making process, which includes a simulator for evaluation of the system performance. It has been estimated that this expert system can improve the productivity of the process from the results of simulation and actual application.

Introduction

Manufacturing lines, today, handle such a variety of products that the mere expansion of conventional techniques seems to have some limitation about improvement of the productivity. Therefore, an expert system, which can handle information for a variety of products in a complex line and ensure high productivity, has been anticipated [1-2].

We have developed a manufacturing route control expert system [3] which, based on a simple structure, enables intelligent decision and control. In this system, a simulator is used to quantitatively check candidates for solution given by the heuristic rules. In this paper, the structure of the system and its application results are introduced.

Billet conditioning line

A billet conditioning line (Figure 1) treats billets, which are half-finished steel goods produced by a continuous caster. The billets are 118 or 155 mm square by 10 meter long. The line first detects the billets' surface and then, based on that information, selects one of three grinding routes for each billet. After the grinding process, each billet joins the other billets of the same lot, which have been processed on the other two routes, and moves on to the next rolling process via an inspection line.

In conventional control system, several sets of control logic decide the routes for billets. But this limits the lot merging order for a given lot sequence. This kind of logic is useful when a line produces large amounts of same products (when a lot consists of decades of billet). However, recently, as users have started to order various kinds of products, lot sizes have decreased. Consequently, systems using only conventional logic result in a longer time consumption for processing small size lots (consisting of a few billets). So in order to increase productivity, it is necessary to develop a software which provides some optimizing method for controlling the movement of billets.

Software programs for conventional control logic systems describe both facility restrictions and performance indices in the same procedure type of program. Moreover, it is well-known fact that the high level know-how makes a program complex and difficult to maintain. In order to make program maintenance easier, we focused on the usage of expert systems. On the other hand, expert systems are said to have difficulty guaranteeing the quantitative feature and maintaining the consistency of the knowledge bases when rules are added or modified.

Considering the above requirements, we have designed an expert system combined with a simulator for quantitative evaluation to maximize productivity.

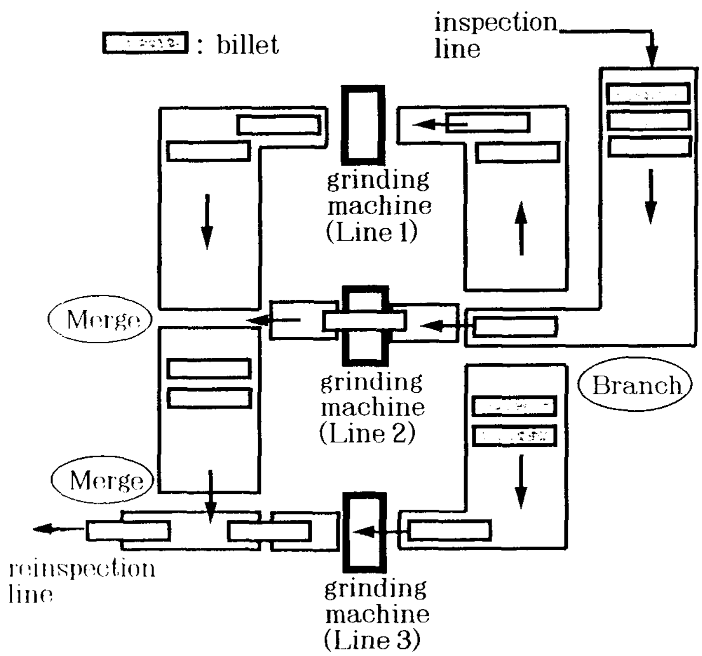

Figure 1: Layout of billet conditioning process.

Configuration of Expert System

The configuration of the expert system is shown in Figure 2. It is designed in such a way as to combine both the characteristics of the rule-based programming and the conventional programming.

The logic to decide the billets' routes is arranged in three layers of knowledge. The top layer of knowledge consists of the rules to decide strategy of selecting route. The inference engine devises several strategies based on this top layer of knowledge. The second layer consists of several dispatching rules to decide a route for each billet. Each strategy drives an individual dispatching procedure which selects a grinding route for every billet, thus candidates for solution are generated. The bottom layer of knowledge forms a simulation model for the billet conditioning process. This simulator executes simulations for the candidates and chooses the best solution which optimizes the performance index.

The main features of this system are as follows:

- The rule-based programming style improves program maintainability.
- The simulator enables the quantitative evaluation of several candidates.

The first feature compensates for the problem of maintainability in conventional systems, while the second feature compensates for the lack of quantitative evaluation in expert systems. When rules are added or modified, the simulator acts as a checking system for those rules. That is, even if the new rules are not necessarily good, the system will not choose a bad candidate as the final solution. Consequently, engineers feel free to add any strategic or tentative rules, and operators can rely on the output from the expert system. This feature really promotes the actual usefulness of this system.

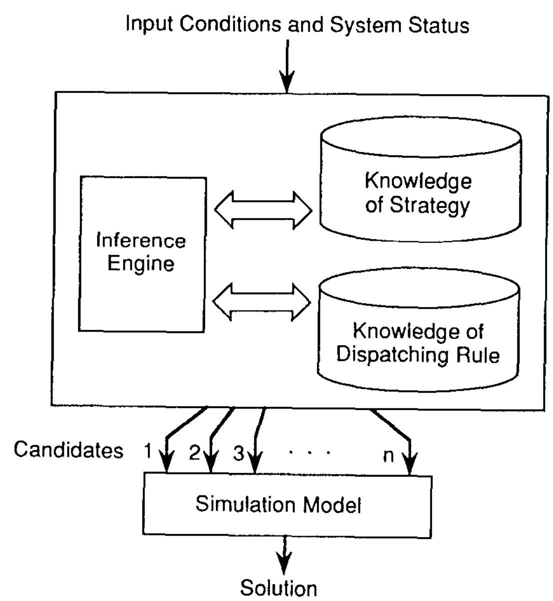

Figure 2: Configuration of expert system.

```
SUBROUTINE  IFPRT

    IF(LOTSIZ.GE.10)
        FACT(i)=1
    IF(CUTTIM.LE.80)
        FACT(i+1)=1
            .
            .
            .
```

(a) Condition routine

```
SUBROUTINE  ACTPRT

    IF(FACT(1)*FACT(2)*FACT(j).EQ.1)
        CALL CAND( j, CF1, PARA1, PARA2 )
        CALL CAND( j, CF2, PARA1', PARA2' )
            .
            .
            .
```

(b) Action routine

Figure 3: Programming style of inference engine.

Knowledge base

The strategic layer of knowledge base is a set of heuristic rules which decide the line control guideline, such as "All machines should be equally used when a big size lot comes", "It is prohibited to use the same route continuously for billets which need long grinding time", and so on. As this layer doesn't specify detailed parts, it helps to lessen the number of rules.

On the other hand, the dispatching rules describe definite methods for branching lots into three routes under the guidelines given by the upper knowledge. For example, under a guideline like "use all machines", it would provide a method to decide a route for each billet according to the processing time and machines' occupied status. In order to decrease the complexity of system, every dispatching rule is written in procedure type of programming.

Inference engine

A production system is used for matching rules in this system. It is written in FORTRAN so as to be easily transferred to other computers.

The subroutine IFPRT judges the truth of all facts used in the conditional part of the rules. The variable FACT is attached to each item such as lot size (LOTSIZ) and grinding time (CUTTIM). As shown in figure 3(a), FACTs are given a logical values of 1 or 0.

the truth of the conditional part in the rules is judged by the subroutine ACTPRT. Figure 3(b) shows that rule j is satisfied when FACT(1) and FACT(2) are true at the same time. After firing a rule, the value of FACT(j) is changed into 0, and two candidates are proposed. One candidate is with parameters PARA1 and PARA2 having the certainty factor CF1, and the other candidate with parameter PARA1' and PARA2' having the certainty factor CF2.

All candidates derived from the rules are checked in the simulator.

Flow of procedure in expert system

We applied the above expert system to control the routes of the products in the billet conditioning line. The objective of this system was to decide a route for each billet and a merging order for each lot. The whole flow of inference procedure is shown in figure 4.

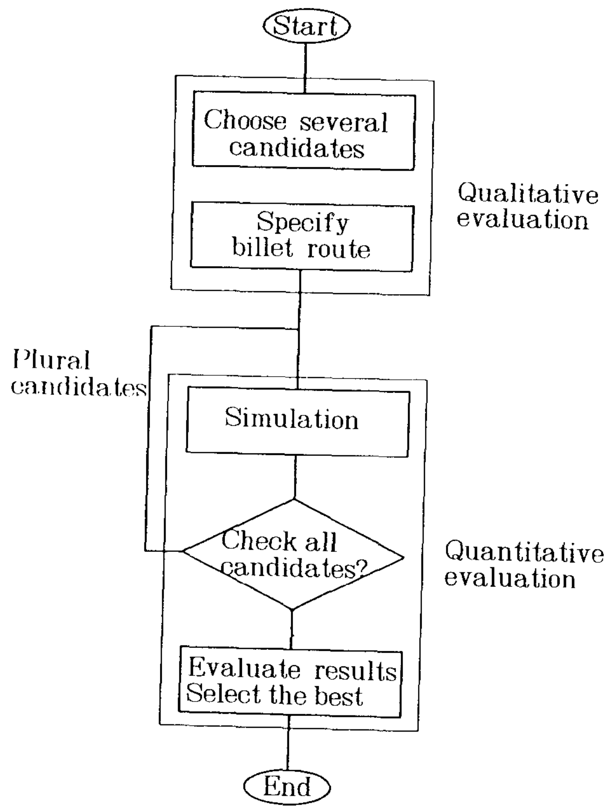

Figure 4: Flow chart of procedure.

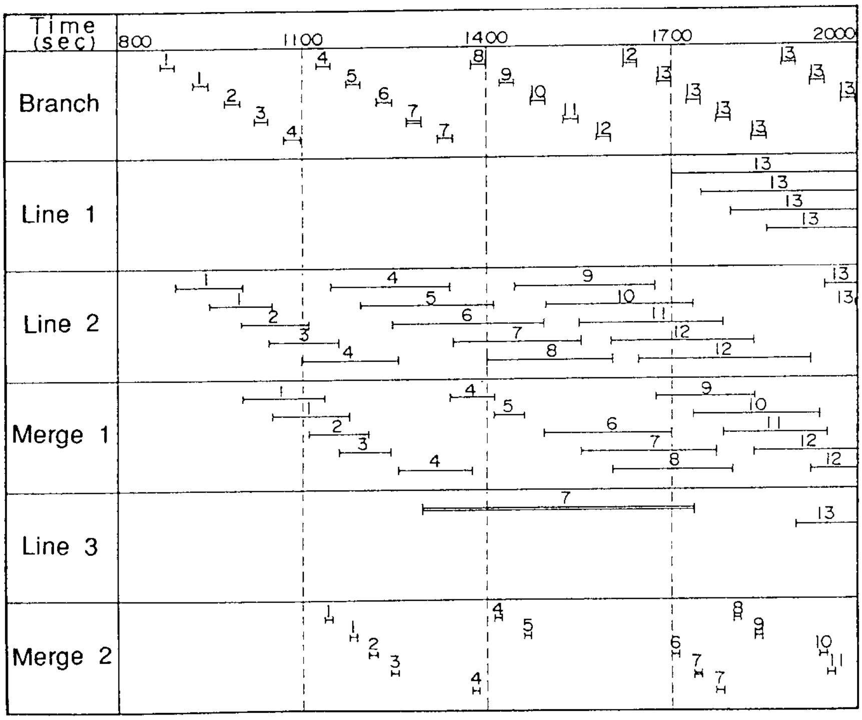

Figure 5: Simulation result of conventional system.

The strategic rules provide several guidelines to branch lots. Moreover, for a series of small size lots, it would be decided whether the lot passes preceding lots at the merging point. For big size lots, a route using ratio, which indicates how to use each route, is decided.

The dispatching rules specify a route for each billet. The following items are taken into consideration in these rules:

- sequences of lot size
- status of each grinding route
- estimated grinding time of each billet
- subsequent lot size and so on.

Finally, the simulator evaluates these candidates quantitatively. From the results of its evaluation, the system outputs one candidate as the final solution which optimizes the performance index.

Results of case studies

To adjust rules and to evaluate the system, we checked this system by means of simulation. The following results compare the performance of the expert system with that of the conventional system.

The first example is a simulation with a series of small size lots. Its time chart is shown in figure 5 and figure 6. In these figures, the vertical axis corresponds to the process of the conditioning line, the horizontal axis shows time. A line in the figures represents that a billet exist in the corresponding process, and the number attached to the line identifies its lot . The conventional system (Figure 5) mainly used route 2 in order to avoid routes which took longer processing time like route 1 and route 3. In figure 5, billet 7 (double line) was input into route 3, as the entrance buffer of machine 2 had been filled up. As the result of this route selection, number 7 billet waited for 4.5 minutes at the merging point until the billet 6 finished its processing. The expert system (Figure 6), on the other hand, branches the lots into route 2 and 3 appropriately.

Table 1: Improvement of performance in simulation results.

Case	Reduction of total manufacturing time (%)
A	3.91
B	2.17
C	5.11
D	10.87
E	4.87

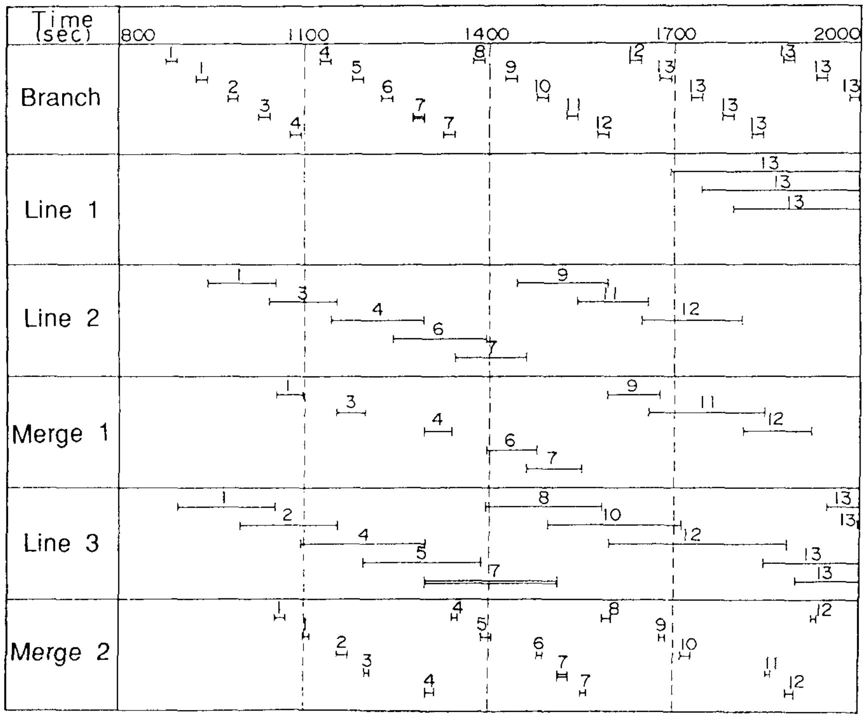

Figure 6: Simulation result of expert system.

In addition to this example, we studied five various combinations of conditions, A through E. For the performance index, the total manufacturing time compared with the conventional method is used. Table 1 shows that the expert system decreases the total time spent for processing all the billets, in all cases, and by 5% on average.

Since this factory is capable of producing 65,000 ton of steel per month, this result corresponds to 3,000 ton increase in production volume.

Application results

We tried to use this system in an actual process. The best evaluation method is to compare the performance using the conventional system with that using the expert system in the same condition. But actually, one never encounters the same situation, such as the same sequence of lots size, number of billets, grinding time, and so on. So we compared the time spent for each size of lot statistically.

Figure 7 shows the results of the application. The horizontal axis shows manufacturing time for each lot, that is, time elapse after the first billet of lot enters the process until the last billet of lot finishes its process. The vertical axis stands for the sizes of lot, and many sampled data for each lot size are plotted in the figure. Circles in figure 7 represent the cases of the expert system application, and the others show the cases of the conventional system. This figure reveals that the expert system is helpful to increase the productivity.

Conclusion

In this paper, we reported on the applied results of artificial intelligence technologies to the manufacturing line control. The expert system combined with a simulator could successfully compensate for the weak point of conventional systems. Using a rule-based programming, the system becomes intelligent and its maintainability is remarkably increased. The combined simulator enables quantitative evaluation of the solutions obtained from the expert system. Consequently, it provides the system with high reliability.

This system is applied to the billet conditioning line in the Kobe Works of Kobe Steel Ltd. It has been proven that this system can improve productivity of the process by more than 5%, in such difficult situation that a variety of products are mixed in a manufacturing process.

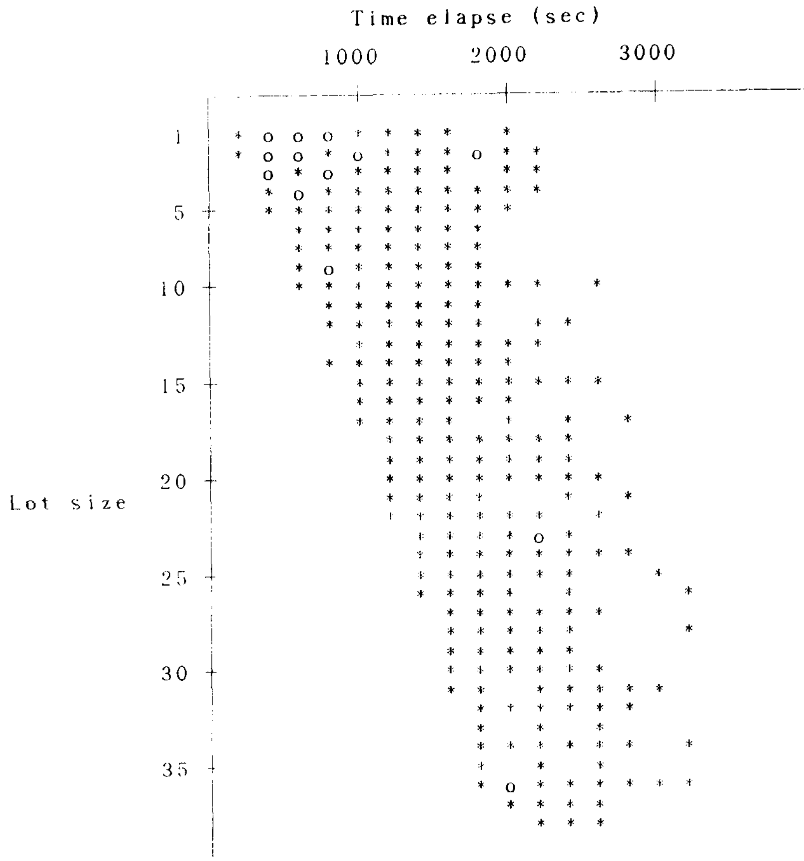

Figure 7: Results of application.

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Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

The EAF Bottom Gas Injection: A Technoeconomical Evaluation

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Abstract

The bottom natural gas injection system for EAF has been installed and operated at a sponge iron based production facility.
The main benefits observed under different conditions of sponge iron melting are reported.
The economical benefits like lower energy consumption and higher metal scrap yield are also disclosed.

PREVIOUS WORK AT IMIS AND AT DEACERO had shown that scrap based steel production is enhanced in EAF by bottom natural gas injection.
The main benefits observed by this practice are:

- 20-40 KWH/ton
- 5-15 min. in tap to tap
- 0.5-1% metallic yield
- minimization of unmelted scrap reactions
- more chemical and thermal homogeneization
- better desulfurization

Based on the above it was sugested to install the natural gas injection system in a DRI based steel production facility of ISPAT at Michoacan, Mexico.

The objective was to reduce metal ejections through the EAF charging door and get all benefits associated with natural gas bottom blowing.

This report describes the natural gas injection system, its installation and operation, and results obtained during 3 campaigns performed at the No. 1 EAF of ISPAT Mexicana.

The Natural Gas Injection System (NGS)

The system comprises basically 4 items:

- Injection Element
- Sleeves
- Extraction/installation device
- Stirring control (piping and flow/pressure controls)

On the other hand a complementary tailored package is provided with the NGS which includes:

- Operating practices for the NGS
- Maintenance practices for the NGS

The following is a brief description of each item suplied with the NGS.

Injection Element. Fig. 1 is a cross section view of an Injection Element. The ceramic body is

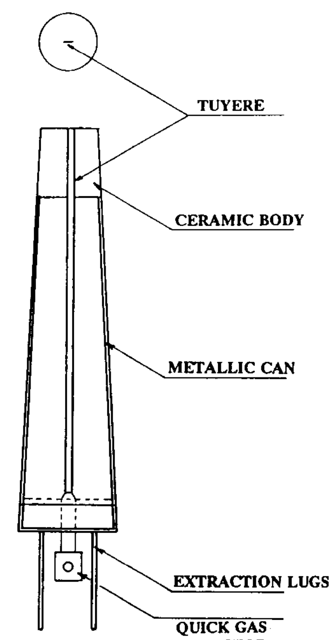

Fig. 1 Injection Element

made by isostatic pressing of MgO-C powders followed by a curing heat treatment. The tuyere is designed for the specific EAF considering: Tons of liquid metal, bath height and agitation requirements. Fig. 2 is the characteristic flow/pressure curve for the ISPAT tuyere.

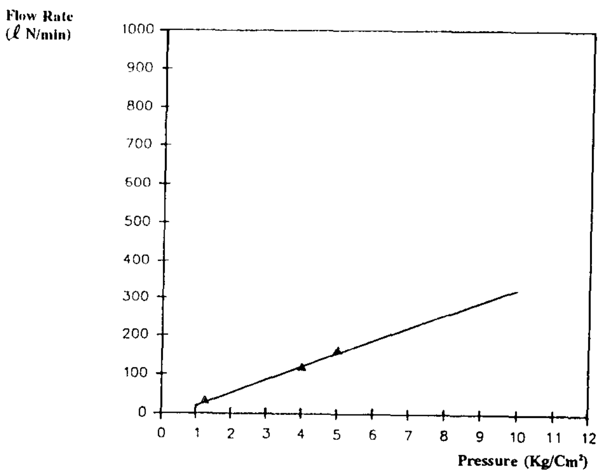

Fig. 2 Characteristic flow/pressure curve for the ISPAT tuyere.

The total height of the injection element is also tailored to the specific EAF lining.

Sleeves. Normally a set of 3 sleeves is designed for each installation. The purpose of sleeves is twofold: Make easier the maintenance operations and withstand the high erosive conditions at the gas exit area. Fig. 3 shows schematically a set of sleeves.

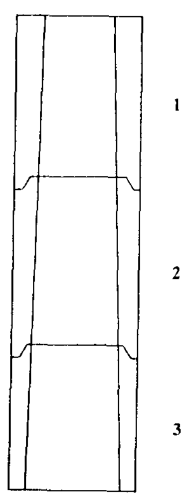

Fig. 3 Set of Sleeves

Extraction/Installation Device. Fig 4 shows a schematic drawing of the extraction/installation device.

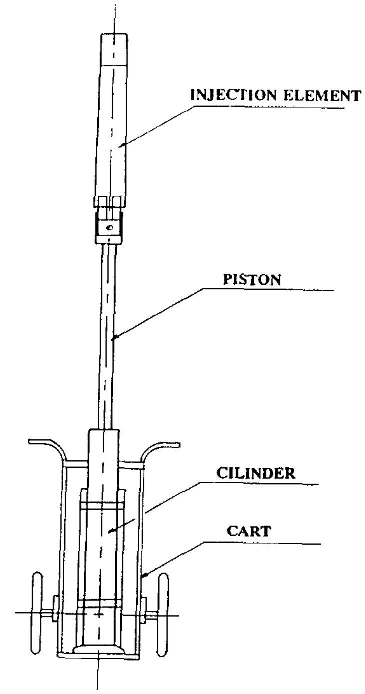

Fig. 4 Extraction/Installation Device

This device is used to facilitate the maintenance operations of the injection element. During installation a special refractory (zirconia) paint is applied on the element's surface having a thickness of approximately 1 mm. This operation is very important in order to avoid any sintering between sleeves and injection element and make easier its extraction at the end of the 15 day campaign.

Stirring Control. Given the metallic height, total mass and temperature, the agitation power is a direct function of the gas flow rate entering in the furnace bath. Thus in the NGS having the tuyere designed for specific conditions, the stirring control is a matter of gas flow rate control. Fig. 5 presents the stirring control system which is prepared to deliver natural gas or nitrogen through three different gas lines.

The system is conditioned to be operated automatically from a control desk in the furnace pulpit on a very simple configuration as shown in Fig. 6.

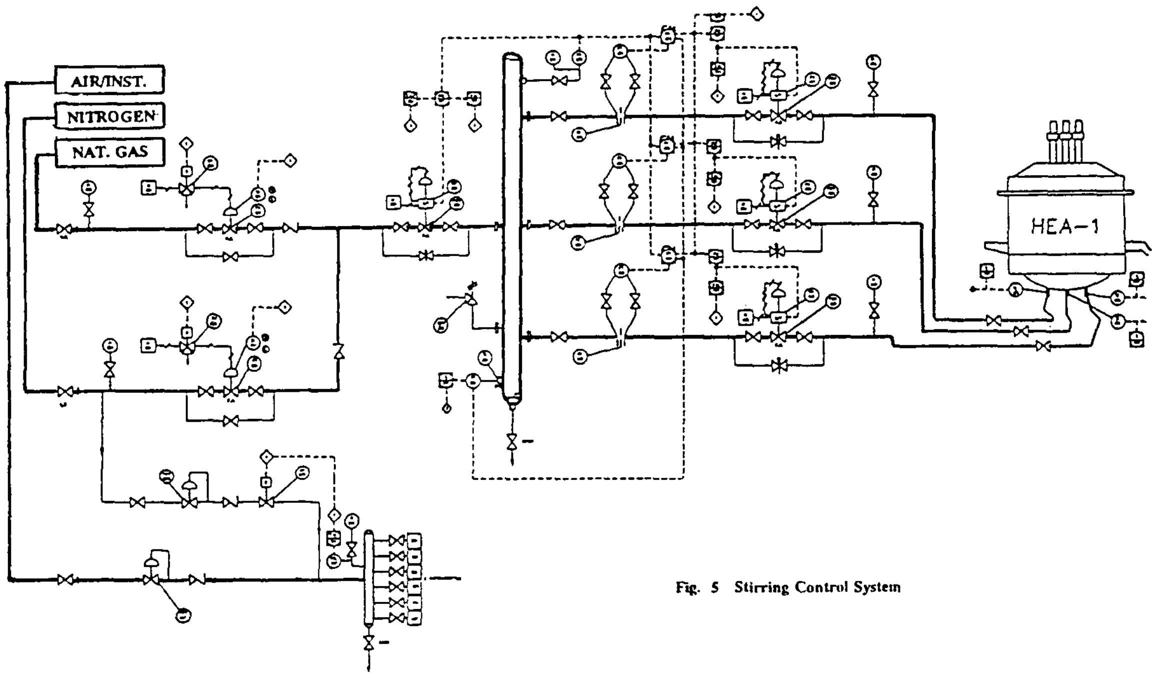

Fig. 5 Stirring Control System

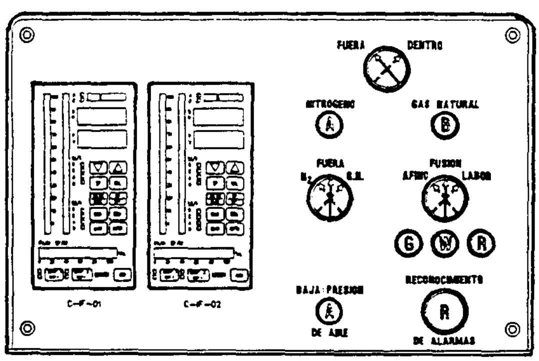

Fig. 6 Stirring Control Desk

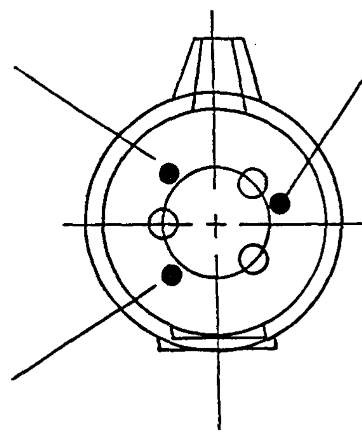

Fig. 7 Injection Element's Position

System Installation and Operation at ISPAT

ISPAT (formerly SIBALSA and in turn formerly SICARTSA) has a steelmaking shop with four 200 ton EAF. A 15% - 25% scrap is normally charged before the continuous feeding of DRI. Steel produced is continuously casted to slabs. Fig. 7 presents the injection element's location at the bottom of the EAF No. 1.
Fig. 8 shows the refractory arrangement around the injection element and sleeves.

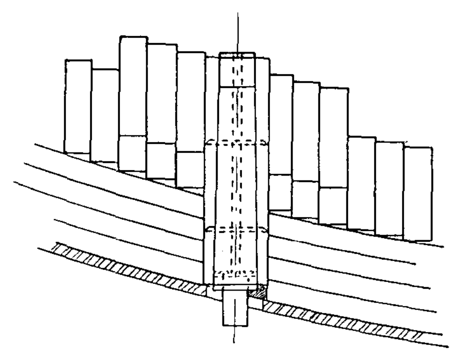

Fig. 8 Refractory Arrangement

Operation of the NGS was performed as shematically illustrates Fig. 9.

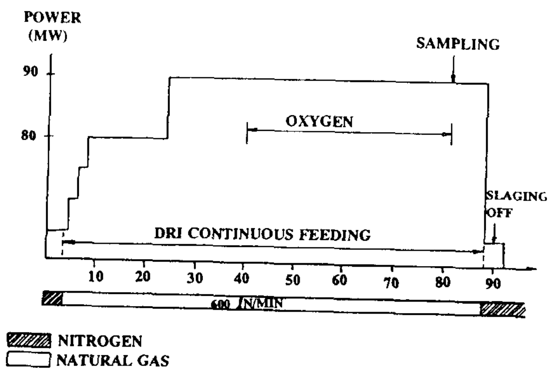

Fig. 9 Typical Practice Using the NGS

The injection element wearing was monitored by using a mathematical model illustrated in Fig. 10. When wearing reaches the first sleeve, a fettling operation is performed maintaining a minimum gas flow rate. The above practice stops the vigorous stirring keeping a gentle (non visual) agitation and, the most important, stops wearing. At the end of the 15 day campaign the injection element and the sleeve No. 1 are replaced, and so on.

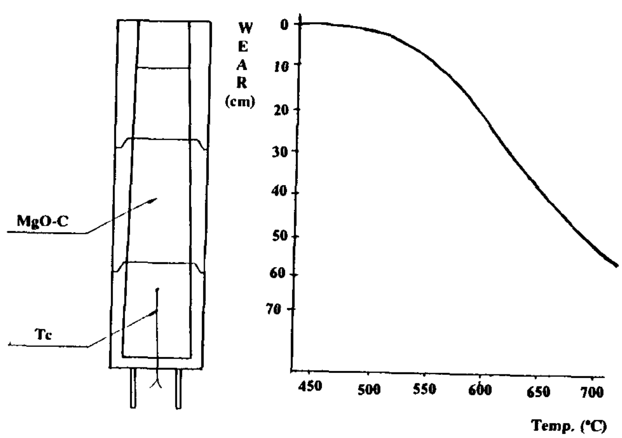

Fig. 10 Mathematical Model for Wearing.

Results

In the first campaign sleeves of Cr2 O3 - MgO were used. These sleeves were erosioned very fast because of some problems with pressure and gas flow rate fluctuations.

During the first heats appeared some small "ferrobergs". By decreasing DRI feeding rate to 3200 kg/min and targeting melt down temperatures close to tapping temperatures, the "ferrobergs" formation was avoided.

A high temperature in element No. 1 lead to stop the operation to check the element condition in order to be sure about said wearing in that area.

A severe damage in the element and sleeve was found confirming the model's prediction.

During this campaign a decrease in melting time and electric energy consumtion was observed compared with the practice without natural gas injection.

Results and technical data related with the three campaigns are shown in table No. 1. During the second campaign sleeves and injection elements of MgO-C gave better results. In addition all problems related with instrumentation and control devices were solved.

An increase in the DRI feeding rate was necessary because high temperatures were obtained at melt down. The oxygen injection was increased in comparision with the first campaign and important electrical energy savings and reduction in tap to tap time were observed.

This campaign was stopped because the tuyeres were blocked with burned dolomite; this material was used to repair the furnace bottom.

During the third campaign tuyeres and sleeves of MgO-C were also used. Minor changes in tuyeres area, pressure and natural gas flow rate during melting and refining were performed.

Results regarding electric energy savings, reduction in tap to tap time and productivity were very satisfactory.

The reduction in tap to tap time was very important having being possible to establish a daily production record: 10 heats in EAF No. 1 (2000 tons of liquid steel/day). Because of energy restrictions (by cost) only twenty hours are available to produce steel.

Table 1 Main results observed in average during the first 3 campaigns at ISPAT

	EAF No. 4 *	1st Campaign	2nd Campaign	3rd Campaign
Heats	-	48	26	53
Charge				
Scrap (%)	14.6	25.7	15.1	18.4
DRI (%)	85.4	74.3	84.9	81.6
Liquid steel produced (TLS/Heat)	210	203.7	202.5	211.1
Yield (%)	94.0	92.9	94.8	96.0
Temp. at meltdown (°C)	-	1589	1617	1605
Final carbon (%)	-	0.10	0.06	0.11
Energy Consumption (KWH/TLS)	747.6	706.1	679.5	665.0
Oxygen Consumption (m^3N/TLS)	5.1	5.7	9.5	8.7
Melting time (min.)	111.1	96.7	94.5	93.8
Refining time (min.)	19.4	12.9	14.1	10.7
Tap to Tap time (min.)	138.2	136.0	132.8	122.8

* No Stirring

Other Effects Observed

1.- **Steel/Slag Ejections.** The bath temperature has a strong influence on DRI melting: there is a possibility to have cold spots in the lower part of the bath during melting with static bath (no stirring). Also, some problems with oxygen injection at melt down are present when the temperature is increasing taking place strong reactions producing liquid ejections through the charging door.
One of the main consequences of natural gas stirring is a thermochemical bath homogeneization avoiding cold spots and decreasing overflow possibilities.

2.- **Reduction in Energy Consumption.** Important electrical energy savings were obtained during natural gas injection: the average in three campaigns shows savings for more of 60 KWH/TON of liquid steel.

3.- **Reduction in tap to tap time.** Using natural gas injection helps to increase the DRI feeding rate, decreasing the melting time.
During trials a reduction of 14 minutes in the tap to tap time, was observed. The average number of heats/day was increased in almost

5.- **Hidrogen.** Some heats showed hidrogen values of 4 ppm.

Conclusions

Bottom natural gas injection has proved the following benefits on DRI based EAF:

a) Better thermochemical homogenization.
b) Energy savings of 30-60 KWH/TON.
c) Higher productivity.
d) Elimination of steel/slag ejections.
e) Improvement on yield.

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Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

High Technological Application of Blue Dust in the Manufacture of Metals & Materials

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Abstract

Blue Dust, available at Bailadila mines of National Mineral Development Corporation Ltd., (NMDC), India is unique in nature. It is a naturally occurring fine grained high grade iron ore with very low levels of impurities. Studies conducted by NMDC to utilise this high purity natural iron oxide have proved that this could be utilised in manufacture of hi-tech products like Pure iron, Hard & Soft magnetic materials, high quality sponge iron & steel, reduced iron powder etc. With the development of process technology and new applications. Blue Dust is going to be a material of multi-dimensional use in future, which till now was considered to be a waste material.

India is blessed with large iron ore reserves amounting to about 17 billion tonnes. Out of these Hematite deposits are 11 billion tonnes, rest being Magnetite deposits. Some of the Hematite iron ore deposits are of super high grade i.e. above 67 % Fe content. Many of these high grade massive hematite deposits are interpersed with pockets of Blue Dust, an unconsolidated powdery variety of iron ore of generally iron content & blue colour. It is commonly accepted that Indian hematitic iron ore are derived from BHQ (Banded Hematite Quartzite) by leaching of Silica, resulting in enrichment of iron content. Blue Dust formation is favoured in structurally and geologically favourable zone (faults & synclines) where continued leaching and also reworking of previously formed ore bodies by circulating solutions results in disintegration of such ore bodies to form blue dust.

The blue dust under reference occurs at Bailadila Iron Ore Mines of National Mineral Development Corporation Limited (A Government of India Undertaking). This blue dust has free and irregular shaped grains containing very small quantities of silica and alumina as gangue material with other impuritries being negligible. This blue dust is, perhaps one of the purest naturally occuring hamatite iron ore. The total reserves which are nearly 22 million tonnes could be broadly classified into following categories:

Type I	Fine grained Blue Dust
Type II	Medium grained Blue Dust
Type III	Coarse grained Blue Dust

The uniqueness of this blue dust is the free state of silica gangue which makes it amenable to concentration to produce high purity concentrate. The typical chemical and size analysis of different types of Blue Dust are given in Table-1 and Table-2.

TABLE-1

TYPICAL CHEMICAL ANALYSIS OF DIFFERENT TYPES OF BLUE DUST "AS AVAILABLE " SAMPLES AT BAILADILA, DEPOSIT - 14.

Chemical constituent	Assay %		
	Fine grained	Medium grained	Coarse grained
Fe	69.00	67.00	65.34
SiO_2	1.00	2.16	5.40
Al_2O_3	0.20	0.60	0.60
LOI	0.18	0.38	0.29
P	0.010	0.015	0.010
S	Traces	Traces	Traces

Fig. 1 shows the mineralogical and textural feature of the blue dust.

PROCESSING OF BLUE DUST

In order to produce super concentrate for high tech. application, the "as mined" blue dust is subject to beneficiation processes like screening, gravity separation, magnetic separation. etc. The process flow

TABLE-2

TYPICAL SIZE ANALYSIS OF DIFFERENT TYPES OF "AS AVAILABLE" AT BAILADILA, DEPOSIT - 14

Size in mm/ Tyler Mesh		Fine grained Wt %	Medium grained Wt %	Coarse grained Wt %
	+ 40 mm	Nil	0.7	0.5
-40 mm	+ 10mm	2.7	6.9	6.6
-10mm	+ 6 mesh	9.1	9.2	15.5
-6 mesh	+ 20 mesh	10.1	11.1	16.6
-20 mesh	+ 65 mesh	6.8	8.6	9.0
-65 mesh	+ 100 mesh	2.4	8.6	3.9
-100 mesh	+ 325 mesh	29.2	48.0	31.5
-325 mesh		39.7	6.9	16.4

sheet to be followed is decided in each case by Petrological Studies.

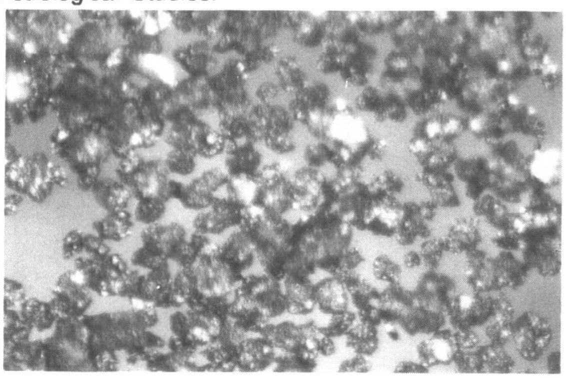

FIG. 1.

The typical Chemical Analysis "as mined" blue dust and Super Concentrate produced is given in Table-3.

Fig. 2 shows beneficiated blue dust with rare silica grains

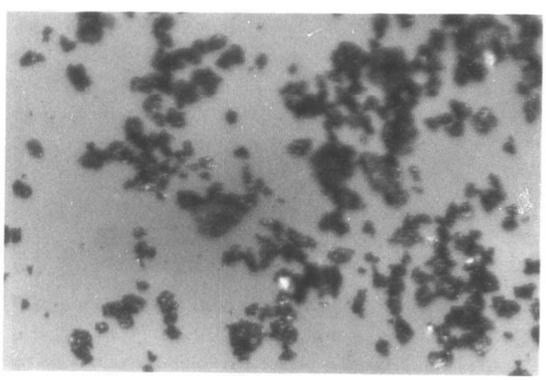

FIG. 2

TABLE-3

TYPICAL CHEMICAL ANALYSIS FINE GRAINED BLUE DUST "AS AVAILABLE" IN MINE AND SUPER CONCENTRATE OBTAINED

CONSTITUENTS	"AS AVAILABLE" WEIGHT %	SUPER-CONCENTRATE WEIGHT %
Fe	67-68	69.6
Fe203	97-98	99.4
Si02	1-2	0.16
Al203	0.6-1.0	0.05
Mn0	0.05-0.1	0.05
Mg0	0.3-0.4	0.04
Ti02	< 100 ppm	-
V205	< 10 ppm	-
Cr203	< 10 ppm	-
Cu	< 20 ppm	-
Ni	< 20 ppm	-
Co	< 5 ppm	-
Zn	5 ppm	-
Na20	0.018	-
K20	0.016	-
P	0.01-0.02	0.008
S	< 100 ppm	Traces
Cl	Traces	Traces

APPLICATIONS

Blue dust concentrate has been tested for production of various high-tech products. This material has been found as a suitable feed stock for following applications-

(a) Production of Pure Iron/Soft Iron Strips.
(b) Production of High Quality Sponge Iron.
(c) Production of Iron Powder
(d) Production of Ferric Oxide

(a) Production of Pure Iron/Soft Iron Strip

The super-concentrate which was obtained by processing of blue dust was subjected to reduction with hydrogen as reductant. The iron powder produced from super concentrate had the following chemical analysis -

TABLE-4 CHEMICAL ANALYSIS OF PURE IRON

Fe(Total)	99.50%
SiO_2	0.24%
Al_2O_3	0.10%
TiO_2	0.01%

Soft pure iron has been manufactured from this iron powder. The properties obtained from the soft pure iron so produced meets the specifications of many industrial applications. Telephone industry uses soft magnetic iron strips with iron content of 99.1%. The soft iron powder produced from blue dust super concentrate had iron content of 99.5% making it suitable for this application. This pure iron was subjected to roll compacting carried out with a small 6" diameter roll in horizontal position, to produce fully densed iron strips. These fully densed iron strips were tested for their magnetic properties. Table No. 5 contains the results obtained as compared to the values indicated by the actual users-

TABLE -5
PROPERTIES OBTAINED ON IRON STRIP PRODUCED

Strip Hardness	Reqd	NMDC	
Vickers	115 - 130	105	
Coercivity - Hc	0.80	0.81	860°C *

* Annealed for 3 hrs in H_2 and furnace cooled.

Table No 6 shows the data for Magnetic Forces Vs Remanance for the standard materials compared to the NMDC iron strip. The higher annealing temperature of 860° (1580°F) enablesproduction of matrial with values equivalent to the standard soft iron material.

TABLE -6

Annealing Temp.	825oC(1517oF) Standard	860oC(1580oF) NMDC
H(O)	B (Gauss)	B (Gauss)
1.25	9,000	8,900
2.50	11,000	11,100
3.75	12,000	12,900
6.25	13,000	13,900

Remark : Annealing condition 3 hrs. at temp. in hydrogen and furnace cooled.

b) Production of High Quality Sponge Iron

It has been possible to manufacture very high quality sponge iron with high degree of metallisation from blue dust super concentrate by carbothermic reduction. These sponge iron cakes are suitable for manufacture of special alloy steels. Typical analysis of the sponge iron cake is as follows -

TABLE 7
CHEMICAL ANALYSIS OF HIGH QUALITY SPONGE IRON

Fe	› 97%
C	0.1 - 0.3%
P	0.02% max.
S	0.015% max.
Mn	0.014% max.

(c) Production of Reduced Iron Powder

Iron Powders are essential raw material for manufacturing automobile components through powder metallurgy route. Iron powder also finds application in Welding technology.

Studies were conducted on Blue dust Super-Concentrate to produce reduced iron powders using hydrogen as well as coal as reductant.

i. Iron Powder Using Coal as Reductant

The reduced iron powder obtained was of very good quality and compared well with other internationally available powders. Table-8 gives the comparision of this iron powder with NC-100.4 grade of Hoganas, Sweden.

TABLE - 8

COMPARISION OF PROPERTIES OF REDUCED IRON POWDER FROM BLUE DUST AND NC 100.24 OF M/S. HOGANAS, SWEDEN.

Powder Properties	Blue Dust	NC 100.24
Apparent Density, g/cm3	2.39	2.43
Flow rate Sec/50 gm	29.7	28.5
Screen analysis		
% +212 um	T	0.0
180	T	0.0
150	2.1	1.7
106	21.4	19.3
75	36.6	28.1
+ 45	27.4	28.8
- 45 um	12.5	22.1
		R:NC
GD g/cm3 at 4.2 t/cm2	6.54	6.55
(die lub.) 600 MPa	7.01	6.99
800 "	7.29	7.24
GD g/cm3 at 4.2 T/cm2	6.57	6.59
(+0.8% Zn - St) 600 MPa	6.97	6.94
800" "	7.16	7.10
GD-max g/cm3 at 4.2 t/cm2	6.61	NA
GS N/mm2 at 400 MPa	30.4	24.0
(die lub.) 600	52.3	48.3
GS N/mm2 at 400 MPa	16.0	12.2
(+0.8% Zn-St) 600	22.9	18.8

GD = Green Density, GS = Green Strength

SINTERED PROPERTIES

Material	Density g/cm3	Tention strength N/mm2	Elongation %	Dim. change AL%	Hardness HV 10
NMDC	6.97	213 ± 5	20.2 ± 1.3	- 0.21 ±0.01	52 ± 2

The special features of this reduced iron powder are -

i) HIGH PURITY
ii) EXCELLENT COMPRESSIBILITY
iii) HIGHER GREEN STRENGTH
iv) COMPACTIBILITY

ii. IRON POWDER USING HYDROGEN AS REDUCTANT

It has been possible to produce high quality iron powder using hydrogen as reductant. Table -9 gives the comparision between NMDCs iron powder, Pyron R.80 and other powders.

TABLE - 9

COMPARISION OF THE CHEMICAL & PHYSICAL PROPERTIES OF BLUE DUST POWDER WITH OTHER COMPETITIVE IRON POWDER.

Chemical Properties

	NMDC	Pyron R-80	Hoeg-anaes	Domfer
Carbon	0.01	0.01 - 0.05	0.02	0.02
Sulfur	0.004	0.005	0.01	0.02
Phosphorus	0.006	0.012	0.01	0.02
Manganese	----	0.40 - 0.65	----	0.15
Acid Insolubles	0.3	0.2 - 0.45	0.2	0.23
Hydrogen Wt. Loss	0.2	0.2 - 0.5	0.4	0.34

Physical Properties

	NMDC Powder	Pyron R-80
Apparent Density, gm/cc	1.39	1.26
Green Density, gm/cc	6.4	6.19
Green Strength, psi	7060	7640
Dimensional Change, %		
From Die Size	-0.10%	-0.27%
From Bar Size	-0.17%	-0.34%

PROPOSED APPLICATION

The reduced iron powder produced from blue dust is found suitable for following applications :

1. Low Density 1.3 - 1.5 g/cc - Friction materials and bearings
2. Medium Density 2.5 g/cc - P/M parts
3. Super fines/powders (10 microns) - Metal injection moulding field.
4. Roll compacting of the medium density grade into strips for the electronic industry.
5. Welding electrodes.

(d) Production of Ferric Oxide (for manufacturing magnetic material)

i. Ferric oxide through Physical Processing

Magnetic materials like ferrites for electronic and electrical industries are being largely manufactured from synthetic ferric oxide - manufactured from steel plant pickling liquor. It has beenpossible to produce natural ferric oxide from blue dust suitable for manufacturing various grades of ferrites.

The various grades produced in a Demonstration plant set up by NMDC by physical processing techniques are indicated below -

TABLE-10

SPECIFICATIONS OF VARIOUS GRADES OF FERRIC OXIDE

GRADE/ SPECI-FICATION - %	GRADE-I SUPER GRADE	GRADE-II HIGH GRADE	GRADE-III NORMAL GRADE	GRADE-IV NORMAL GRADE
Fe203	›99.30	›99.00	›98.50	›98.50
Si02	‹0.30	‹0.40	‹0.60	‹0.60
Ca0	‹0.05	‹0.05	‹0.05	‹0.05
Mg0	‹0.03	‹0.05	‹0.05	‹0.05
Mn0	‹0.01	‹0.01	‹0.30	‹0.30
A1203	‹0.05	‹0.10	‹0.20	‹0.20
Cl	T	T	T	T
S	TRACES	TRACES	TRACES	TRACES

The above grades are being used for manufacture of hard ferrites & medium quality soft ferrites. The natural ferric oxide produced from blue dust have the advantage of non presence of impurites like chloride & manganse etc. which are present in synthetic ferric oxide are harmful to the furnaces used in manufacture of ferrites.

ii. Ferric Oxide through Chemical Process

Ultra pure ferric oxide with impurities less than 60 ppm levels, is required for professional grade soft ferrite components and ferrites for micro wave and low power loss materials. Laboratory Scale Tests have confirmed possibility of manufacturing ultra pure ferric oxide from blue dust. The typical chemical analysis of the ferric oxide obtained through laboratory scale tests is given in following Table.

TABLE-11

COMPARISON OF ANALYSIS OF PRODUCTS

CONSTITUENT		IROX-NKK CO., LTD	CHEMIRITE LTD. CSS-410 E	NMDC EXPERI-MENTAL PRODUCT
Fe203	%	99.45	99.3	99.50
Si02	%	0.008	0.005	0.006
Al203	%	0.006	0.015	0.002
Ca0	%	0.046	0.005	0.001
Mg0	%	0.002	-	0.002
Ti	%	‹0.001	0.004	‹0.001
Mn	%	0.212	0.26	‹0.001
Cu	%	-	0.004	0.002
Ni	%	0.013	0.011	0.002
Cr	%	0.001	0.023	‹0.001
Zn	%	0.001	0.003	‹0.001
Na	%	0.001	-	0.001
K	%	0.001	-	0.001
Cl	%	0.078	0.13	‹0.1
S04	%	0.056	0.04	NIL
P	%	‹0.001	-	0.002

Specification of equivalent materials which are at present being produced by a couple of Japanese companies using different input materials are also indicated in above table. It can be seen that the ferric oxide obtained from blue dust is of equivalent quality or even better, particularly, in respect of the metallic impurities.

CONCLUSION

Blue dust in Bailadila mines is one of the purest naturally occuring hematite iron ore. Tests have proved its wide appliability for manufacturing high-tech metals & materials.

A commercial plant for manufacturing ferric oxide used for producing magnetic materials is under way.

Similarly, there is a proposal to set up a plant to manufacture iron powder for use in powder metallurgy.

Tests are currently in hand to study possibility of producing high quality steel through different routes like (i)plasma smelting & (ii) fluidised bed technology . Once these studies are proved successful, this will open a new route for manufacturing high quality steel.

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Steel 2000 — Technological Trends and Globalization

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Abstract

Improved steel quality, lower process costs, higher productivity, environmental friendliness and energy efficiency will be the guiding factors for the world steel industry in the decade ahead. Steel, as an an internationally traded engineering material, will need to be supplied in form and quality that satisfy the exacting customer requirements. Competition from alternative materials is progressively building up.

Technological developments in cokemaking, ironmaking, near-net-shape casting, smelt reduction and direct steelmaking are highlighted. Automation, computerisation and artificial intelligence are expected to play a far more decisive role than was thought possible before.

Globally, a moderate expansion of the steel industry can be expected. Developed countries will be chiefly concerned with modernisation and restructuring to remain cost-effective in a highly competitive market. Technologically, the large integrated steel plants of the past will yield place to smaller flexible DRI/Scrap based EAF units. The installation of new integrated steel plants in the third world will, however, continue.

The change-over of East Europe and Russia to free market economies will have its impact on world steel industry. There is a pronounced move towards privatisation of steel elsewhere also - in Latin America, India, Philippines etc.

There is also a trend towards globalisation of the steel industry. Apart from technical and equity participation in steel enterprises, international trade in steel is being increasingly tied up with international joint ventures.

THE STEEL INDUSTRY IN THE DEVELOPED world will have to plan its future in light of the changing world economic scene and the emergence of an enlarged world market for its products. Competition will be far tougher, not only amongst steel producers themselves, but also between steel and other competing materials. The emphasis will be on quality and price.

Customer-Oriented Quality

Over the past few decades, the exacting customer demand for higher service performance and reliability have been pushing up the steel quality requirements. In the flat products area, the demand for lower and lower S, P, H_2, N_2 & O_2 contents is building up continuously over the past 2/3 decades. The future requirements will be even more stringent. For instance, for offshore line pipe steels, S and P contents are likely to be lower than 0.0015% and 0.002% respectively; the notch toughness values have gone up to over 150 Joules; and both sulphide and oxide inclusions need to be lowered to reduce the cracking tendency in service. Likewise, the quality demands in the case of high tensile steel tyre cords and tin plates are even more stringent. Auto-flats, ready for direct consumer use, must have built-in corrosion protection, dent resistance, formability, weldability etc. And then, these quality steels must be available at a competitive price.

The steel industry to-day is now working closely with the customers from the design stage onwards to develop steels that meet the customers' competitive demands, as well as to counter the threats of plastics, aluminium and other materials. Product servicing at the consumers' end has become a dominant market feature. For example, coated steels for customer industries must not only meet the exacting processing needs, but the steel industry is expected to provide all relevant technology services for trouble free consumption.

Competing Materials. Of the materials replacing steels, aluminium is best suited to scrap recycling and is making serious inroads into three major steel usage sectors:

a) Packaging, especially beverage cans
b) Construction industries and
c) Automotive and transportation sector.

The aluminium beverage can accounts for a predominantly large market share at present in several western countries, and it can be reasonably expected that in the near future, beverage cans may be all aluminium in the developed countries worldwide.

Extruded aluminium products have been making strong inroads in the past two decades into the traditional steel strongholds such as the building and transport as well as other engineering industries.

In the automotive sector, aluminium and its alloys are expected to replace around 20% of the steel in the passenger car from the current 10% level by 2000 to 2010 - in replacing engine blocks, air intakes, gear boxes, wheel suspensions etc. Alcoa in close cooperation with VW (Audi) is setting up an aluminium car body plant in Germany. Investigations indicate that aluminium and its alloys can perhaps replace about 450 kg of steel in a medium-sized car, making it lighter, more energy-efficient and environment-friendly.

Steel Industry Challenges

The steel industry today is facing several challenges and must therefore modernise/update its facilities to effectively meet them:

- Improved quality
- Effective technology for lowering cost
- Energy efficiency
- Environmental friendliness
- Increasing competition from alternative materials.

The technological advances which are being capitalised by the steel industry during past decade or so will enable it to face these challenges more effectively than ever before. The on-going efforts at capacity rationalisation, modernisation and restructuring will continue to effectively counteract these increasing challenges.

Technology Trends

The 'Coke Oven-Blast Furnace-BOF-Continuous Casting' route will continue to provide the major share of crude steel even in the year 2000 and beyond. In the on-going search for alternative ironmaking routes without the use of coke, new technologies including several commercial scale operations like Corex, DRI, iron carbide are likely to emerge. The share of ironmaking alternatives may rise to around 15 to 20% of the total iron production for steelmaking.

By 2000, AISI direct steelmaking and other smelt-reduction technologies may become commercially acceptable under specific conditions.

In steelmaking proper, rapid adoption of near-net-shape casting is expected to take place in the decades ahead to save energy and improve productivity, respond to the flexible market demand and reduce cost of production.

The cokemaking technologies are being continuously improved to meet the challenges of stringent pollution control legislation, higher productivity, improved quality, reduced energy cost and all these at a cheaper cost.

Cokemaking. Cokemaking technology perhaps will undergo the greatest change in the coming decade and this will spill over into the 21st century. The new coke ovens are aiming at improved coke quality with higher yield, reduced specific energy consumption, pollution control to almost zero levels, enhanced battery life etc. In this context, the new advanced system of 'jumbo cokemaking reactors', now under development in Germany, appears to be promising.

Ironmaking. There is every hope that in this decade, blast furnace will move from the present "Coke plus auxiliary fuel" operation to a "Coal plus auxiliary coke" regime using increased amount of coal injected into the BF through the tuyere zone. Over the past decade, BF productivity has been improving consistently and the coke rates are decreasing. Already production levels of 3 ton/cu m/day have been achieved in smaller furnaces and by the turn of the century such production levels are realistic also for large blast furnaces. With all these cost savings and environment-friendly measures, it is expected that blast furnace liquid iron cost is expected to match fairly well with the scrap prices prevailing in the developed countries.

Steelmaking. The BOF and EAF steelmaking routes will continue their predominant status over other routes of steelmaking in the forseeable future. By the turn of the century, obsolete steelmaking processes like the open-hearth will be completely retired, leaving the field primarily to BOF and EAF steelmaking. The BOF may comprise 70% of the entire steel production of the world.

In electric steelmaking, use of DC single electrode EAF operations is gradually supplanting the conventional 3-electrode AC furnace operations during the past few years. It is envisaged that by DC operation of EAF, full computerisation and increased output per capita can be achieved much better and also in a more consistent manner.

Near-net-shape casting. The success of NUCOR Steel Plant (SMS technology) in producing hot rolled carbon steel strip from on-line rolling of thin slab will pave the way for many more installations for hot strip production in the EAF sector, cutting into the market share of the major mills. Mannesmann Demag and Voest-Alpine have also come up with their version of the thin slab casters and on-line hot strip mills for the production of hot strip. Concurrently, plans are underway to retrofit thin slab casting technology into the major mills of the integrated steel plants based on BOF steelmaking. Developments are also taking place in improving the thin slab casting techniques to improve the quality of the flat products to meet the customers' stringent requirements.

Automation and expert systems. With increased computer use, process automation, adoption of expert systems and a knowledge-based approach as well as with the rapid developments taking place in these areas, it is very likely that future steel plant will be run more and more on continuous operation-bases, to achieve even higher productivity of both men and machines.

Many of the unit processes have their own expert systems which in the near future will be integrated to yield a fully continuous steel plant operation. Indications are already available that by using many of these improved expert systems dovetailed to sectoral and continuous processing, integrated mills will improve their productivity levels to less than around 3 man hours/ton shipped from a level of more than 12 man hours/ton shipped several years ago. In specific instances, even lower man hours/ton shipment can be achieved.

From Sheltered Market to Market Economy - USSR and Eastern Europe

The sweeping political, economic and social changes in Eastern Europe and Russia have had severe impact on the structure and functioning of the steel industry in these countries. The process of adjustment from a controlled and sheltered market, to a highly competitive market economy is bound to be arduous and long in most of these countries.

East European steel industry. In the case of East European steel industry, the sudden deprivation of the Soviet support apart, some of the major problems in general are:

i) the technology gap;
ii) low productivity levels and decline in production;
iii) difficult supply position of raw materials, consumables and spares;
iv) excess capacity;
v) need for large-scale environmental clean-up;
vi) lack of finances (hard currency) required for modernisation;
vii) lack of marketing concepts and skills; and
viii) need for new management outlook and skills to meet the challenges of the highly competitive market economy.

According to the Working Party on Steel of the Economic Commission of Europe, the outlook for the steel industry in the East European countries and the former USSR is not very bright. It is feared that many steelworks in these countries will close down and that the production and consumption of steel in the region will continue to decrease. If the ongoing restructuring programmes of the steel plants were to continue and political stability returns, the steel output in the region may pick-up after only 1995. A rough ECE estimate indicates that the total crude steel production in the region may be around 137 to 150 million tons in 1995 from the 1991 level of 169 million tons, and may stabilize around 178 million tons by 2000-2005.

During 1990-1991, the steel output in most East European countries has come down substantially, ranging from 18 per cent in the case of Czech and Slovak Federal Republic to as high as 28 per cent in the case of Hungary. In the former USSR, the fall in steel production was 12 per cent. As the countries are in a state of transition, new investment in the iron and steel industry is hardly probable.

Russian Steel - Uncertain Future

The dissolution of the USSR has created a certain element of uncertainty for the highly centralised steel industry. The general tendency has been towards assumption of control by the newly formed republics of their own steel industry. The steel industry in Russia is exploring export opportunities not only to avoid reduction in the production levels, but also to earn some much-needed hard currency. As the expertise to plan and manage export business is lacking in most Russian steel plants, they have had to retain western market research organisations to identify export opportunities. They are also on the look out for large-scale foreign participation in their steel industry. It is reported that some fifty joint ventures have already been established in the metallurgical sector. The transition to market economy has been accompanied by significant changes in the costing and pricing practices, changes in the production planning and product distribution, elimination of monopolistic foreign trade etc. The aim is to establish technological complexes, as for instance the one planned for Cherepovetz Iron and Steel Works.

Privatisation

Along with restructuring and modernisation, there is a pronounced movement towards privatisation in the steel industry. The first such large-scale privatisation started in UK in the eighties. In recent years, other countries which once tread the socialist path, have also begun to turn away from the public sector ideology. Latin America is in the forefront at present in this privatisation movement; for instance, recent privatisation of USIMINAS and COSIPA in Brazil; Altas Hornos de Mexico SA, SICARSTA and SIBAS in Mexico etc. Countries like India, Philippines etc are also seem to be moving in the same direction.

Globalisation Trend

Parallely, there is a trend towards globalisation of the steel industry. Though in the immediate context, it is difficult to conceive of a totally 'international' steel industry cutting across national barriers and aspirations, there are certain factors that favour globalisation. However, in view of the strategic nature of the steel industry in times of peace and war, 'national' steel industries may continue to flourish. Yet, their future progress will be largely influenced by global factors.

The world trade in steel is gradually developing into one large free market place, accelerating the pace of globalisation of the steel industry. Hopefully, international economic relations in the coming decade and beyond will be generally governed by free-trade practices. The third world's raw materials and energy potential will increasingly affect international trade in steel. Also, because of comparatively lower production costs, semi-finished products from third world countries may flow into the finishing mills of the industrially developed countries around the world. The large reservoir of skilled/semi-skilled manpower as well as technical and managerial talent available in the developing countries and around the world elsewhere can be harnessed to produce iron and steel based on the latest technologies, at competitive costs.

International participation. The free flow of technology and trained manpower apart, there is every likelihood of greater international participation in steel enterprises across the world. International trade in steel is expected to be closely tied up with international joint ventures, both between the developed countries themselves as well as between the developed and third world countries. A number of such ventures are already in existence and operating successfully and more are in the offing. Even more are expected to materialise in the course of this decade. This international participation may be of various types: financial and equity participation with buy-back arrangements; technical, managerial, and marketing cooperation ventures etc. Technologically, the large integrated steel plants around the world may yield place to smaller and more flexible manufacturing units based on DRI/scrap-EAF route. This, however, will not prevent the installation of some new integrated steel plants in the third world in the coming years.

In terms of product quality and performance too, the world is already quietly moving towards globally applicable standards, not only for steel grades and products but also for machinery and equipment. The recent move by the European Community to enforce ISO 9000 services within the Community as well as in its dealings with other nations is bound to spur its globalisation process. Most of the steel producing countries have revised their national standards to conform to ISO 9000 services or are in the process of doing so, to take advantage of export opportunities presented by the enlarged Euromarket.

The iron and steel industry is definitely entering a new era of changed economic equation around the world. The major preoccupations of the industry as at present will be the growing concern for the environment, the crucial need for energy efficiency and conservation, the need to remain cost-effective and competitive in an era of increased costs and mounting competition. While the steel industry can be expected to meet these challenges in the coming decades because of its inherent strength and flexibility to change, it has to perforce think and organise globally, if steel were to continue to be the most reliable and user-friendly engineering and construction material.

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Techno-Economic Evaluation of the Development and Application of DRI in India

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Abstract

The DR industry in India was launched in 1980 and ever since then, it has not looked back. With large reserves of non-coking coals and the discovery of adequate reserves of natural gas, both coal and gas based DR plants are being set up in India. After initial start-up problems, almost all the coal based plants are now operating fairly well - some have even exceeded their rated capacity. India's first gas based DR plant is reported to be operating well and two other large capacity plants are fast nearing completion. Although under the prevailing conditions, the operating cost of a coal based DR plant in India is marginally higher than a gas based plant, the choice between the two would depend on overall economics.

THE DIRECT REDUCTION (DR) INDUSTRY came into prominence in India in the early Eighties, principally because of the extremely high capital cost involved in setting up conventional integrated steel plants, so much so that the prevailing steel prices were not even able to support the fixed costs of many integrated units and also because shortage of melting scrap posed serious problems for the mini mills. India has, therefore, pursued the adoption of the DR route, so as to make DRI available to steelmaking units - both in the integrated as well as the mini-steel sectors. In many cases, DRI has also been used downstream in the so called composite plants consisting of captive DRI producing facilities and steelmaking units. To cater to these needs, DR technology based either on coal or natural gas has been adopted. This has led to a rapid growth of the DRI industry in India.

DR Industry in India

In India, the DR industry was launched in 1980 with the commissioning of 30,000 tpa capacity demonstration-cum-production unit at Kothagudem (Andhra Pradesh) in South India built with UNIDO assistance using SL-RN technology. The second DR plant, again essentially coal based but using the ACCAR technology, with a capacity of 150,000 tpa, was installed in 1983 at Keonjhar (Orissa) in Eastern India. The third rotary kiln based plant of 90,000 tpa capacity based on TISCO Direct Reduction (TDR) process, was set up at Joda (Orissa) in Eastern India in 1986. This was a joint venture project of Tata Steel and the Orissa Government. Another rotary kiln based plant of 150,000 tpa capacity, using the CODIR process - Sunflag - went on stream in the latter half of 1989 at Bhandara (Maharashtra), in Western India, as the first composite DR-EAF steel plant in India.

The next coal based DR plant (Bihar Sponge Iron) commenced production in July 1989. Having a capacity of 150,000 tpa, this plant based on the SL-RN process, is situated at Chandil (Bihar) again in Eastern India. Another coal based DR plant which is presently under construction, is that of Tamilnadu Sponge Iron Ltd. (South India), which will have two rotary kilns of 30,000 tpa capacity each. As summarised in Table-1, at least a couple of other coal based units are reported to be in advanced stages of project implementation.

Table 1 Coal based DR plants in India

Plant	Location	Process	Capacity, tpy	Start up
SIIL	Kothagudem (Andhra Pradesh)	SL/RN	30,000 30,000	1980 1985
OSIL	Keonjhar (Orissa)	ACCAR	150,000	1983
IPITATA	Joda (Orissa)	TDR	120,000	1986
Bihar Sponge Iron	Chandil (Bihar)	SL/RN	150,000 150,000**	1988
SUNFLAG	Bhandara (Madhya Pradesh)	KRUPP-CODIR	150,000 300,000*	1989 1992
Jindal Strip	Raigarh (Madhya Pradesh)	Indigenous know-how	100,000	1992
Tamil Nadu Sponge	Salem (Tamil Nadu)	SL/RN	60,000*	1992
Hindustan Electro-graphite	Durg (Madhya Pradesh)	SL/RN	60,000*	1992
Bellary Steels	Bellary (Karnataka)	SL/RN	30,000	1992
Goldstar	Vizag (Andhra Pradesh)	SL/RN	220,000 220,000**	1992 1994
Praksh Industries	Champa (Madhya Pradesh)	SL/RN	165,000*	1992-93
Raipur Steels	Raipur (Madhya Pradesh)	SL/RN	60,000**	1992-93
Monnet Ispat	Raipur (Madhya Pradesh)	N.A.	200,000**	N.A.
Prasmas' Steels	Kovvur (Andhra Pradesh)	KRUPP-CODIR	120,000**	1992-93
Singh Alloys & Steels	Durgapur (West Bengal)	SL/RN	60,000**	1992-93
Kumar Metallurgical	Hyderabad (Andhra Pradesh)	SL/RN	60,000*	1992-93

* Under construction
(N.A. - not available)
** Planning stage

Once large reserves of natural gas were located in India in the Eighties, both the 'on-shore' and in 'off-shore' areas, along with the development of gas based distribution systems like the Hazira-Bijapur-Jagdishpur (HBJ) pipeline as well as the Government liberalising the use of natural gas for DRI production, the floodgates have literally been opened for the growth of gas based plants in India. India's first gas based DR plant (Essar) having two Midrex modules of 440,000 tpa capacity each, has come-up at Hazira (Gujarat) in Western India. Natural gas from Bombay high, after desulphurisation and refining, is being used for reduction. The plant uses iron ore from Balaidila (Madhya Pradesh) and pellets from Kudremukh (Karnataka). The other gas based DRI plant which is underway (Grasim Industries) is located at Raigad (Maharashtra), again in Western India, with an annual capacity of 0.75 Mt. Using the HYL III process, the plant is expected to start commercial production in the second half of 1992. Other gas based plants being put up by Usha Rectifier and by Nippon Dendro Ispat using the Midrex process, are scheduled to go on stream by the fourth quarter of 1992 and 1993, respectively. Other plants which are presently in the planning stage, are shown in Table-2.

Table 2. Gas based DR plants in India

Plant	Gas source	Process	Capacity,	Location	Start up
Essar Steel (I)	Bombay High	Midrex	880,000	Hazira	1990
Grasim	Bombay High	Hyl III	750,000*	Raigad	1992
Usha Rectifier	HBJ	Midrex	800,000*	Jagdishpur	1993
Essar Steel (II)	Bombay High	Midrex	800,000**	Hazira	-
Essar Steel	Krishna-Godavari Basin	Midrex	720,000**	Kakinada	-
Nippon Dendro Ispat	Bombay High	Midrex	1,000,000*	Raigad	1993
Kudremukh	Imported LNG	-	750,000**	Mangalore	-
Bharat Forge	Bombay High	-	600,000**	Raigad	-

* Under construction
** Planning stage

There is no doubt that gas based DR, though a late starter, has already emerged as an integral part of the Indian steel industry.

Figure-1 shows the location of various DR plants in India.

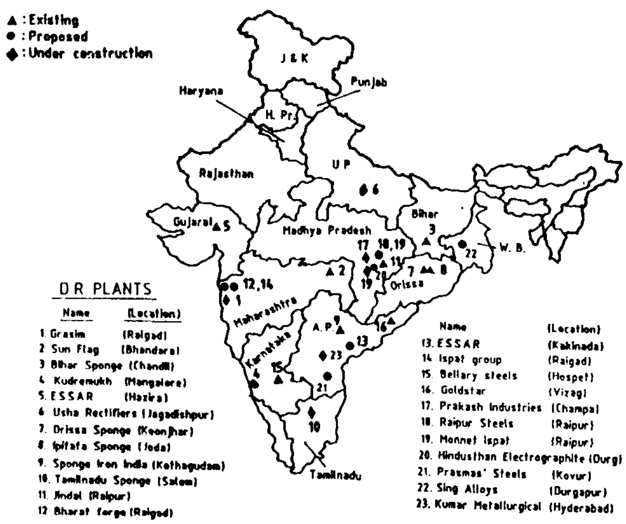


FIG. 1: LOCATION OF DR UNITS IN INDIA

The primary reason for the sudden emergence of gas based DR in India, has been the stupendous growth in the availability of natural gas during the last two decades. Figure-2 shows a profile of the growth of the "balance recoverable reserves" in India.

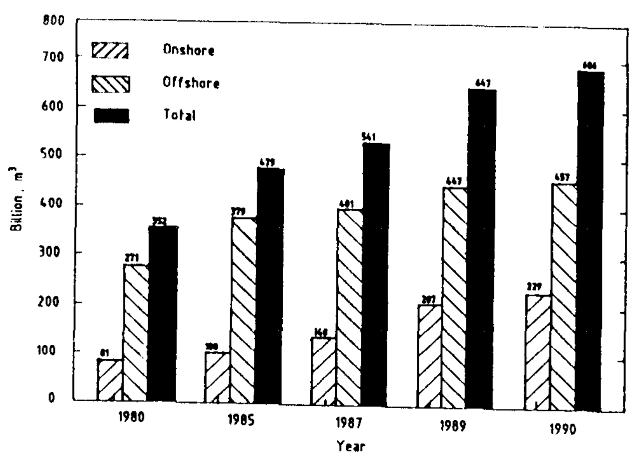


FIG. 2: AVAILABLE NATURAL GAS RESERVES IN INDIA

The total increase has been from 352 Billion m^3 (1980) to over 680 Billion m^3 in 1990. The net production, which excludes the quantities 'flared' and 'reinjected', has also increased steeply from 1522 million m^3 in the early Eighties (Fig.3) to over 11,170 million m^3 in 1989-90.

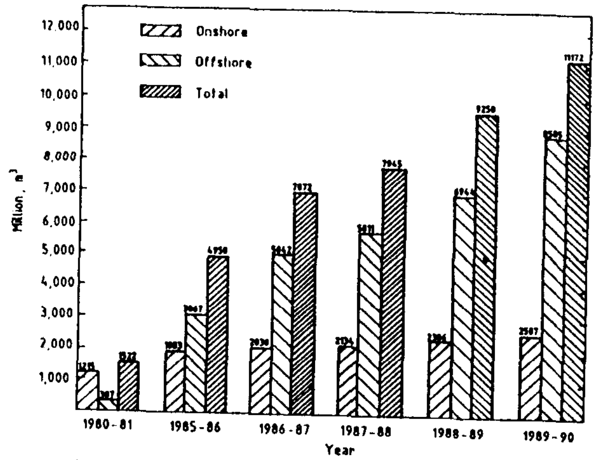


FIG.3: NET PRODUCTION OF NATURAL GAS IN INDIA

The quality of natural gas available in India and its price are indicated in Table-3. As far as its suitability is concerned, Indian natural gas appears to be acceptable to the technology suppliers after desulphurisation, provided consistency in this 'natural' commodity can be ensured.

Table 3: Composition and price of natural gas in India

Component	Bombay High	North-East Region	Krishna Godavari Basin	HBJ
Methane	78.84	80-90	95-97	84.51
Ethane	7.23	4-8	1.0-1.5	7.70
Propane	4.59	2-7	0.15-0.25	2.45
Butane	1.98	1-7	-	0.13
CO_2	6.49	0.5-1.0	0.2-3.0	5.20
Price, Rs/1000 Nm^3	1980	750-800*	1940	3315

* Special price to encourage usage

Operating Experiences of the DR Plants in India

The first DR plant of India, Sponge Iron India Limited at Kothagudem, has been operating well and has so far completed more than 25 campaigns in the old unit and more than 12 in the new unit which was installed in 1985, to double the plant capacity. In 1989-90, the plant produced 55,000 t of DRI, achieving 92% of its rated capacity. From April to November 1990, the plant produced a total of 39,000 t and the target for the year 1990 was fixed at 55,000 t which was met. Plant operators believe that this is the maximum which can be produced with Singareni coal, which contains 30% ash.

Orissa Sponge Iron Limited (OSIL), has a series of initial start-up problems, particularly related to injection of oil through the underbed ports. The plant has achieved about 70% of the rated capacity (actual production in 1990-91 and 1991-92 being 90,030 and 102,000 t respectively) on a sustained basis. This was mainly because the plant was supposed to use 80% coal + 20% oil, but subsequently, owing to the steep hike in oil price, it had to switch over to 100% coal operation, thereby limiting the kiln capacity to around 100,000 tpa.

Ipitata Sponge Iron Limited (ISIL), immediately after commissioning, ran into a lot of teething problems, mainly related to kiln refractories. In 1989-90, the plant produced 64,000 t of DRI (about 70% of its rated capacity) with daily productions of 300-330 t (rated capacity : 300 tpd). The capacity of the plant was then enhanced to 120,000 tpa. The modifications made with the help of Lurgi included complete replacement of refractory bricks and castables, which was the prime cause of intermittent shutdowns earlier. Improved operations in 1989-90 enabled the company to generate some surplus funds, for the first time since its inception and the plant is now regularly producing 330 tpd of over 90% metallised iron. In March 1991, the plant achieved its highest monthly production of 10,747 t and also completed its longest campaign of 120 days. In 1991-92, the plant produced 85,350 t. The gross profit of the Company jumped from Rs 29.7 million to Rs 152.0 million. Net sales and processing charges have advanced by over 250% to Rs 419.4 million from Rs 152.4 million in the previous year. After providing for depreciation and preliminary expenses of Rs 42.0 million, the outcome was a net profit of Rs 110 million against a net of loss of Rs 0.53 million in the previous year.

Sunflag Iron and Steel - the first DR-EAF based composite steel plant in the private sector - has overcome some of the teething problems with the help of its technical collaborators Krupp and Demag. Sunflag commenced trial runs in August 1989 and has yet to achieve its full capacity production. The rated capacity of the kiln is 500 tpd, but on an average it has produced 350 t (maximum production so far has been 420 t). Whenever higher production has been attempted, severe accretions have been formed inside the kiln. The arc furnaces at Sunflag have used upto 100% DRI in the charge but its normal usage is restricted to 50-70% for optimum operation. This is the first time in India that such a high proportion of DRI has been used on a commercial scale in steelmaking. Sunflag is engaged in raising its DRI capacity to 3,00,000 tpa in 1992. It also plans to set up a captive power plant based on waste heat recovery from the kilns and by burning coal fines. In 1991-92, the plant made a net loss of Rs 38.0 million.

Bihar Sponge Iron Limited (BSIL) commenced production in July 1989. The initial operating results from this plant were excellent and the plant produced a total of 50,350 t of DRI during the period July to December 1989. On a daily basis, BSIL is producing 410-415 tpd and the average monthly production is 12,000 tpm. The longest campaign so far has been of 150 days and the average campaign life is around 90 days. The Company has achieved 108% capacity utilisation during the year 1990-91 producing a record of 160,300 Mt of DRI. The estimated turnover for the year ended March 31, 1991 was Rs 695 million as against Rs 271.1 million during the previous year, achieving a growth of 165%. However, in 1991-92, the plant made a net loss of Rs 10.40 million. Work on capacity expansion has already started and will cost Rs 1,300 million.

The financial results of the four major coal based DR units in India - Ipitata, OSIL, BSIL and Sunflag for 1991-92 are presented in Table-4, which show that Ipitata has done extremely well and that only Ipitata and OSIL earned profit, the other two plants have incurred losses.

The first gas based DR plant of India, Essar Gujarat, started trial production at Hazira in the third week of March 1990. Iron ore (70% of the charge) is from Bailadila (MP) and pellets (30%) come from Kudremukh (Karnataka) or from Bahrain and Brazil. The plant is reported to be operating well and against a rated output of 53 tph, it is producing 65-68 tph, which can be increased upto 80 tph, but is restricted to these levels because of limitations in infrastructural facilities. Sulphur content in the natural gas is very high and although ONGC is stripping the gas of sulphur, even then the nickel catalyst in the reformer has already got contaminated once and had to be changed. There were some problems in the drag chain and other parts of the HBI unit, but this has now been overcome. The normal carbon content in the product is over 1% which, on demand, can even be raised up to 3% making the HBI with very low sulphur levels of 0.006%, ideal for steelmaking. Essar Gujarat has increased the price of HBI by Rs 400 and currently its price is Rs 6,000/t.

Table **4:** Performance of coal based sponge iron plants during 1991-92

(Rupees in million)	IPITATA	OSIL	BSIL	SUNFLAG
Net sales or income from operations	419.4	439.5	462.9	1344.2
Other income	12.7	6.6		
Total expenditure	237.1	267.9	430.2	
Interest	43.0	39.0	102.0	
Gross profit after interest but before depreciation	152.0	139.3	110.7	55.9
Depreciation	42.0	37.2	121.1	93.9
Miscellaneous expenses written off (previous year adjustment)		6.3		
NET PROFIT	**110.0**	**95.7**	**(-10.4)**	**(-38.0)**
Paid up equity	120.0	59.7	N.A.	N.A.

Figures in bracket show losses. N.A. Not available

Scrap/DRI Demand-Availability Scenario

The projected demand for scrap upto 2000 AD based on the analysis of various users and producers of ferrous scrap in the country is shown in Table-5. The demand for melting scrap by 1995 will be around 11 Mt (1 Mt for the integrated steel plants and 10 Mt

Table 5: Projected demand and availability of scrap in India (Million tonnes)

Year	1994-95	1999-2000
Total estimated demand	11.1	11.5
Indigenous availability	3.1	4.1
Net Deficit	8.0	7.4

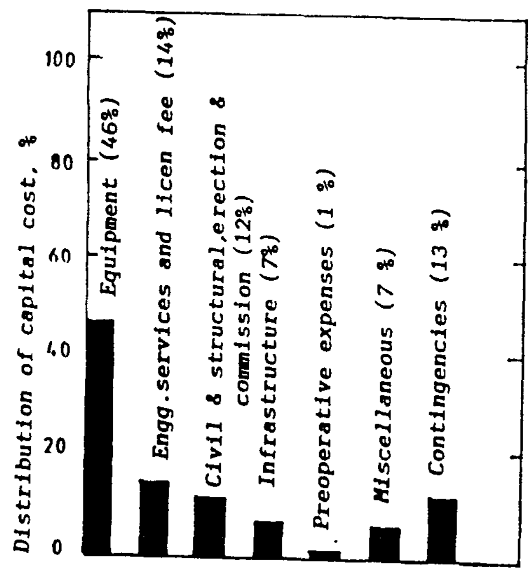
for mini-steel plants, foundries and induction furnaces). The domestic availability, would however be only around 3.1 Mt thus leaving a gap of around 8.0 Mt. The corresponding figure for 2000 AD is projected as 7.4 Mt. With international scrap prices hardening at $ 140/t and a freight cost of $ 40-50/t, the foreign exchange outgo, if the gap is met by imports, will be tremendous.

As a result of various pulls and pressures, price of heavy melting scrap jumped from Rs 5400/t in December 1990 to Rs 7000/t in August 1991 and came down to Rs 6550/t in March 1992. DRI prices too, which had gone up from around Rs 4000/t in March 1991 to over Rs 5200/t in August 1991, have now come down to around Rs 4700/t in March 1992. The current prices of heavy melting scrap and DRI in India are around Rs 5800-6500/t and Rs 4700-4900/t respectively. As of March 1992, the installed DRI capacity is about 1.7 Mt per annum - one gas based DRI plant of 0.88 Mt and seven coal based plants of 0.82 Mt aggregate capacity.

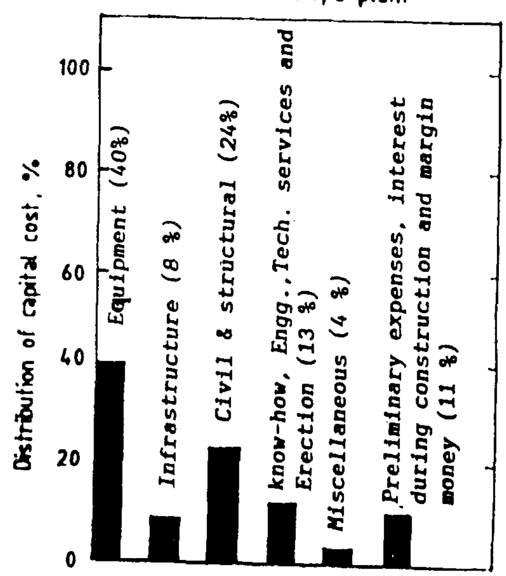
Economic Considerations

Under the prevailing conditions, the capital cost of a 150,000 tpa coal based plant would work out to around Rs 1200 million (Rs 8000/- per annual tonne capacity) as againt Rs 6500 million (Rs 6500/- per annual tonne capacity) for a 1000,000 tpa gas based plant.

For a typical 1 Mtpa gas based plant, the distribution of capital cost is shown in Fig.4a - plant equipment constitutes the major share (46%). Likewise, the distribution of capital cost of a 150,000 tpa coal based DR plant (Fig.4b) shows the major cost components are plant equipment (40%) and civil structurals (24%).



4 a) Gas based 1.0 mtpa plant



4 b) Coal based 150,000 tpa plant

Tables-6 and 7 show the operating costs of coal and gas based DRI units in India. The cost figure of the production of gas based DRI is only marginally less (Rs 4061) than that of the coal based DRI (Rs 4168).

Table 6: Operating cost of a 150,000 tpa capacity coal based DR plant

(Capital cost per annual tonne capacity : Rs 8000/t)

Item	Specific requirement t/t of DRI	Cost, Rs/t of DRI
Iron ore @ Rs 430/t (including Rs 50/t for transport)	1.6	688
Coal @ Rs 1075/t	1.1	1183
Dolomite @ Rs 450/t	0.06	27
Electricity @ Rs 1.80 per kwh	150 kwh	270
Production cost		2168
Fixed cost Interest + depreciation	@ 25%	2000
Total operating cost		4168

Table 7: Operating cost of 1 Mt gas based DR plant in India

(Capital cost per annual tonne capacity : Rs 6500/t)

Item	Specific requirement t/t of DRI	Cost, Rs/t of DRI
Pellets @ Rs 1400/t	0.5	700
Lump ore @ Rs 430/t (including Rs 50/t for transport)	1.1	473
Natural gas @ Rs 3.31/Nm^3	300 Nm^3	993
Electricity @ Rs 1.80 per kwh	150 kwh	270
Production cost		2436
Fixed cost Interest + depreciation	@ 25%	1625
Total operating cost		4061

As raw materials, iron oxide feedstock (iron ore/pellets) and reductant (coal/natural gas), account for the major chunk of the total variable cost in DRI manufacture, the cost of production would be largely controlled by raw material costs. Commercially, the choice between the two would depend on overall economics. However, there is no denying the fact that gas based processes are globally way ahead and this will be true in India as well in the long run. Amongst others, a gas based plant has advantages such as higher productivity (2 t/m^3/day compared to 300-500 kg/m^3/day) and lower specific energy consumption (2.4-3.0 Gcal/t of DRI compared to 4.0-4.5 Gcal/t of DRI). DRI from gas based plants is totally free from char unlike DRI from coal based plants, which invariably contains 1-3% char. The disadvantages of a gas based plant are use of high cost iron ore pellets and the price of gas. For the users, one advantage of gas based DRI is that it can be in the form of dense hot briquetted iron (HBI) which is easy to charge in the furnaces and is not prone to reoxidation when stored.

Future of DR in India

The efforts initiated by the Government of India three years ago to encourage the production of DRI are now beginning to pay handsome dividends. The choice between the two DRI routes - coal based and gas based - would depend on the overall economics. At today's prices, the cost of putting up an optimum sized coal based DR unit of 120,000 tpa in a totally green field location would be in the range of Rs 900-950 million, and another Rs 100-150 million for co-generation of power from the kiln waste gases, if all costs are appropriately taken into account. Similarly, for an optimally chosen gas based unit of around 800,000 tpa capacity, the cost involved would be in the region Rs 4800 million. With sponge iron presently selling at around Rs 4700/t, such installations would be less profitable if they are merchant DR units. This situation is likely to become more adverse with the landed price of imported scrap coming to around Rs 6000/t. Transportation of large quantities of gas based DRI may necessarily demand the adoption of briquetting.

The future prospects for gas based DR in India would depend primarily on the price at which consistent quality of natural gas is made available. The other important factor to be taken into consideration is the transportation cost - both for raw materials as well as the product. Thus, the choice of a logistically suitable location to optimise both gas and iron oxide transportation costs, would assume paramount importance vis-a-vis the profitability of such a venture. For natural gas based plants, the economics gets favourably influenced if the plant is close to the source of gas, since gas transportation through pipelines costs around Rs 800/1000 m^3. This becomes a critical issue for judging the viability of such ventures. It will, therefore, be preferable to set up gas based plants near the gas fields or close to landfall point (in case of an off-shore gas source) to keep costs down. Whether the market exists in such areas to absorb the large volumes of DRI produced or whether the product again has to be re-transported over long distances to the users, is the "moot" point.

Conclusions

The future of the DR industry in India appears to be very bright. Whether this opportunity can be suitably made use of by private entrepreneurs, joint sector or even public sector units, remains to be seen. If this is successfully done, India can certainly replace Venezuela as the world capital of direct reduction by the turn of this century.

Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

India's Rapid Strides in the Field of Direct Reduction

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ABSTRACT

India with its rich spiritual and cultural background is marching at a neverbefore pace of industrialisation. In the Iron and Steel sector, there has been much needed fresh air and Direct Reduction processes have found wide acceptance. This is reflected in the rapid growth of Sponge Iron capacities over the last decade - from 0.03 million tonnes in 1981 to 1.70 million tonnes in 1991 - a 57 fold increase, an increase higher than anywhere else in the world in the same period. What is more, there is no levelling off of the growth curve in the foreseeable future and it is estimated that the installed capacity of D R plants will spurt to 8.0 million tonnes by 2000 AD, with over 1.2 million tonnes capacity being added in the current year itself. On the one hand, this growth has demonstrated the capacity of the Indian industry to surmount several difficulties encountered by a developing country, such as alternative allocation of scarce energy resources, technology absorption & the vagaries of the market place whereas on the other hand, it has thrown up new challenges for the Indian as well as the World steel industry in the areas of availability of good raw materials, technologies requiring less energy in the D R using Mini-steel plants, Foundries etc., as also technologies for cheaper generation of electric power.

A PERSPECTIVE VIEW OF INDIA's D R GROWTH

INDIA'S FIRST DIRECT REDUCTION (D R) PLANT with a capacity of 30,000 tpa, a coal based plant, commissioned in the year 1980 was at Paloncha in the State of Andhra Pradesh. The installation of this first plant, with a very small capacity by the world standards even at that time, required considerable effort of metallurgists, steel makers, planners, the State Government, the Government of India and active encouragement by UNIDO and others in pooling the resources for its successful completion and commissioning.

India has never looked back since and several plants were commissioned in the subsequent years. The installed capacity of D R plants had - as may be seen in Figure-1 - a 57 fold increase in the previous decade from 0.03 million tonnes in 1981 to 1.70 million tonnes by the year 1991.

Table-1 indicates the growth in capacity year-wise as well as the details of location and technology employed in each of the plants. As may be seen in Figure-2, the initial growth was confined to the eastern part of the country which is richly endowed with coal deposits. Therefore, it was but obvious that these initial plants employed coal based technologies like SL/RN, KRUPP - CODIR, ACCAR, TDR etc. and their capacity addition was comparatively modest due to the inherent characteristic of coal based D R plants. Nevertheless, these were very important additions to the Sponge Iron capacities of the country which helped in technology absorption and the user Mini-steel industry to familiarise itself with, and adaptation of the product.

There was a dramatic increase in the installed D R capacity of the country when India's first gas based Sponge Iron plant was commissioned in the year 1990 at Hazira in the Western part of India. The installed capacity jumped from 0.60 million tonnes to

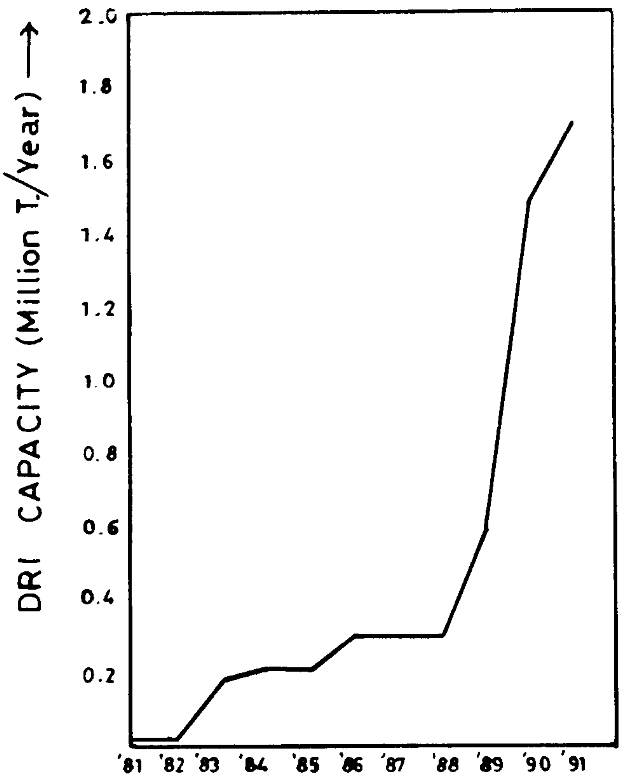

FIG: 1. GROWTH OF DRI CAPACITY IN INDIA (1981-1991)

Table 1. Details of the growth of D R plants in India (Period 1980-1991)

Year of Start up	Owner	Location	Technology	Capacity in million tpa
1980	SIIL	Paloncha	SL/RN	0.03
1983	OSIL	Keonjar	ACCAR	0.15
1984	SIIL	Paloncha	SL/RN	0.03
1986	IPITATA	Joda	TDR	0.09
1989	BSIL	Chandil	SL/RN	0.15
1989	SUNFLAG	Bhandara	CODIR	0.15
1990	ESSAR	Hazira	MIDREX	0.88
1991	GOLDSTAR	Vizianagar	CODIR	0.22
			Total	1.70

to 1.48 million tonnes. Thus, the growth of Direct Reduction not only spread to the far flung western part of India - 2000 Kms. away from the traditional Iron & Steel belt of India - but also spearheaded the adaptation of gas based technologies for the production of Sponge Iron, in India. This pioneer gas based D R plant employing MIDREX technology was the first Hot Briquetted Iron (HBI) plant and was the largest plant in the country.

The establishment of this first gas based plant involved considerable effort on the part of the State Govt. of Gujarat, industrially a highly progressive State in Western India and the promoter ESSAR group of industries, in convincing the authorities that it will be economically advantageous for the country to allocate Natural Gas for the Sponge Iron industry apart from allocation to some other industries such as Fertilizers, Petro-chemicals, Electrical Power etc. This was a considerably difficult task in view of the importance of Fertilizers in the agro-based economy such as India. However, it was possible to establish that from the economic stand point, 3 Sponge Iron plants can be set up for every single Fertilizer plant. Thus, the allocation of Natural Gas for Sponge Iron manufacture has already drawn the attention of Indian planners. It may be interesting to note that today, HBI from the single gas based D R plant is commanding 65% of the Sponge Iron market in India (Fig:3).

In the meanwhile, the Indian Government had undertaken active steps to encourage the growth of Sponge Iron industry. Accordingly, the Sponge Iron Industry was delicensed and a policy formulated to encourage new Mini-steel units capable of using 30% to 70% Sponge Iron as its feed material.

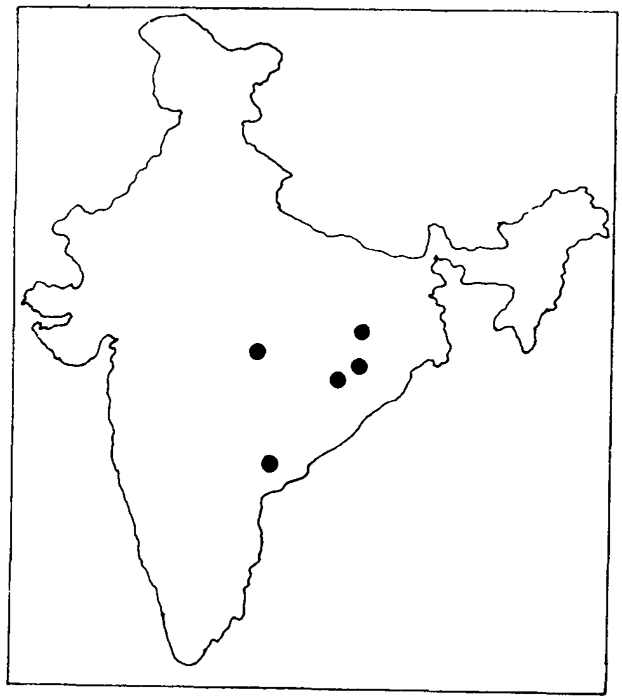

FIG:2 - GROWTH OF DRI IN INDIA IN THE INITIAL STAGES

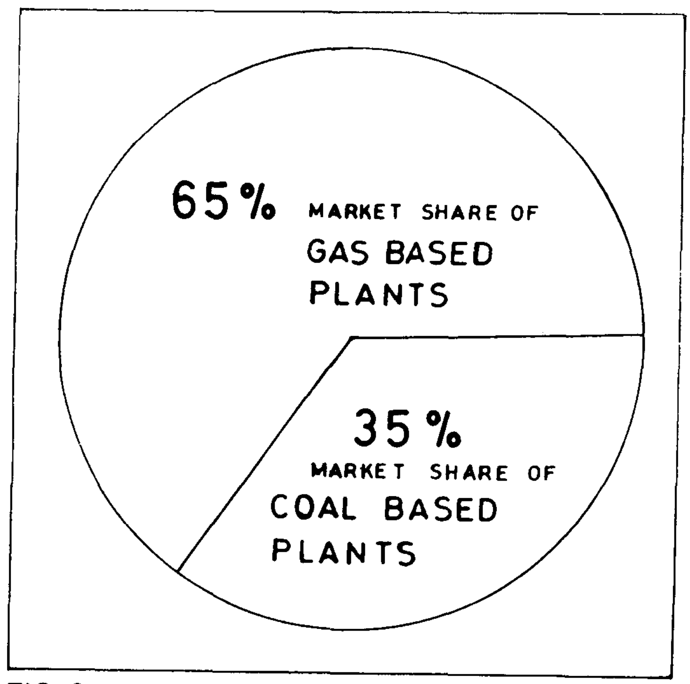

FIG:3 - MARKET SHARE OF COAL AND GAS BASED DRI IN INDIA.

Table-2: Future Growth of DRI Plants in India

Year of Start up	Owner	Location	Technology	Capacity million tpa
1992	HEG	Durg	SL/RN	0.06
1992	JINDAL STEEL	Raigadh	JINDAL	0.10
1992	T.N. SPONGE	Salem	SL/RN	0.06
1992	VIKRAM ISPAT	Alibag	HYL-III	0.75
1992	ESSAR	Hazira	MIDREX	0.44
1993	NIPPON DENRO	Alibag	MIDREX	1.00
1993	KUMAR METALLURGICAL	Nalgonda	SL/RN	0.06
1993	JINDAL STEEL	Raigadh	JINDAL	0.40
1993	BELLARY STEEL	Bellary	SL/RN	0.06
1993	RAIPUR ALLOY	Raipur	SL/RN	0.06
1993	SUNFLAG	Bhandara	CODIR	0.15
1994	SIIL	Paloncha	SL/RN	0.10
1994	PRAKASH INDUSTRIES	Raipur	SL/RN	0.15
1994	USHA RECTIFIER	Jagdishpur	MIDREX	0.80
1994	BSIL	Chandil	SL/RN	0.15
			Total	4.34

ADDITIONAL CAPACITIES IN NEAR FUTURE

Table-2 lists the details of the new D R plants likely to start up in the near future from which it may be noted that some indigenous D R technologies have also been developed for the coal based plants and as far as the gas based plants are concerned, apart from the MIDREX technology, HYL-III technology is also to be employed. Figure-4 shows the location of these new plants on the Indian map, from which it may be seen that unlike Figure-2 shown earlier where the growth was restricted largely to the eastern part of the country, the D R growth is fairly wide-spread in the central, western and southern parts of India. It may also be observed that the proportion of gas based D R capacity which was 51% of the total in Table-1 would have gone up to 64% after the setting up of the plants mentioned in Table-2.

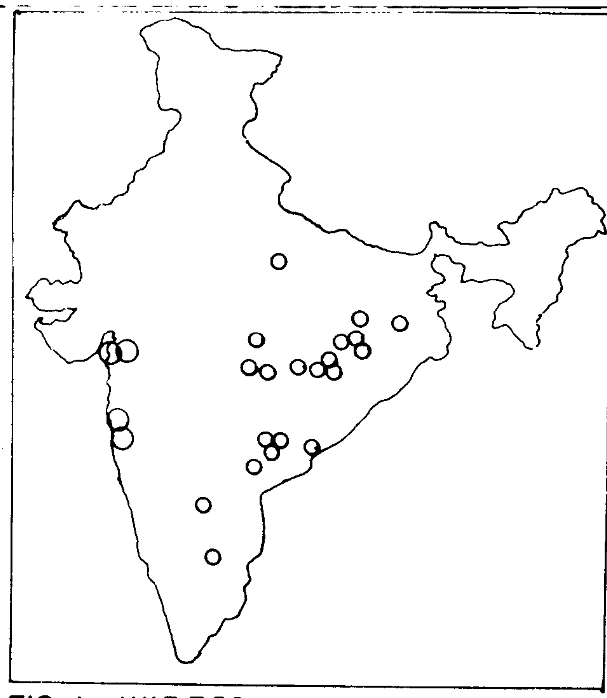

FIG:4. WIDESPREAD GROWTH OF DRI PLANTS IN INDIA

Based on the above indications, Figure-5 shows the trend in the growth of Indian D R capacities in the near future. It may easily be seen that there will be an impressive growth rate, making the achievement so far look small, and if all goes well, India is poised to be amongst the top of World D R producing countries in the near future with the likely installed capacity around 6.0 million tonnes per annum, by 1995.

POTENTIAL FOR FURTHER GROWTH

The relationship of a country's per capita steel consumption and industrial growth expressed in GDP is well known. As illustrated in Figure-6, India's per capita steel consumption at 20 Kg. is quite low as against the world average per capita consumption of 150 Kg. steel.

It is expected that the per capita steel consumption will increase from the present level of 20 Kg. to at least 26 Kg. by 2000 AD, if the fast pace of industrial development that India has embarked upon, is to be sustained. (The higher estimate of 30 Kg. per capita appears debatable). This 26 Kg. per capita steel consumption will work out to approximately 26.0 million tonnes of annual finished steel demand for the country by 2000 AD from the present level of around 15.0 million tonnes per annum. It is estimated that a sizeable proportion of the additional approximately 11.0 million tonnes of finished steel capacity required to be created will employ the DRI-EAF route which is more efficient and economical - especially in view of the non-availability of coking coal required in the BF-BOF process in many parts of India.

A unique feature of the Indian steel scenario is a significant proportion of steel produced by the Induction Furnaces. These Induction Furnaces are also using DRI to the extent of 20 to 30% of its feed-stock.

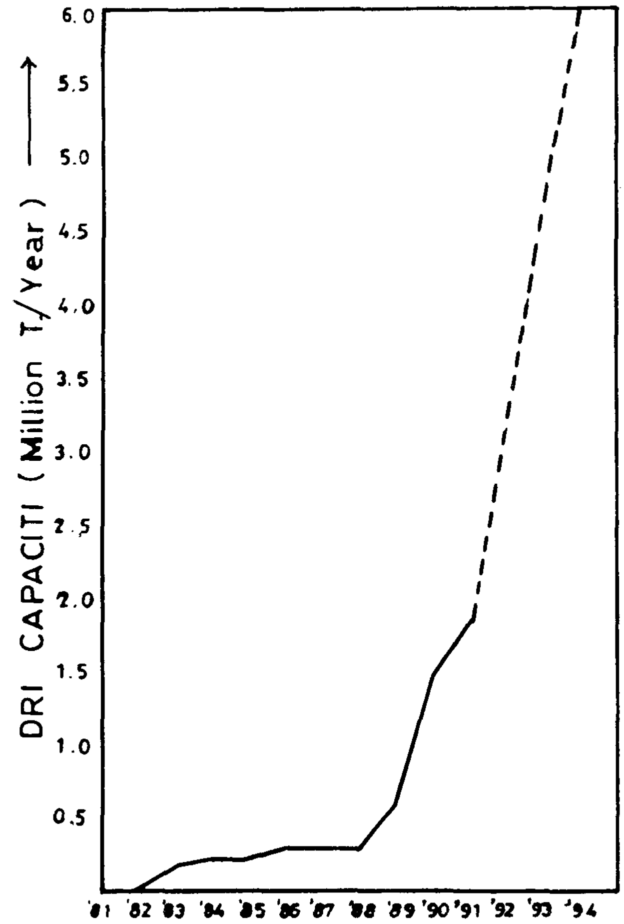

FIG:5. FUTURE DRI CAPACITY IN INDIA

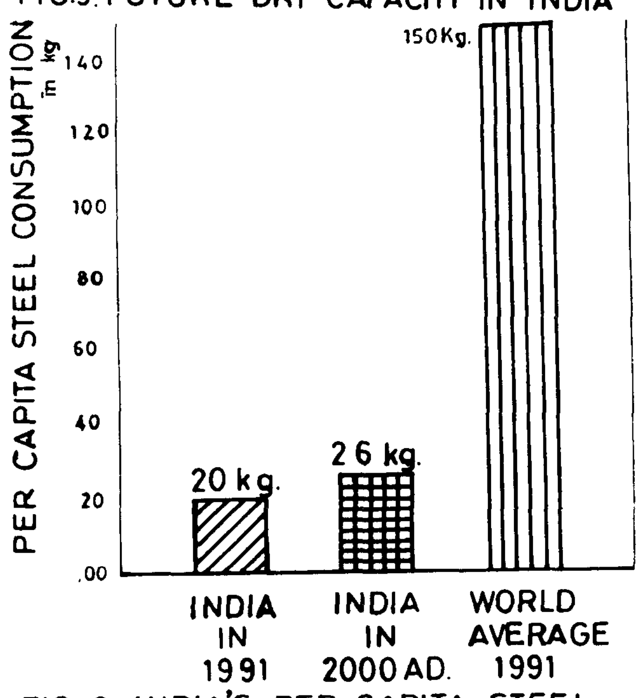

FIG: 6. INDIA'S PER CAPITA STEEL CONSUMPTION

It can be safely argued that the proportion of steel produced by the Electric Arc Furnace and Induction Furnace based Mini-steel plants which are the chief users of Sponge Iron, will be of the order of 33% of the total steel production in India. In keeping with the trend elsewhere in the world, this proporation in India is likely to be sustained, if not improved upon in the near future. Moreover, DRI is increasingly used by the Foundry industry for the production of Quality Castings. The use of DRI by the large integrated steel plants, though not popular at present, holds out a good potential.

Keeping this in view, various estimates have shown the demand gap of melting scrap in the region of 8 - 9 million tonnes per annum by 2000 AD. If this capacity of 8 - 9 million tonnes per annum of Sponge Iron is achieved, it then will mark the peak of growth.

CHALLENGES OF GROWTH

Any rapid growth, such as witnessed and foreseen on the Indian Sponge Iron scene, requires consolidation, without which, the optimum benefits of the growth cannot be expected to accrue. In turn, the consolidation effort throws up fresh challenges. Some of these challenges, if not met by careful planning, may inhibit further growth and may seriously limit the benefits to be derived from the growth. Thus, the Indian Sponge Iron growth scenario appears to be throwing up the following challenges;

1. Difficulties in getting Natural Gas Allocation: Although the economic importance of allocation of Natural Gas for the manufacture of Sponge Iron is well established by now, there are equally strong claimants for the use of Natural Gas such as Electrical Power, Fertilizers, Petro-chemicals etc. Thus, it is increasingly difficult to obtain gas allocation for the manufacture of Sponge Iron. A judicious policy for allocation of Natural Gas is called for.

2. High Infrastructure Cost: The cost for the development of infrastructure such as electrical power line, water pipeline, building of jetty, captive power plant, natural gas pipe line, railway siding, roads etc. is quite high and may at times work out to as high as 20 to 25 per cent of the capital cost.

3. Availability and Compatability of Raw Materials: Although large reserves of iron-ore and non-coking coal are available in the country, suitability of these raw materials for Sponge Iron production through rotary kiln is limited. To widen the raw material base, it may be necessary to consider beneficiation of iron ore and the use of agglomerated feed stock like oxide pellets.

4. Moderate Quality and High Price of Natural Gas: As far as the gas based plants are concerned, the quality of gas supplied has to be better and consistent. This is a matter to be properly appreciated by the monopoly gas suppliers. Against the moderate quality, the price of natural gas supplied to Indian Sponge Iron plants is quite high when compared with similar developing countries like Mexico, Venezuela, Malaysia, Indonesia, Iran, Quatar etc.

5. Competition from Imported Scrap: Although Sponge Iron or Directly Reduced Iron (DRI) has more predictable chemistry when compared with steel melting scrap and is more desirable from the quality stand point, traditionally the users have always tended to compare its price with scrap. The Indian Govt. has

lowered the custom's duty on scrap drastically from 35% in the past to 10% now. This factor of lower custom's duty coupled with recent liberalisation on the Foreign Exchange front is quite favourable for the importation of scrap in India. Therefore, Sponge Iron has to face stiff competition from imported scrap. This competition can best be met by more quality conciousness on the part of DRI producers and more DRI being produced in the Briquetted Form.

6. Limitations of Mini-steel plants for the use of DRI: Out of the 179 Electric Arc Furnaces (EAF) in India, a very large proportion is with a size less than 15 T capacity. Similarly, Induction Furnaces also are less than 3 T capacity. It is estimated that an average EAF unit is able to use only 40% and an average Induction unit 30% of its charge as DRI. A very few of these units employ continuous charging of DRI.

   Therefore, there is a vital need to modernise these Mini-steel units incorporating the use of continuous charging, water cooled panels, water cooled roof, preheating of ferrous charge materials, oxy-fuel burners, Ultra High Power Furnaces etc. The proportion of DRI use can also go up if the carbon percentage in the DRI is consistently higher than 0.8% and again if more DRI is available in the Briquetted form.

7. The Removal of Constrains Affecting the Performance of Mini-steel plants: One of the major constraints faced by the Indian Mini-steel industry is the availability and cost of power. The availability of power is poor, inconsistent and its cost is very high. Steps should be taken to make the power consistently available and wherever feasible to encourage Mini-steel plants to go for captive power plants.

   On the other hand, metallurgists and technologists should orient their efforts in the direction of;

   (a) Radical reduction in the power consumption by the smaller EAFs and Induction Furnaces such as obtaining in India.

   (b) Methods to generate cheaper power and reduce transmission losses. In this connection, mention must be made of Fuel Cell technology for power generation and the developments in the field of Super Conductivity which can be of great help in the Indian situation.

CONCLUSION

India with its rapid strides in the field of Direct Reduction is poised to top the list of DRI producers in the world. This growth has been achieved largely due to Indian enterprise with active support and encouragement by the Indian Government, despite several constraints faced by a Developing Country. With this growth, India has assimilated both coal based and gas based technologies and there is a fairly wide-spread use of DRI. India with the help of the rest of the world will have to address itself to meet the challenges thrown-up by the growth.

ACKNOWLEDGEMENT

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Experiences on Controlled Steam Quenching of Alloy and Special Steels at Mukand Ltd.-India

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Abstract

Mukand Ltd. Bombay, the largest electric arc furnace complex in India, is the only wire rod producer in the country having in-line Easy Draw Continuous (EDC) controlled cooling facility. Though this was installed initially for in-line patenting of high carbon wire rods, the experiences gained during the last decade helped in extending the steam quenching technology to several other alloy and special steel grade wire rods. The process applicability is getting increasingly enhanced and the techno-economic advantages are being fully established. This paper describes the innovative efforts put in at Mukand during the past decade and the development of inhouse process computerisation of key operating steps, which helped in extending steam quenching to sophisticated alloy and special steel grade wire rods. Possible futuristic efforts are also highlighted towards the twin objectives of improved metallurgical quality and reduced manufacturing costs.

SEVERAL TECHNOLOGICAL DEVELOPMENTS have taken place in the last three decades in the field of controlled cooling of hot rolled wire rods (1-5).

Among the various established applications of controlled cooling, arriving at a near patented structure for high carbon rods is perhaps the most prominent one.

Use of boiling water as cooling medium for controlled cooling of hot rolled wire rods was the significant development in this area (6-7). Based on the research in film boiling and its application as a controlled cooling medium for in-line patenting of hot rolled wire rods, the Easy Draw Continuous (EDC) process was developed. The demands for higher quality and greater flexibility, need to process coil weights above 1000 kgs and higher rolling speeds in modern wire rod block mills were instrumental in the refinement of the original Easy Draw (ED) Process into EDC process.

Easy Draw Continuous (EDC) Cooling Process

The EDC process consists of an inclined laying head which lays the wire rod to an adjustable conveyor 1 which is exposed to air, giving the wire rod time for recrystallization and grain growth. From conveyor 1, the wire rod turns are transferred down to the end of conveyor 2 which is submerged in hot water and after requisite quenching time the wire rod turns are transferred via conveyor 3 to the coil reforming station.

Thus controlled cooling in EDC can be divided into three distinct zones:

* Cooling in air on conveyor 1.
* Cooling in water, adjusted by means of water temperature and speed of conveyor 2.
* Air cooling on conveyor 3 and in the reformer tub.

A comparison between ED and EDC processes shows that the EDC system has the following advantages:

* Coil weight is limited only by the capacity of coil assembly and handling equipment.
* Better homogeneity in rod structure.
* Better control over scale formation.
* Better possibility of treating low carbon rods.

EDC System at Mukand

The EDC system, presently operating at Mukand, incorporates many of the improved design features as shown in Fig. 1. This unit, which is probably only the fifth in the world was commissioned in June 1982. The unit is attached to a eight stand twist free high speed (65m/sec) Morgardshammar block mill. The system comprises of five consecutive sections corresponding to five stages of controlled cooling, which are described below:

Primary Cooling Section. The wire rod emerging from the last stand of the block mill, which usually is at a temperature of around 1050°C, is cooled here by water sprays to a pre-determined temperature, called the laying temperature. Cooling of wire rod is controlled by adjusting the water pressure and percentage opening of the three valves fitted in this region.

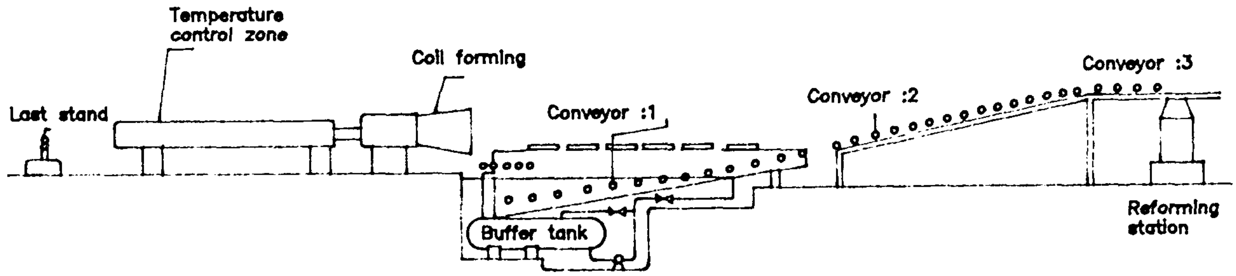

Fig.1 Arrangement for EDC system

Loop Laying and Conveyor 1 Section. The wire rod is then laid loop by loop on conveyor 1. By adjusting the speed of conveyor it is possible to adjust loop density and the time held in still air for each loop.

Process Tank. Here, the loops move on to conveyor 2 and are subjected to quenching in boiling water. The water temperature which can be varied, is usually kept above 95° C for high carbon wire rods.

Cooling in Air or Conveyor 3. This takes place on the quenched loops emerging from conveyor 2.

Reformer Tub Section. The wire rod loops coming out of the process tank and air cooling section are then collected in the reformer tub.

Mukand's Experience on Application of EDC

Mukand primarily installed the EDC with a view to achieve patented properties of high carbon wire rods, in-line with the rolling. However, based on the experiences gained while using the EDC for high carbon wire rods and through applications of certain innovative concepts, Mukand was able to achieve the flexibility of its EDC system to cater to various other grades of steels. These include:

* In-line solution annealing of stainless steel wire rods.
* In-line production of dual phase steel reinforcement bars.
* In-line production of suitable base structure conducive to shortening the spheroidising annealing cycle for cold headed quality steels like ball bearing, AISI 4140 and others.

The experiences for each of the above classes of steels are detailed below:

High Carbon Steels. Mukand has been a major supplier of high carbon wire rods in the domestic market. With its continuous improvement efforts and application of latest computerisation methods, Mukand has successfully developed and standardised EDC controlled cooling technology for high carbon rods. Today, the quality of high carbon wire rods produced at Mukand is comparable to the best available elsewhere. The diameter of high carbon rods that can be processed through EDC at Mukand varies from 5.5mm to 12mm. These wire rods are used in several applications including automobile, power, construction and engineering. Typical EDC parameters for high carbon rods are given in Table I.

Table I. EDC process parameters for high carbon wire rods.

Wire rod dia. (mm)	Carbon range (wt%)	Temperature before coil forming (^{o}C)	Conveyor 2 speed (m/s)	Water level of Conveyor 2 (mm)	Loop density (nos/m)	Total time in water (s)	Temp.at water exit (^{o}C)
5.5	< 0.5	830	0.6260	400	31.5	20.3	550
	>0.5	830	0.6869	400	28.0	18.5	550
8.0	<0.5	840	0.4236	400	22.5	30.0	500
	>0.5	840	0.4236	400	22.5	30.0	500
10.0	<0.5	840	0.3530	400	19.3	36.0	500
	>0.5	840	0.3060	400	22.3	41.5	500
12.0	<0.5	840	0.2400	400	19.5	53.0	500
	>0.5	840	0.2190	400	21.5	58.0	500

Mechanical properties of high carbon EDC processed wire rods for various sizes and chemical compositions are given in Table II. Based on the experience on the process standards, the following relation for ultimate tensile strength (UTS) was developed with a standard deviation of 2.62 kg/mm^2.

UTS (kg/mm^2) = 110 (%C) + 19.15(% Mn) + 30.18 - 1.82 (rod dia in mm).

Table II. Mechanical properties of high carbon wire rods processed through EDC at Mukand

Wire rod dia. (mm)	Chemical Composition (wt%) C	Mn	Mechanical properties UTS (Kg/mm^2)	RA (%)
5.5	0.46	0.56	81.4	46.0
	0.56	0.56	100.5	43.6
	0.66	0.63	106.0	41.6
	0.85	0.66	125.2	37.8
7.0	0.57	0.58	87.0	42.0
	0.60	0.56	93.0	43.0
	0.73	0.56	93.0	43.0
	0.73	0.63	110.0	40.0
	0.86	0.57	128.0	35.0
8.0	0.39	0.54	74.0	47.4
	0.56	0.62	94.9	41.0
	0.75	0.73	119.0	35.0
	0.82	0.70	121.7	35.0
10.0	0.66	0.80	101.1	40.3
	0.70	0.68	103.0	38.0
	0.79	0.68	118.0	38.2
12.0	0.53	0.60	81.3	38.0
	0.67	0.60	96.4	38.0
	0.71	0.71	102.0	36.3
	0.80	0.66	111.5	34.0

In Fig.2, UTS of wire rods processed through Mukand is compared with lead patenting, Stelmor and Morgan's latest TOA Mist patenting (TMP) processes.

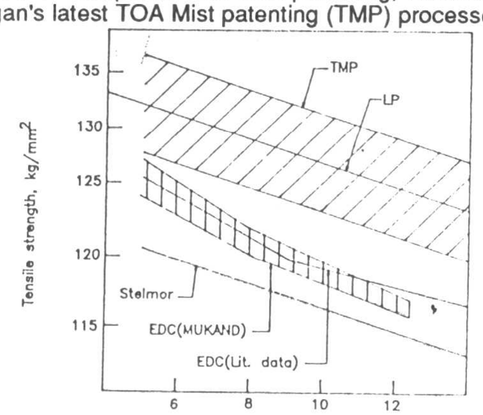

Fig.2. Comparison of tensile strength of high carbon wire rods processed through various systems.

Mukand's high carbon EDC wire rods show micro-structure closer to lead patented wire rod. Typical micro-structures are given in Fig.3

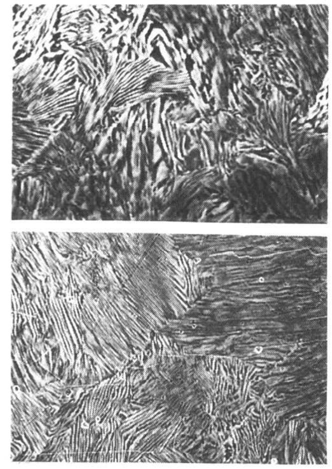

Fig.3. Typical microstructure of high carbon wire rods processed through EDC

Stainless Steels. Mukand has been rolling AISI 304 wire rods to 6 mm and above sizes since 1978. Prior to commissioning of block mill together with EDC facility, all wire rods had to be solution annealed in batch type furnaces before further processing. Once the block mill and EDC were installed in Mukand's wire rod mill, the following factors were considered "favourable" in using this system for quench annealing of austenitic stainless steel wire rods:

a. Higher rolling speed of 60 m/s.

b. High finishing temperature of 1080° C.

c. Smaller wire rod sections.

d. A quick temperature drop from over 800°C to around 400°C in about 25 seconds in the process tank and aire cooling sections.

e. Possibility of controlling the cooling parameters in almost all sections in the entire cooling system.

In solution annealing treatment of austenitic stainless steel wire rods, adequate softening is ensured for the purpose of further drawing. The relation between the austenitic grain size and hardness of austenitic stainless steel is shown in Fig.4. To attain the desired degree of softening, it is necessary that the grain size number is less than 6.

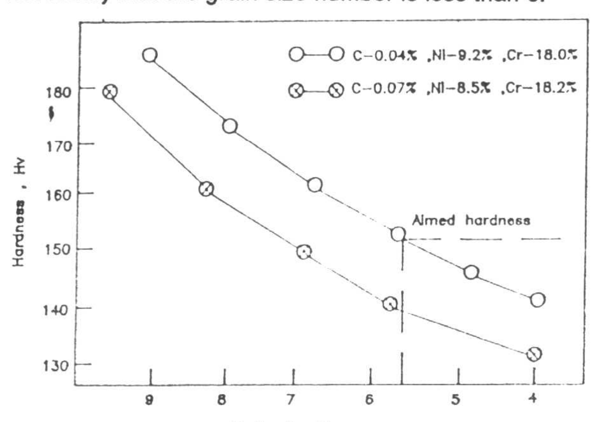

Fig. 4. Relationship between grain size and hardness of austenitic stainless steel.

Following aspects are found useful for ensuring softness of austenitic steel wire rods, directly solution annealed through EDC.

a. High temperature reduction in block mill:

Degree of dynamic recrystallisation and grain growth in the wire rod is directly proportional to the temperature at the time of hot reduction.

High temperature in block mill also helps in keeping higher laying temperature. The temperature rise in block mill (with higher rolling speeds) can favourably be used for obtaining higher grain size in hot rolled wire rod.

b. Speed of conveyor 1:

By controlling the speed of C1, the time for recrystallisation and grain growth in air, before water quenching, can be controlled. When this is combined with higher laying temperature, optimum softness can be ensured.

During the last decade Mukand has been able to successfully produce over 120,000 MT of in-line quench-annealed stainless steel rods processed through EDC.

Comparison of EDC and Non EDC AISI 304 Wire Rods. The mechanical properties obtained on wire rods processed through EDC and Non EDC are given in Table III. The extent of ductility achieved through EDC is quite apparent.

Table III. Comparative data on EDC and non EDC AISI 304 wire rods

Parameter	Test Results		
	Non EDC	EDC	ASTM A 276
Wire rod dia.(mm)	6	5.5	0.08 max.
Chemical composition(wt%)			
Carbon	0.06	0.07	0.08 max
Manganese	1.37	1.61	1.00 max
Silicon	0.63	0.61	1.00 max
Phosphorous	0.027	0.016	0.045 max
Sulphur	0.023	0.026	0.030 max
Chromium	18.00	18.00	18.0/20.0
Nickel	9.00	9.12	8.0/10.5
Mechanical properties			
UTS-(kg/mm2)	65-67	65-67	52.5 min.
Elongation(%)	56-60	65-66	40.0 min.
RA(%)	64-68	74-76	50.0 min.
Hardness(BHN)	179	150	-

Another interesting feature observed was the reduction in scale thickness on the wire rods rolled through EDC. The estimated reduction of metal loss due to scale was of the order of 25%.

Dual Phase Steel. Application of EDC for production of dual phase steel is another example of exploring the flexibility offered by EDC process. Dual phase steels are high strength, high ductility steels used popularly in automotive industry, due to their higher strength to weight ratio. Mukand was among the first to explore the dual phase steel technology for the production of reinforcement bars. The reinforcement bars developed at Mukand are known as SUPERSTEEL 60. The most popularly used reinforcement bars have a design strength of 415 MPa with an elongation of 14%, while Mukand's SUPERSTEEL 60 has a design strength of 600 MPa with a minimum elongation of 12%

Normally, the strength in reinforcement bar is achieved either through micro-alloying or by using cold deformation like twisting. SUPERSTEEL 60, processed through dual phase route, has high strength levels without the use of either of the above mentioned methods, but through innovative use of the EDC system.

Strength of dual phase steel can be expressed as

$$\sigma_{ss} = \sigma_m v_m + \sigma_f (1-v_m)$$

where

σ_{ss} : Tensile strength of dual phase steel.
σ_m : Tensile strength of martensite:
σ_f : Tensile strength of ferrite
v_m : Volume fraction of martensite.

Thus, the strength of dual phase steel is influenced by the properties and volume fractions of the two phases present in the steel.

In order to obtain the desired metallurgical structure, the bars are quenched from inter-critical temperatures at suitable quench rates.

Therefore, quenching temperature and cooling rates are important parameters. Carbon content in the austenite, the hardenability and percentage volume of austenite are fixed by critical quenching temperature T_Q. The cooling rate has a decisive effect on the extent of transformation of austenite, strength and plasticity of ferrite. Typical chemical composition of dual phase steel bars is given in Table IV and microstructure of SUPERSTEEL 60 is shown in Fig. 5.

Table IV. Typical chemical composition of SUPERSTEEL 60 bars

Wire rod dia.(mm)	Chemical Composition(wt %)				
	C	Mn	Si	P max.	S max.
8.0	0.20	0.80	0.25	0.035	0.035
10.0	0.18	0.80	0.25	0.035	0.035
12.0	0.16	0.80	0.25	0.035	0.035

At Mukand, the following parameters were monitored and closely controlled to arrive at desired dual phase structure and optimum mechanical properties for SUPERSTEEL 60 BARS.

a. Billet reheating temperature.

b. Block entry temperature.

c. Block exit temperature.
d. Primary cooling seetings.
e. Conveyor 1 speed.
f. Conveyor 2 speed.
g. Water level.
h. Circulation of water in EDC tank.
i. Temperature of water in EDC tank.

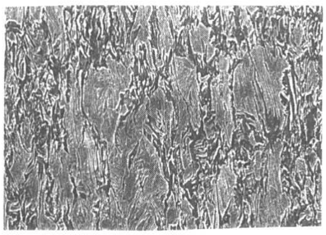

Fig.5 Typical microstructure of 'SUPERSTEEL 60'

Simulation of Inter-critical Annealing on EDC. Simulation of inter-critical annealing on EDC is essentially done by controlling:

a. Block entry and exit temperatures of wire rod.
b. Primary cooling settings.
c. C1 end temperature - by controlling the speed of C1, the time of exposure of wire rod to air before it enters into water tank is controlled. Temperature of wire rod before entering the process tank, which corresponds to T_Q is a key parameter to obtain desired microstructure and mechanical properties.
d. C2 speed and water temperature - by controlling C2 speed and water temperature, both the dipping time and quenching rate of wire rod are controlled.

Typical heat treatment cycle followed in the wire rod mill is shown in Fig. 6.

Mention must be made here of the fact that the EDC system was used in an unconventional manner for the production of SUPERSTEEL 60. While in the conventional usage, the EDC quenching medium is boiling water, in case of SUPERSTEEL 60, water at 30-40°C was used as quenching medium. During the extensive trials, studies were conducted on the effect of hot deformation on transformation temperatures Ac_1 and Ac_3. The effect of water temperature on dual phase steel characteristics, leading to the desired mechanicl properties of 600 MPa yield strength and 12% elongation was established.

Cold Heading Quality Steels. Hot rolled wire rods of cold heading quality steels covering low alloy, boron and ball bearing steels are generally spheroidise annealed since cold formability is a pre-requisite for further processing of these types of steels.

Extensive laboratory studies carried out indicated that by suitably modifying the base structure, spheroidise annealing can be considerably reduced. The base structure which reduced spheroidise annealing time could be achieved by controlling the cooling rate of wire rod after finished rolling i.e. when the wire rod passed through the EDC system.

Fig. 7 shows the effect of cooling rate after rolling, on the degree of spheroidisation of carbides and on the hardness of medium carbon steel, after spheroidise annealing. It can be seen that spheroidisation was faster when the cooling rate of wire rod was higher. The higher cooling rate helps in modifying the base structure which accelerates the spheroidisation. However, the laboratory trials at Mukand indicated that in grades like En-31 and AISI 52100 a rapid cooling rate from a high austenitising temperature produced high percentage of plate martensite and retained austenite. Here, though spheroidisation proceeded rapidly, the final hardness was quite high, and a high degree of segregation of carbides was observed.

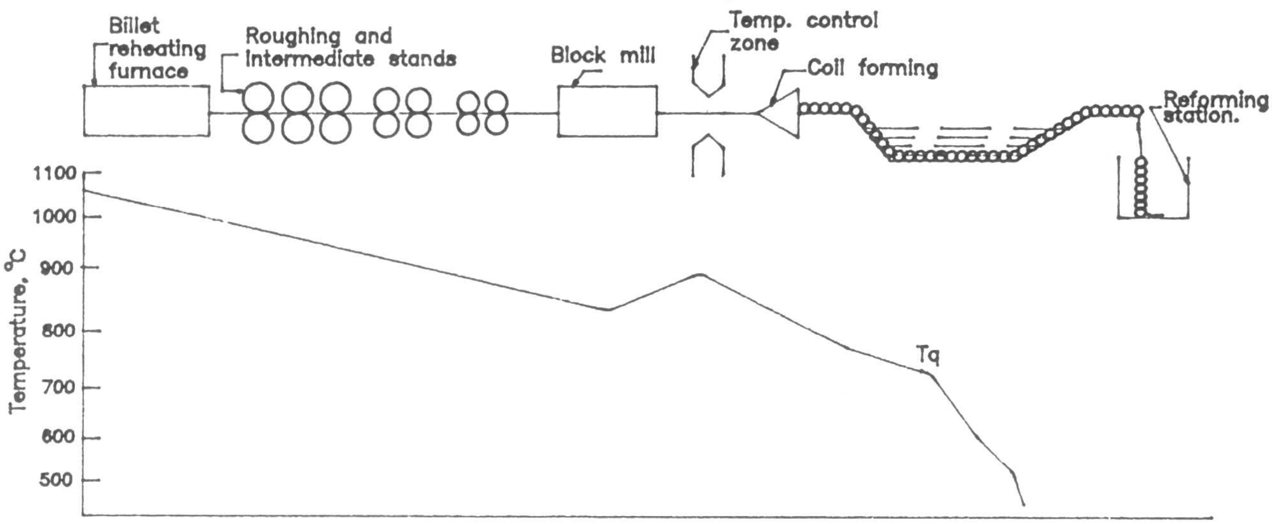

Fig. 6. Simulation of intercritical annealing in EDC.

Based on these findings, different cooling patterns are being currently standardised at Mukand for different grades of steels to arrive at suitable base structure conducive to reduce spheroidise annealing time by around 50% over the conventional one.

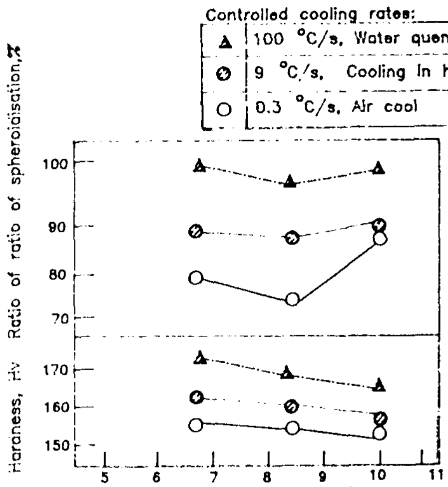

Fig.7. Effect of cooling rate after hot rolling on degree of spheroidisation and hardness of medium carbon steel.

Process Computerisation

Application of process computerisation of EDC system is a part of Mukand's continuous efforts for improving process capability, effectiveness of EDC and extending its application to various grades of steels.

Need for computerisation of EDC was felt due to the following:

a. Control over on-line parameters is essential to obtain consistent product quality.

b. Simplification of process parameters tailored for applications other than patenting. Process computerisation of EDC involves:

* Use of sophisticated instrumentation for monitoring on-line process parameters of EDC at various stages.
* Hardware for data acquisition and processing.
* On-line control of process parameters.

Typical flow chart for process computerisation of EDC is shown in Fig. 8.

Primary cooling zone of EDC was found most amenable for process computerisation since:

a. This is the first major part of the system where the temperature of the rod can be controlled to desired levels.

b. Signals, corresponding to various EDC parameters can be easily made available and processed.

c. Primary cooling zone is controlled by valve openings and water pressure.

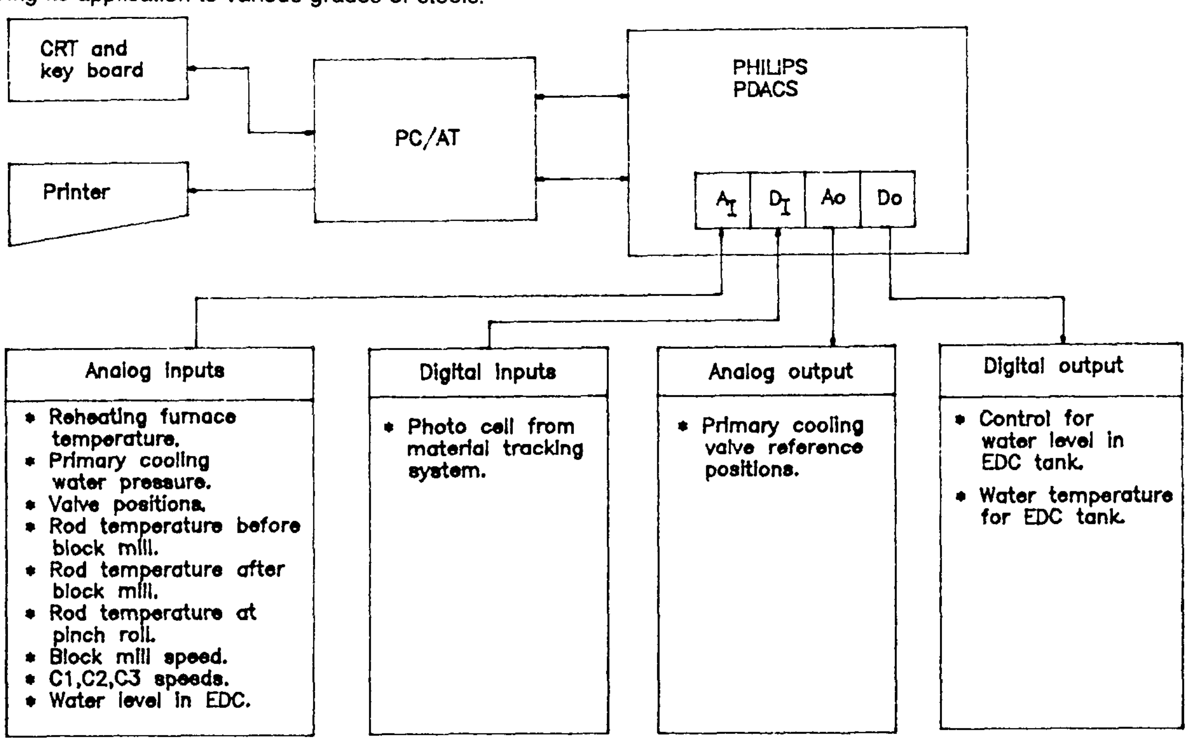

Fig. 8. Typical flow chart for process computerisation of EDC system.

Conclusion

With the help of the extensive experience gained and through better understanding of metallurgical flexibility available with EDC process, Mukand has successfully applied the steam quenching technology to various grades of steels. Judicious application of EDC system has resulted in reducing operating costs and processing time. Further attempts are being made to extend this technology to special quality wire rods such as cold heading varieties for their economic processing.

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Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

Emerging Technologies for Ironmaking — an Indian Perspective

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Abstract

India is endowed with adequate reserves of raw materials to sustain a large iron and steel industry. However, a major constraint is availability of good quality coking coal. Development of Smelting Reduction (SR) Process for liquid iron making using non-coking coal as an alternate to coke based blast furnace route has gained significant thrust in recent years in the industrialised countries and this is also of great significance for India. This paper deals with the rationale for development of suitable SR Process with respect to raw materials available in India particularly non-coking coals having high ash and high volatile matter . The theoretical concept behind SR Processes currently under development as well as effect of post-combustion on process viability has been dealt with in depth. The paper concludes with indicative techno-economic projections under Indian context.

IN MODERN TIMES, THE STEEL INDUSTRY in India began in the early 20th century with the setting up of integrated steel plants at Jamshedpur and Burnpur. After independence in 1947, the development of steel industry was taken up in real earnest and three integrated steel plants of capacity 1 million tonne each were commissioned at Bhilai, Rourkela and Durgapur during late fifties and early sixties. Thereafter, not only the capacity of these plants and the plant of Tata Steel at Jamshedpur have been enhanced but also two new integrated steel plants have been set up at Bokaro and Visakhapatnam.

There has also been significant growth in the production of steel in the secondary steel sector through the electric arc furnace route. A large number of mini steel plants have been set up. The total installed capacity for steel production in India is 17.6 Mt through integrated steel plants and 6.8 Mt through the electric arc furnace route.

Production of sponge iron has assumed great importance in view of the rising prices of scrap and the increasing demand of iron bearing materials for the secondary steel sector. In 1980s a number of sponge iron plants based upon rotary kiln technology have been established and are being successfully operated. In recent years one gas based DR plant has started at Hazira in Gujarat and a number of other units are in the process of being set up. The present total production capacity of sponge iron is 1.45 Mt.

Per capita consumption of steel being very low, there exists significant present and latent demand of steel in India.

India is endowed with extensive reserves of raw materials required for sustaining a large steel industry. The recoverable reserves of iron ore (hematite and magnetite) are estimated to be about 12 billion tonnes [1], that of coking coals about 9 billion tonnes, manganese ore about 154 million tonnes, limestone about 8 billion tonnes and dolomite about 5 billion tonnes. With the advantage of availability of a large reservoir of trained scientific and technical manpower and relatively low wage levels prevailing in the country, India has potential to grow into a major steel producer with global linkages.

During the last one year, Indian economy has been in transition with liberalisation in industrial, economic and trade policies of Government of India aimed at integration of the Indian economy with the global economy. With de-licensing of the steel industry and the encouragement given to private sector for setting up new steel plants and the encouragement given to the foreign companies to participate in the equity of such plants, it is expected that the steel industry in India will grow at a fairly steady rate exceeding 6% per year.

Rationale for Development of Alternate Routes of Ironmaking

Development of Smelting Reduction (SR) Processes as a promising alternative to blast furnace has gained significant thrust in recent years. The basic approach is to produce liquid iron in a reactor using iron ore/pre-reduced ore and non-coking coals with oxygen; and to use the reactor gases for preheating/pre-reduction of iron ore in some cases. Major incentives for development of smelting reduction processes are:

- Utilisation of non-coking coals as fuel and reductant with minimum or no pre-treatment
- Flexibility in quality of raw materials usage including direct use of fines
- Projected economic operation in a smaller scale
- Simplified process steps with high productivity
- Greater environmental compatibility

As the quality of Indian prime coking coals is poor and the reserves are very limited, development of suitable smelting reduction process for production of iron utilizing the abundantly available non-coking coals in India is of paramount importance from a long term perspective.

Nature of Raw Materials Available in India

Iron Ore. Quality parameters required for iron ore in SR Processes are more flexible compared to that of blast furnace. Processes currently being developed, can utilise fines as well as lump ore depending upon the type of pre-reduction unit. Some process developers have claimed that their process can use fines without any pre-treatment. Corex Process needs lump ore and/or prepared agglomerated burden.

Iron content of the ores are generally specified to be above 64% though it is not a limitation to the process. Reducibility of ores could play an important part in processes practicing high degree of pre-reduction. Low decrepitation tendency is also desirable in processes employing shaft furnace. High alumina content in Indian ore ($>2\% Al_2O_3$) would not significantly affect the SR Process since there is no cohesive zone present as in blast furnace.

Out of the total iron ore reserves in the country about 75% is hematite and rest magnetite. Iron ore sources are mostly located in states of Bihar, Orissa, Madhya Pradesh, Karnataka, Goa and Maharashtra. Table-1 shows reserves and state-wise distribution of iron ore (hematite). Iron ores available in most of the major deposits in the country are likely to be suitable for SR Processes.

Coal. SR Processes generally utilise non-coking coal both as reductant and fuel. Quality requirement of coal, however, depends to some extent on the nature of the process. As in all metallurgical processes, ash content of the coal plays an important role and should be as low as practicable. Volatile matter in the coal is released in the smelting reactor and too high a V.M is not desirable from heat balance considerations. Most of the developing processes abroad use coal having ash content in the range of 8-15%. High VM coals ($>30\%$ VM) have also been successfully used where high degree of post combustion is

Table 1. Grade-wise recoverable reserves of iron ore (Hematite)

(in million tonnes)

Sl. No.	Zone	States	High grade ore (Fe +65%)	Medium grade ore (Fe 62-65%)	Low grade ore (Below 62%)	Unclassified	Others	Blue dust	Total
1.	Zone A	Bihar	-	1660.43	1111.96	310.86	-	-	3083.25
		Orissa	82.39	1440.54	728.80	342.01	-	8.60	2602.34
	Sub-total Zone A		82.39	3100.97	1840.76	652.87	-	8.60	5685.59
2.	Zone B	Madhya Pradesh	629.45	410.14	689.73	394.46	0.44	62.00	2186.22
		Maharashtra	0.20	31.43	30.07	119.85	-	-	181.55
	Sub-total Zone B		629.65	441.57	719.80	514.31	0.44	62.00	2367.77
3.	Zone C	Karnataka	185.80	441.11	69.68	200.45	0.58	0.55*	898.17
4.	Zone D	Goa-Daman-Diu	0.43	139.45	1058.27	89.04	-	4.56*	1291.75
5.	Zone E	Andhra Pradesh	2.19	3.37	7.83	2.55	-	-	15.94
		Rajasthan	-	0.21	6.32	1.29	-	-	7.82
	Sub-total Zone E		2.19	3.58	14.15	3.84	-	-	23.76
	Total		900.46	4126.68	3702.66	1460.51	1.02	70.60 5.11*	10267.04

Note: * Indicates black iron which is iron ore with 10% manganese practiced.

Other parameters like ash fusion characteristics, reactivity, caking properties, decrepitation tendency etc. have little bearing on the process. As a result, any rank of coal can be utilised, keeping in mind the ash and VM content. Both lump coal and ground coal (~ 200 mesh) are used according to specific reactor type. Indian non-coking coals, though available in plenty, generally have high ash and VM (Ash >20%, VM>30%). Use of these coals as such in SR Process would call for high degree of post combustion in the SR reactor to maintain heat balance and to avoid generation of surplus energy besides having high slag volume with corresponding loss of energy efficiency, as well as operational problem. Therefore use of washed coal would be advantageous.

Total non-coking coal reserves are estimated to be around 130 billion tonnes, of which nearly 30% come under proven category. Total reserves of coking coal in India is about 28 billion tonnes of which only 5.3 billion tonnes are prime coking coal representing about 3% of total coal reserves. [2]

Grade-wise availability of non-coking coals in different coal fields in the country are given in Table-2.

As seen from the table, adequate reserves of coals (B and C grades) having ash + moisture in the range of 20-30% are available which should be suitable for SR Processes.

Different SR Processes under Development

Considerable efforts have been made for development of SR Processes during the last two decades or so. Out of the many processes that were taken up for development, the following five processes are being actively pursued presently for commercial development. The main concepts of these processes and the present status of their development are briefly described below:-

Corex (Voest Alpine, Austria) [3]. This is a two stage SR Process in which hot pre- reduced (> 90% degree of metallization) iron bearing

Table 2 Catagorised proven reserves of non-coking coals in Gondwana coal fields of India

(in million tonnes)

Coalfield	Grade of Coal					
	A	B	C	D	E.F.G	TOTAL
RANIGANJ	80.00	1066.00	3929.00	936.00	884.00	6895.00
BORJORA					71.00	71.00
JHARIA	63.51	38.50	73.14	404.26	4999.59	5579.00
WEST BOKARO			9.38	35.44	98.08	142.90
RAMGARH				3.50	3.63	7.13
NORTH KARANPURA	28.15	38.71	38.72	253.85	2183.56	2542.99
SOUTH KARANPURA	155.15	106.44	264.55	388.51	954.38	1869.03
AURANGA					8.78	8.78
HUTAR	28.39	43.66	21.33	14.50	2.08	109.96
DALTONGANJ	10.00	20.00	29.00	4.00	20.86	83.86
DEOGARH	0.87	16.19	22.81	8.03	11.34	59.24
RAJMAHAL			33.00		1080.88	1113.88
UMARIA					18.90	18.90
PENCH-KANHAN	62.66	122.37	213.94	226.14	258.11	883.22
SINGRAULI			507.25	684.50	2408.15	3599.90
BISRAMPUR	32.31	131.65	1.19	1.20	4.80	171.15
SONHAT		2.53	2.53	6.31	14.64	26.01
JHILLIMILLI	63.60	44.71	24.14	13.13	66.10	211.68
CHIRIMIRI	66.14	116.11	116.09	11.00	10.99	320.33
SOHAGPUR	101.29	158.09	209.04	124.94	55.55	648.91
PATHAKHERA		8.71	25.14	50.37	64.03	148.25
KORBA	228.86	50.92	50.92	43.47	1653.59	2027.76
JOHILLA		34.92	57.45	12.22	3.87	108.46
MOHOPANI					7.83	7.83
CHANDA-WARDHA			91.99	819.15	715.13	1626.27
KAMPTEE		24.17	240.93	199.35	247.07	711.52
UMRER					85.10	85.10
Ib-RIVER			3.17	103.56	1520.43	1627.16
TALCHER	16.07	118.31	118.94	47.14	2899.17	3199.63
GODAVARI VALLEY	24.95	199.51	1113.39	1825.78	1433.37	4597.00
GRAND TOTAL FOR GONDWANA	961.95	2341.50	7197.04	6216.35	21785.01	38501.85

materials are smelted to produce liquid iron in a dome shaped reactor where energy is supplied by partial combustion of coal with oxygen. In order to ensure high degree of metallization of the iron bearing materials in a shaft reactor located above the smelter reactor, the conditions in the smelter reactor are controlled such that the exit gases from the smelter reactor are highly reducing (~95% CO + H2). These gases after hot dedusting and temperature adjustment (to about 850 deg. C) are introduced at the bottom of the shaft.

The process originally developed in a 8 tph capacity pilot plant in Germany is presently working successfully in ISCOR, South Africa where one Corex module of 300,000 tpa capacity is in commercial operation. Presently, this is the only SR Process which has been developed on commercial stage.

DIOS (Japan) [4]. In 1988 the Japan Iron and Steel Federation (JISF) commenced R & D programme on New Direct Iron Ore Smelting Reduction Process (DIOS Process) as a joint project of eight Japanese integrated steel producers and Coal Mining Research Centre. Based upon preliminary investigations, a pilot plant of capacity 500 tpd of hot metal is scheduled to be commissioned in Keihin Works of NKK in 1993.

The plant consists of three elements - A molten iron bath SR Furnace (SRF), a fluidised bed pre-reduction unit and a coal addition type gas reformation unit. The pilot plant is designed to be flexible to test single stage concept where reduction is carried out fully in foaming slag in the smelter reactor with high degree of post combustion of reactor gases and realisation of high heat transfer efficiency. The pilot plant will also be able to function as a two-stage unit where the gas generated in SRF is utilised to pre-heat and pre-reduce the iron ore fines upto FeO stage. It will also be able to function as a three stage system with additional step of reformation of SRF gas by injection of coal fines before entering the pre-reduction furnace.

Hismelt (Australia) [5]. Based upon developmental work carried out by CRA, Australia and Klockner, Germany, a joint venture for development of Hismelt Process has been taken up by CRA and Midrex of USA. A 0.10 million tpa facility is under construction in Kwinana in Western Australia. In the Hismelt Process smelting of partially reduced iron ore is carried out in a molten iron bath by injecting powdered coal fines through shrouded bottom tuyeres and by injection of hot air blast (1200 deg. C) on to molten bath from the top. Exit gases from the smelting reactor are used for pre-reduction and hot pre-reduced ore is introduced into the molten bath.

AISI Process of Direct Steel Making (USA).The American Iron & Steel Institute (AISI) undertook the direct steel making initiative in 1987. A pilot plant of capacity 5 t/hr was constructed based upon conventional steel making converter technology and utilising deep slag bath approach for high post combustion. Recently, the programme has included a pre-reduction system using HYL type shaft reduction technology for producing wustite feed for the smelting reduction furnace. The smelting reactor is a horizontal vessel with a production capacity of 10 t/hr. The crude liquid metal from smelter reactor is envisaged to be directly converted to steel by injecting fluxes and oxygen in a continuous reactor.

Ferrum Liquid Phase Recovery Process (FLPR) (CIS) [6]. Moscow Institute of Steel & Alloys has developed a single stage liquid iron production process and tested it in a 350,000 tpy plant in Novoliptsk. The FLPR Process is a single stage process in which -20 mm coal & iron ore are introduced in a rectangular smelting reactor which operates at near atmospheric pressure. The reduction of iron oxides takes place in foamy slag phase and about 70% of post combustion of reactor gases is realised by introducing O_2 through side tuyeres located at two levels along the long wall of the rectangular reactor. The location of the bottom row of tuyeres is such that it leaves an undisturbed zone at slag-metal interface and also ensures a proper gradient of oxygen potential from top to bottom of the reactor.

Broad Analysis of Theoretical Concepts. The theoretical concepts adopted in development of different smelting reduction processes can be analysed either from the view point of number of stages involved or the mechanism for enhancing heat & mass transfer. Based upon review of the published information a broad picture is presented below:

Single Stage Concept. In the single stage concept, entire metallurgical reactions for ironmaking are carried out in a single reactor. As such, the energy requirements for the smelting reactor are high and can be met only if coal is burnt with oxygen and the reactor gases are combusted to achieve a high degree of post combustion (~70%) and high heat transfer efficiency.

As already mentioned, FLPR Process developed in Russia is a single stage process. DIOS Process Pilot Plant in Japan will also test the single stage concept. It is understood that AISI project also includes testing of single stage concept.

The obvious techno-economic implications of the single stage concept are:

1. Low capital cost as the equipment is of simple design (operating at near atmospheric pressure in FLPR Process)

2. Use of iron ore and coal without or marginal pretreatment/agglomeration as they are directly added to molten bath.
3. Surplus fuel gas will have very low calorific value and as such supplementary fuels will be required to meet the demand of other units of the steel plants.
4. Oxygen requirement will be somewhat higher than two stage concept as the single stage process is likely to be less energy efficient
5. The quality requirements for iron ore and coal are not stringent.

The success of single stage process would depend upon achieving steady high degree of post combustion of reactor gases and high heat transfer efficiency.

Two Stage Concept. In two stage concept, there are two distinct reactors-one for pre-reduction and another for smelting of hot prereduced materials. For linked operation of the two reactors, high pressure is advantageous. The two stage processes use either shaft reactor (as in case of Corex, AISI) or fluidised bed reactor (as in case of Hismelt, DIOS) for the pre-reduction purpose. The choice of pre-reduction reactor imposes certain quality requirements on iron bearing materials. In case of shaft furnace use of sized materials as well as their low temperature degradation behaviour is important. The fluid bed reactors can treat iron ore fines directly without agglomeration but the sticking tendency of iron ores could creat operational problems. Followings two variants have been taken up for development:

Variant-I. The processes in this category like Corex are based upon high degree of pre-reduction (PRD) and very low degree of post combustion (PCD). Of course, Corex has an unique feature in that gasification of coal takes place in the upper portion of the reactor. With hardly any post combustion in the smelter reactor, the energy requirements for different metallurgical reactions have to be met by partial combustion of coal. This puts a limitation on the quality of coals in terms of F.C. and VM content that can be utilised in this process.

The techno-economic implications are:

1. Capital cost is relatively high in view of high pressure operation and treatment of hot gases for use in the pre-reduction furnace.
2. Oxygen requirement in this variant is very high.
3. Large volume of high CV surplus gas is available and the viability of the process depends largely upon the extent of credit possible for this byproduct.
4. Only selected coals can be used.

Variant-II. The processes under this category are based on low PRD and moderate to high PCD. Most of process concepts being developed fall under this category e.g. Hismelt, DIOS, AISI. This process concept enables use of high V.M. coals in view of high degree of post combustion.

The techno-economic implications are:

1. The capital cost is relatively high as compared to the single stage concept.
2. The capital cost will be lower than that for Variant-I as the oxygen requirement will be substantially lower.
3. The surplus gas availability will more or less balance with the fuel requirements for other units of modern integrated steel plant.
4. The quality requirements of coal are not stringent.

Three Stage Concept. This involves an additional step of gas reforming between the smelter reactor and pre-reduction reactor. Japanese have reported interesting results with injection of fine coal in hot reactor gases enriching the reducing potential of the gas by reformation thereby utilising the surplus sensible heat of the incoming hot gases. No results on integrated three stage operations are available and it is difficult to comment on the operational problems that may arise.

Heat & Mass Transfer Enhancement Mechanism. For the high post combustion based processes it is important that the energy released is transfered to the molten bath rather than unduly increasing the temperature of the outgoing reactor gases. Moreover, the requirements of process conditions in terms of oxygen potential are different for reduction of iron oxides and post-combustion. These process requirements are to be achieved simultaneously in the same reactor. For this, two different approaches have been adopted in development of different processes. In one approach the post combustion and reduction takes place in foaming slag and a quiescent layer of slag separates the foaming slag and molten metal. Thus required oxygen potential gradient in the reactor is ensured. For enhancing the heat transfer, bottom stirring with inert gas has been found to be beneficial while achieving high degree of post combustion [7]. While Japanese have reported to have ensured quiescent slag layer through proper design and operation of the top oxygen lance, the Russians have used the location of the bottom row of side oxygen tuyeres to achieve the similar effect.

The other approach which has been adopted in development of Hismelt Process, is to carry out post combustion and heat transfer processes in the gaseous phase above intensely stirred molten bath reactor [8]. In this approach, powdered coal is injected through bottom tuyeres whereas the post combustion takes place with hot air injected from top of the bath. In this case the metal and slag droplets ejected from the bath act as important medium for heat transfer.

Analysis of SR Process Concepts for India

A process model developed by R & D Centre, SAIL [9], has been used to analyse smelting reduction process using Indian raw materials. As the smelting reduction involves a number of endothermic reaction steps, it is important that the heat balance of smelter reactor is met under all conditions of operation.

Heat balance calculations for the following five cases indicate that for typical Indian coal (Ash 24% and VM 28.5%), there is a net heat deficit in the smelter reactor with stoichiometric coal as given below:

	Net heat deficit (Gcal/t HM)
a) Smelting of hot partially reduced ore (Wustite) with no post combustion	1.545
b) Smelting of hot fully reduced ore i.e. DRI of 90% metallization with no post combustion	0.477
c) Smelting of hot partially reduced ore with 70% post combustion	0.250
d) Smelting DRI (90% DOM) with 70% post combustion (Not coupled operation)	0.363
e) Smelting of iron ore with 70%post combustion	0.442

These cases possibly represent the boundaries within which a real two/three stage process is likely to operate. In order to make the process feasible, the heat deficit must be met by supplying additional coal and oxygen in the smelter reactor and post combustion of the gases emanating from the bath.

Net heat available from the coal at various levels of post combustion are given below:

% PCD	Net heat (Gcal/t coal)
0	-0.209
30	0.953
50	1.728
70	2.503

It it thus clear that with Indian coals having high ash and VM content, it would be preferable to aim for as high PCD as possible in order to keep the coal and oxygen consumption within acceptable limits. Fig. 1 shows the effect of post combustion on coal, oxygen and lime consumptions required by the process. A comparison of the specific requirements of raw materials for single stage and two stage process concepts are shown in Table-3.

Table-3 Comparison between single stage & two stage process

Raw materials:

Iron ore		Coal		Lime	
Fe_2O_3	95.84%	Moisture	4.80%	CaO	73.45%
SiO_2	1.96%	VM	28.60%	MgO	7.07%
Al_2O_3	2.10%	Ash	23.80%	SiO_2	9.33%
		FC	42.80%	Fe_2O_3	3.35%
				Al_2O_3	3.90%

Sp. Consumption and generation:

	Single stage process (PCD-70%, HTE-90%)	Two stage process (PCD-50%, HTE-85%) with purge N_2
Coal (kg/t HM)	885	915
Lime (kg/t HM)	228	235
Oxygen (Nm^3/t HM)	481	493
Slag volume (kg/t HM)	466	478
Gas volume (Nm^3/t HM)	1267	1465
Gas Temp (^oC)	1590	1729
Gas composition (%)		
CO	20.00	37.60
H_2	9.69	6.80
CO_2	46.68	22.40
H_2O	22.63	22.00
N_2	0.99	11.20
Net fuel value of dry reactor exit gas(Gcal/t HM)	1.08	1.92
Energy requirement (G Cal/t HM)	5.27	5.44

It may be seen from the table that the energy requirement of the single stage process at 70% PCD is comparable with that for the two stage process at about 50% PCD levels. This shows that in order to make single stage process viable, a higher PCD of atleast 70% with heat transfer efficiency of 90% would be required.

SR Processes with high PCD are much more amenable to treat inferior grades of coal with high percentage of volatiles and ash as generally available in India. Present indications are that, PCD in the range of 50-55% have been achieved by the Japanese investigators and by Hismelt and research work is concentrated towards achieving even higher values. FLPR Process claims to have achieved 70% PCD level in single stage operation.

Considering the above, process concepts involving high degree of post combustion either in single or two stage would be more appropriate for adoption in India.

In India R&D activities in the smelting reduction area has been taken up in right earnest.

R&D Centre, SAIL has concieved a smelting reduction process concept suitable for raw materials available in India. A pilot facility of 25 tpd hot metal capacity is planned to be set up to test single and two-stage process concept based on high degree of post combustion.

Development of a smelting reduction process is also being pursued by a private sector company in the country. The process is a two-stage one. However, a novel idea of pre-reduction in multistage cyclone has been considered for integration with a suitable smelter-gassifier. A pilot facility of 25 tpd hot metal capacity is likely to be installed in due course.

In additon, efforts are being made by yet another private sector company to adopt and adjust to perfection a single stage smelting reduction process. The installation will produce about 1,000 tonnes of hot metal per day once the process is set up, fully developed and perfected.

Techno-Economic Considerations

As majority of the smelting reduction processes are still under development, adequate information particularly on capital cost is not available to work out detailed techno-economic analyses of various concepts. However, the Corex process has been examined more throughly under Indian conditions. An attempt has been made to bring out the implications of important cost factors on two predominant process concepts viz. (i) process with high degree of pre-reduction (PRD) and low degree of post combustion (PCD) e.g. Corex, and (ii) process with low PRD and high PCD.

Capital Cost. The capital cost of two stage processes are likely to be similar except that the

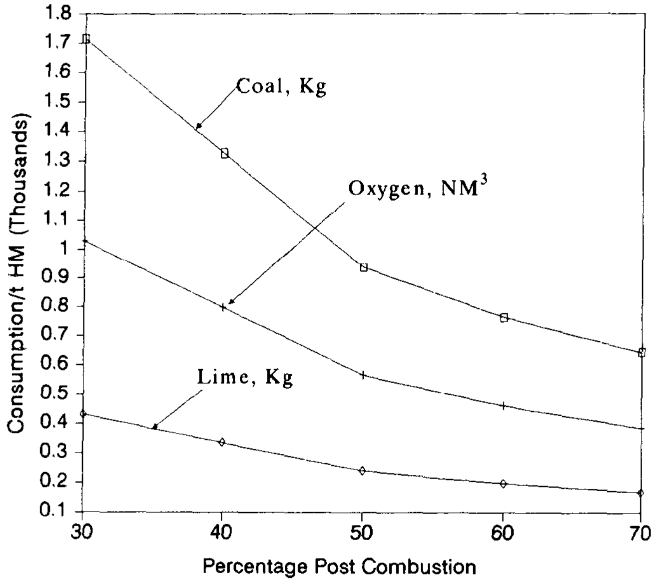

Fig. 1 Effect of post combustion

process with high PCD would require a smaller oxygen plant compared to that with low PCD. On the other hand, capital cost of a single stage process is likely to be cheaper mainly because of elimination of pre-reduction process facilities and relatively low pressure operation.

Operating Cost. In processes with low PCD, there is an inherent limitation in use of high ash, high VM coals. Thus, with Indian coals, say for Corex process, it may be necessary to mix a low volatile component like coke breeze with normal coal to the tune of 25-30% i.e. around 300-350 kg/t H.M. This factor would increase the cost of coal input by Rs. 800-900/t H.M. (US $ 26-30). Alternatively, part of the coal could be devolatilised using sensible heat of the outgoing smelter gas instead of coke breeze in which case, the above cost differential would narrow down.

Power required for oxygen generation is another important cost factor. Oxygen requirement for low PCD process is expected to be higher by 150-200 Nm^3/t H.M. and this would increase the operating cost by Rs. 140-180/t HM (US $ 5-6)

Credit available for the surplus gas generated is the other important factor, particularly for low PCD process which generates larger amount of higher calorific value gas compared to high PCD process. Assigning proportional credit based on the heating value of the surplus gas, additional credit that can be given to the low PCD process is around Rs. 150/t H.M.(US $ 5)

Costs for other factors like labour,utilities, consumables, etc. are likely to be similar for both type of processes.

Considering the above, it appears that single or two stage processes with high PCD will have an edge over the low PCD processes like Corex for producing hot metal based entirely on non-coking coals available in India.

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Blast Furnace Iron Smelting Under Mexican Conditions

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ABSTRACT

An investigation was made of the iron producing section of this plant. The information was mainly taken from the drawing, various daily records and conversations and meetings made with blast furnace operating personnel.

Supplying the modern BOP with hot metal that is both qualitatively and quantitatively stable, is a major task assigned to the blast furnace. Also, it is a matter of paramount importance in its effort for cost reduction. In full realization of these matters of significance and as per direction from management, a recommendation has ben done. The problems in the current operation practices and the action necessary for improvement of such problems are also described. (*This plant has been closed after this report was written.)

RECOMMENDATION

Raw Materials

1. Install screens for all pellets and ores.
2. Crush and screen lump ores before it is dumped into the stock-house bin.
3. Stabilize the metallic burden mix for blast furnace and Fundidora Pellet Plant.
4. improve pellet plant maintenance activities and improve production of house made pellets
5. Clean the raw material yard and separate the ores and pellets piles.
6. Increase efficiency of existing pellet screens.
7. Improve quality of raw material.
8. Increase stability of coke to 58 to get better permeability.

Stockhouse

1. Install coke moisture monitor and control system - NEUTRON GAGE TYPE - and a "DATA LOGGING SYSTEM" to produce hard copy of charging weight and sequence (AN HP 1000 COMPUTER). A single system can serve No. 3 and No. 2 furnaces.
2. Check and adjust if necessary weighing accuracy more frequently.

Furnace

1. Install top gas analyzers (Perkins Elmer type) - one equipment for both the furnaces.
2. Install more thermocouples and check the furnace lining life by sketching temperature profile of furnace cross-section.
3. Measure the cooling water (discharge) temperature manually and compare data of No. 2 and No. 3.

Stove

1. Install a (blast furnace Gas BTU) gas calorie meter to measure blast furnace gas BTU to adjust natural gas volume.
2. Modify stove burners to ceramic burner during next stove relining.
3. Change all the mushroom type hot blast valves to Gate type during next furnace relining.
4. Increase furnace blower capacity to 2800 Nm^3/min and 2.4 kg/CM^2 pressure (at the furnace). Used blower can be purchased from U.S.A. with cheaper price.

Cooling System

1. Insert the cooling plates at shorter pitch during the next relining on No. 3 blast furnace.
2. Use Torpedo car cover to retard heat loss during transportation of hot metal to BOF.

Introduction

Fundidora Steel Works, Monterey S.A. operated two blast furnaces. The blast furnace's No. 2 operation was started in July 1943 and the commissioning of No. 3 blast furnace completes a series of expansion schemes carried out since this blast furnace went into production in 1968. The major modification was carried out in 1975. The major items of this modification are the installation of: (1) a second taphole and tilting runner (2) a Paulwurth Bell Less Top and (3) improved charging equipment.

Raw Materials

Unfortunately, no changes have been made in the raw material handling area. Also, no effort has been made to improve the quality of the raw materials. The major problem in this iron-making area is a large fluctuation in the chemical composition of the ore, and the varying range of particle size (1/4" to 3" with predominantly large lumps).

Raw Material Yard

But, before proceeding to a description of raw material quality, it is relevant to take a closer look at the equipment which supplies the raw materials to both the furnaces and the raw material yard.

At present, the raw materials for Fundidora Works come from near and far: coke from Hullera; iron ore and pellets from many parts of Mexico via rail. Only one portal crane (lifting load 12.5 ton) is presently being used to unload the coke in the yard. Ore is unloaded by a moving crane (bucket capacity 59 cft). Homemade pellets are transported by belt conveyor from Fundidora Pellets Plant to stockhouse bins.

Observations

a) The capacity of the raw material yard is too small to handle (1.3 x 10^6 million tons iron production) raw material for target production. At least one month's supply of raw material must be stocked in the yard.

b) The unloading of all wagons is inefficient and too slow. (The dummarage cost for total wagons per year exceeds US one million dollars).

c) The screening facility for homemade pellets is poor and very inefficient (screening efficiency = 75%). Only 40% of the homemade pellets are being screened.

d) The quantity of raw materials stored in the yard is not enough.

Raw Material Quality

A) Iron Ore

The lump ore consumption rate in the No. 2 and No. 3 blast furnaces is 20% (with the same amount of "Durango" and Hercules being used).

The ore size varies between 1/4" and 3". The crushed and screened ore size should be between +1/4" and 1 1/4". The average ore size should be 0.65" and 80% of the ore should be between minus 1" plus 3/8".

The allocation of iron ore, pellets and coke is carried out at Sidermex's Raw Material Department. The allocation, both quantitatively and qualitatively should be done in a way that effectively minimizes the total production cost of pig iron and that maintains the target production level.

The chemical composition of iron ore varies greatly.

	Fe %	SiO_2 %	Al_2O_3 %	CaO %	MgO %
Durango	62.3	5.67	0.39	4.06	0.32
	59.9	3.63	0.11	2.58	0.14
Hercules	60.59	7.13	0.34	5.87	0.25
	56.57	3.57	0.08	3.93	0.13

This variation in chemical composition of iron ore creates temperature imbalance in the furnace. Care should be taken when adding extra coke to operate the furnace with high thermal load.

B) Pellets

In Fundidora, 80% of the burden to the blast furnaces are pellets. Only 70% of the total pellets being currently used in Fundidora are from the Fundidora Pellet Plant (homemade). The rest of the pellets are Pellets Pena Colorada and Pellet LaPerla.

Insufficient supply of pellets sometimes slows down the blast furnaces. Frequent burden changes occurring during a eight hour period are a very common happening in Fundidora because of the shortage of raw materials. This causes severe problems in blast furnace operation and performance.

Unfortunately the Fundidora Pellet Plant produces only at 50% of capacity and sometimes the pellet plant closes because of a shortage of concentrate.

Pellet Stability

The stability goals of today are:

1. Pellet - +90 ASTM (+1/4") Tumbler
2. Sinter - +82 Shatter Japanese

The pellet quality is primarily based on the pellet stability.

Pellet Size

Pellet size distribution affects resistance to gas flow. A small variation in size maximizes the void fraction and results in a lower resistance to gas flow. The preferred size range should be 3/8" to 1/2" (90-95%). This is very important to run the pellet screening plant efficiently and to eliminate -1/4" fines fraction to less than one percentage (sample to be taken at the stockhouse bin).

Recommendation

1. The chemical composition of pellet (for house pellets) concentrate must be investigated and controlled.
2. The fluctuation of the chemical composition of various pellets should be controlled by separating the pellets according to their composition. Normally, the chemical analysis and pellet size are relatively uniform depending on the sources of pellet concentrate.
3. The present raw material yard must be cleaned before any action is taken to improve the screening facility.

C) Coke

Frequent changes in coke quality at Fundidora may be partly due to the practice of forming the production plan on a short term basis at the coal mines. It is, therefore, desirable that the coke brand be stabilized for a slightly longer time period. Daily variation in the ash content of coke used at Fundidora is very common. Wide changes of ash content and stability at Fundidora Blast Furnace can be clearly seen from the chart. One percentage fluctuation of ash content in coke will change the coke rate about 10-20 lb/ton H.M. or Si content 0.15 to 0.30 in hot metal.

Coke Stability

The average coke stability at Fundidora is 53. Here, it may be mentioned that the most important factor in establishing coke quality is the selection of good coal with less sulphur. But unfortunately economics and availability of good coal play a major role in coke stability.

SIDERMEX MUST ATTEMPT TO IMPROVE COKE STABILITY. The aim should be to reach 58 stability. To improve coke stability the following points should be considered:

1. Increase the coking time.
2. Improve the coal blending practice.
3. Use automatic bulk density control by adding oil at the coal crusher.
4. Improve coal pulverization, that is, -1/8", 85%.

Coke Ash Content

Coke ash content (21%) can be reduced by 3-4% by efficient operation at the coal washing facilities. Each 1% reduction in coke ash reduces 30 lb. of dry coke/ton H.M. The higher ash content in coke requires additional limestone to flux the coke ash which results in higher slag volume. This also reduces blast furnace production.

Coke Sulphur

In Fundidora, coke sulphur is very high. I strongly recommend a full fledged DESULPHURIZATION PLANT to take care of many problems.

Operation

The No. 3 furnace can be expected to produce anywhere from 5 to 6.5 t/100 ft^3 of working volume per day with major changes in the burden mix.

1. 100% pellets (screened).
2. 80% pellets +20 ore (crushed and screened).
3. Pellets (screened), ore (crushed and screened) and sinter (screened).

The production rate for any of the burdens will vary depending on the following criteria:

1. The sizing and screening of the burden material.
2. The physical characteristics and stability of the burden.
3. The reducibility of the burden.
4. The presence of prefluxed pellets or sinter.
5. The percentage of rouge elements in the burden (K_2O, NA_2O, Ti, Zn) and chemical analysis.
6. The stability of the coke.

The data available and the information given by the operating personnel indicates that two major factors must be solved first at Fundidora Works in order to increase furnace production.

To obtain the highest driving rate in these furnaces a permeable, uniform burden must be provided. This can be achieved by proper burden preparation in which ore <u>must</u> be crushed and screened to narrow size spectrum. This operation must be accomplished preferably at the mine sites because of economic reasons. The major reason is that there is presently no sinter plant at Fundidora Works. All the pellets charged into the furnace must be thoroughly screened to a narrow size spectrum. The elimination of fines avoids segregation and channels gases in the stack. The uniform size burden will increase furnace permeability.

RAW MATERIAL PROPORTIONING

Raw Material	Quality	Pig Iron	Slag	Al_2O_3 To Slag		MgO to Slag		SiO_2 To Slag		CaO To Slag		P		S	Si To Hot Metals
	Kg/t		Kg/t	%	Kg/t	%	Kg/t	%	Kg/t	%	Kg/t	%	Kg/t		
Coke	613		116.38	23.20	29.86	0.95	1.22	63.67	81.96	2.60	3.34	0.0			
Pellets Fondidora	1,083		100.17	1.12	12.12	0.35	3.79	6.49	70.28	1.18	12.77	.112	1.21		
"															
"															
Durango Ore	495		58.72	0.79	3.91	0.31	1.53	5.42	26.82	4.29	21.23	1,057	5.23		
Lime Stone	64.2		35.27	0.27	.173	0.45	0.28	0.79	.50	53.46	34.32	0.0	0.0		
Dolomite	257.0		139	0.71	1.82	16.5	42.4	1.36	3.49	35.54	91.33	0.0	0.0		
TOTAL	2,512.2	1,000	450	-	47.8	-	49.2	-	183.05	-	163	-	6.33		

PROPERTIES OF IRON ORE, PELLETS AND MISC. MATERIALS

	Fe	SiO_2	Al_2O_3	CaO	MgO	S	Na_2O	K_2O	P	TiO_2	Mn	Size		
Pellets Fundidora	60.73	6.49	1.12	1.18	0.35	0.02	0.17	0.29	0.11	0.64	0.07	-5/8 -+1/4 - 90%	1/4+5/8 2.0%	5.0%
Pellets P. Colorado	63.21	2.30	.70	2.78	0.23	.050	0.13	0.06	0.32	0.41	.10	-5/8 -+1/4 - 90%	1/4+5/8 2.0%	5.0%
Ore Durango	57.56	5.42	0.79	4.29	0.31	.061	0.13	0.18	1.057	0.63	0.06	-21/2 + 3/8 92%	-3/8 + 21/2 4.0	5.0
Ore Hercules														
Ore Manzanillo	66.20	1.62	0.56	0.23	.10	.010	0.13	0.01	.124	0.15	0.04	-21/2 + 3/8 92%	-3/8 + 21/2 4.0	5.0
Lime Stone	0.65	0.79	0.27	53.46	0.45	0	0.08	0.9	0	0	0	"	"	"
Dolomite	0.57	1.36	0.71	35.54	16.12	0	.10	.10	0	0	0	"	"	"
Quartz	0.28	97.69	0.29	1.02	0.16	-	-	-	-	-	-	-		
Mn Slag	2.00	34.6	5.47	19.10	1.00	.920	-	-	-	-	24.51	"	"	"
Dunite	4.70	38.06	0.98	1.2	39.80	-	-	-	-	-	-	"	"	"

Blast Furnace #2 Blast Furnace #3

Chemical Composition Hot Metal	AIM	Actual	AIM	Actual
C	4.00 - 4.10	3.83	4.00 - 4.10	4.24
Si	1.10 - 1.20	1.21	1.10 - 1.20	1.15
S	0.060 Max	0.59	0.060 Max	0.070
P	0.450 Max	0.411	0.450 Max	0.210
M	0.50 - 0.60	0.42	0.52 - 0.60	0.35

PROPERTIES OF COKE

	Mean $\bar{X}$	Min.	Max.	σ
Fe				
Ash	20.28	19.24	21.96	1.03
Fixed Carbon	78.85	77.16	79.78	1.02
Moisture	3.8	3.0	4.5	0.35
Stability	54.15	53.55	54.65	0.40
Hardness	64.28	63.35	65.10	0.58
Porosity	49.12	48.25	49.8	0.20

AMOUNTS OF PELLETS TO BE USED

	%	Kg/Ton
#2 FCE Pellets	70	1,050
" Ore	30	420
#3 FCE Pellets	69	1,081
" Ore	21	495

ANALYSIS OF COKE ASH

	Mean $\bar{X}$	Min.	Max.	σ
Fe_2O_3	7.5	6.58	8.01	0.51
SiO_2	63.67	63.04	64.8	0.59
CaO	2.6	2.4	3.0	0.23
Al_2O_3	23.21	22.64	23.7	0.32
MgO	0.95	0.84	1.06	0.089
P	0			
K_2O	0.54			
Na_2O	0.38			
TiO_2	0.965			
Mn	0			

Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

Standardization and Technological Development

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Abstract

Unprecedented scientific and technological developments have taken place in the twentieth century. All these developments would have no validity unless they are applied in practice to achieve social and economic benefits to the nations around the world. The very methodology of standardization provides the necessary infrasturcture for transforming technological and scientific developments for practical application. The paper elaborates this theme with examples.

IN RECENT YEARS STANDARDIZATION has made rapid progress like many other fields of learning. Life now would be impossible without standardization as it pervades all spheres of human activity and it is integrated with the day today living.

Standardization, though as an unconscious activity, has existed from prehistoric times. Yet,the earliest deliberate effort on an organized scale can be traced back only to the early part of the twentieth century. The first world war provided a great deal of incentive for its development but it was only after the second world war that standardization received world wide attention and application. The subsequent industrial revolution and the birth of new nations gaining independence from colonization resulted in standardization gaining its present status as the most important tool for national economy.

Basic Principles and Aims of Standardization

The basic principles of Standardization are that standards should:

- cater to the basic need
- assist national development
- assist technological development
- assist optimum utilization of indigenous raw materials, machinery and man-power
- assist commerce and trade
- assist transfer of technology
- assist import substitution
- safeguard health and safety

These are achieved by:

- individual efforts
- collective group efforts
- national efforts
- regional efforts, and
- international efforts

The aims of Standardization are to:

- achieve maximum overall economy in terms of cost, human effort and conservation of essential raw materials
- ensure maximum convenience in use
- adopt best possible solutions to recurring problems
- define requisite levels of quality and procedures for evaluating the same
- safeguard health and safety

Role of Standardization in Technological Development

Science is the knowledge acquired by study, acquaintance with or mastery of any department of learning. Technology is the application of this scientific knowledge to practical purposes in any particular field.

It would not be difficult to understand that Standardization is an essential raw material to enhance the pace of development of science. It is also the basic raw material to assist transformation of science for practical application which is really technological development.

There could be great discoveries, and outstanding scientific developments in certain fields. These have limited value unless such developments are tested and proven for use and written into authoritative documents so that they could be applied in practice to achieve social and economic benefits.

The very methodology of Standardization provides the necessary infrastructure for incorporating the technology appropriate for a country depending on its state of development. Further, if the correct procedures are adopted, national standards could be based on international standards thus incorporating the latest technology on the subject currently available in the world suitably adapted to the country's needs. Thus, Standardization provides one of the most important means for transfer of technology.

Standardization is a record of the state of technology. Standardization must remain firmly bound to economic activity having its roots in company standards, in technological development, in technical supervision and in science.

Standards underline the whole process of assessing raw materials and getting them into usable condition. Purity levels are determined and other physical and chemical properties are characterized at many stages using standardized test methods and grading systems to specify quality and performance.

Modern industrial production, from watchmaking to shipbuilding, depends heavily on an intricate flow of standard interchangeable parts. With the expansion of the world's industrial production networks beyond national boundaries, international standardization for a broad range of manufacturing industries has become a clear necessity.

It is no longer unusual, thanks to standardization, for products to be assembled in one country from components manufactured in several other countries using manufacturing equipment made in yet other countries. A typical European automobile may have parts coming from as many as 400 different suppliers scattered over more than 30 countries.

The chain of food production and distribution represents the world's oldest example of division of labor: cultivation, harvest, storage, processing, and distribution. Each function is dependent on a different skill and technology and if the interrelationships between each function are not clearly understood, the chain is easily strained or broken.

International standards in the fields of agricultural machinery and food products help to clarify the complex technical and commercial requirements of world food security. ISO food and agriculture standards include international agreements on sampling and testing, grading, packaging and transport.

Equally important to the goal of world food and health security are the wide range of international standards needed for medical equipment, radiography, surgical implants, laboratory apparatus, and aids for the handicapped.

World food and health security are, of course, dependent on the ultimate quality of our air, soil, and water resources. International standards published by ISO in the environmental protection field include internationally agreed methods for identifying and quantifying environmental hazards such as toxic chemicals and radioactive wastes.

There will never be an international standard outlining how to create a brilliant idea, but to share that idea common communication standards are required.

Communication standards begin with standard alphabets and the basic symbols of mathematics, music and art, and continue with the complex array of specialized conventions which are required for information transfer. International graphic symbol standards are widely used for traffic signs and public assistance facilities. Similarly, standard forms and codes are important for efficient international communication in commercial administration and banking.

Recent rapid advances in communication technology itself present unforeseen challenges and opportunities for orderly development. In this respect, the work of ISO in developing standards for computers and information processing is a remarkable achievement; both with respect to what has already been accomplished, and in laying the basic groundwork for future international collaboration.

Today, there are international standards approved by ISO for data processing vocabularies; for computer terminal keyboards, for machine readable coded character sets; for computer programming languages; for interchangeable memory units; and for magnetically coded information or credit cards.

Future international standards already in various stages of development deal with local area networks, electronic imagery, industrial robots, and interface specifications for a broad range of computer and telecommunication systems and components.

standardization has become an important tool for reducing the risk of injury in the home and at work, and in travel and leisure activity.

International standards relating to workplace safety include provisions to protect operators of industrial machinery, procedures for the safe handling of hazardous materials, specifications for the design and performance of protective clothing, and requirements for colors and symbols for safety signs and warnings.

Minimizing the risk of human injury in automobiles and aircraft requires the use of several hundred standards covering safety glass, seat belts, lighting and braking systems, signalling devices, and exhaust systems. The development of international agreements on safety standards and regulations has been especially important for international trade in automotive products.

In the home, standards provide for the safe installation and operation of household equipment, for the reliable performance or fire protection and alarm systems, for the appropriate use of glass and other building materials, and for the general safety of children's toys. Internationally agreed standards can also significantly reduce the risk of injury in sports and recreational activity, for example, in specifying safety requirements for gymnastic and skiing equipment.

How much vibration is too much for a sensitive machine or for the human being? Which thermal insulation materials can be used in housing construction, or for liquefied gas containers? What is a valid test of flammability for textiles? How do we compare the performance features of paint coatings? What are the energy characteristics of solar radiation at ground level?

Finding agreement on the validity and an appropriate application of scientific principles in answering questions such as these constitutes an important aspect of modern standardization.

The science of acoustics, for example, helps provide the technical basis for performance standards used in sound recording and reproduction; for design standards used in buildings; and for standard measurement techniques used to determine noise levels of aircraft.

Similarly, advances in X-ray, microwave, and ultrasonic science have led to important developments in standard non-destructive testing techniques for such diverse applications as micro-circuit connectors and pipeline welds.

Standardization thus provides an important mechanism for bringing the benefits of scientific research and technical know-how into widespread practical application. In this respect, international standardization work has become a particularly fruitful form of international technical collaboration.

Conclusion

It would suffice now to summarize the benefits of standardization to the different sectors concerned - Producer, Trader, Consumer and Technologist.

To The Producer:

- provide short cuts to design procedures by furnishing ready-made and generally acceptable solutions to recurring problems.
- make possible longer production runs with fewer changes in production line and reduce tooling and set-up time
- streamline inspection, testing and quality control procedures to reduce rejections
- easy procurement of raw materials, parts and components from ready stocks
- reduce stocks and inventory
- simplify servicing and maintenance
- facilitate training of staff and operators
- reduce overheads
- facilitate marketing and avoiding disputes
- increase productivity

To The Trader:

- easy procurement
- streamline inspection and testing
- reduce investment in inventory
- simplify servicing
- low overheads
- facilitate marketing and avoiding disputes
- increased sales and profitability

To The Consumer:

- easy inspection and testing
- easy procurement
- reduced investment in inventory
- simplification in servicing
- reduced prices
- reduction of disputes

To the Technologist

- authoritative basis for judgment
- accurate equipment and tools
- acceptable solutions for recurring problems
- starting point for research and development

References

ISO Standards and Publications

Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

Standardization Activity in Industry in Relation to Steel Products

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ABSTRACT

Steel in its various forms is one of the major consumed materials in most industries and therefore the provision of quality steel products at economical prices and scheduled delivery is essential for the achievement of overall economy in industry. Among various means to achieve this, the standardization of steel products themselves and standardization in the area of their utilization has become an important tool for industrial managements to achieve this objective. It is normally assumed that standardization in this area mostly involves the development of national standards and their implementation by users. Actually to ensure overall economy in the area of steel production and utilization, a good deal of standardization effort has to be done at the user end. The engineering industry consumes a major part of the steel products consumed by the industry. The article exaines the overall picture of standardization activities in both engineering industry and steel plants, to achieve economical and quality production.

STANDARDIZATION, QUALITY CONTROL AND RESEARCH AND DEVELOPMENT are basic to most manufacturing processes and are essential for modern industrial production and for development and growth of industry in a controlled and logical way. They are also essential for raising productivity, achieving overall economy, improving quality and marketability of products and services. Standards at national level have been issued by national standards bodies for nearly a century now but it is only for the last few decades that it is being more and more recognized that economic and other benefits of such standards are not adequate and lasting unless supplemented by concerted efforts at company level in involvement in development of the national standards and their implementation and in carrying out standardization and rationalization activities in various other areas. While national standardization aims to achieve national economy, this can only happen with full application of the activity at industrial level.

In times of recession and with trade deficits hitting a country's economy the need is normally for,
(a) improvement of running of plants through use of modern management techniques
(b) increase in export of quality goods by being competitive
(c) more concentration on import substitution
(d) efficient utilization of production potential
(e) rational utilization of matertials and reduction of wastage
(f) increase in efficient research and development and innovation. The introduction of new products and materials as a result of R&D has to be followed by efforts to manufacture the item within the country.
Among various techniques and actions to be taken, the application of standardization can play an important role and make a major contribution in achieving these objectives.

COMPANY (OR INPLANT) STANDARDIZATION

Progressive managements have recognized the importance of using standardization activity to help in achieving optimum utilization of its resources of Men, Machines, Materials and Money to ensure higher productivity, reduced costs, improved quality and smoother operations, all without much investment. The activity is carried out informally in most industrial enterprises, often without recognizing it as such, but the benefits are enhanced and more lasting when the activity is carried out in an organized way and formally as a distinct activity - normally called company or inplant standardization.

Aims of Company Standardization.

Company standardization broadly aims at:
- Achieve maximum overall economy in terms of cost and human effort
- conserve essential raw materials
- ensure maximum convenience in use
- adopt best possible solutions to recurring problems
- define requisite levels of quality and lay down procedures for evaluating the same

- create order in companies' activities through coordination and documentation
- povide means of import substitution.

Areas of company standardization

Standarization can be beneficially carried out in practically most areas of a company's activities like:
- design and development
- production
- materials management
- quality assurance
- maintenance
- packing & transportation, and
- adminstration and personnel

Types of Company Standards

Company standards can be broadly classified as technical and adminstrative.

The technical standards normally are those that:
- document technical policy matters
- provide information on
  - basic technical subjects
  - properties /application of materials, parts, etc
- provide guidance for selection of items for use in a company with a view to control variety proliferation
- prevent dependence on brands
- specify policies of the company in relation to total quality control
- specify methods of testing, inspection,sampling, in-process and final products
- specify requirements for purchase of equipments, materials, and other items
- specify processes for manufacture, finishing, preserving, packaging, despatch, etc.
- classify and codify items purchased, stocked or manufactured (for identification and controls)
- elaborate procedures for evaluating benefits of activities in the company including company standardization itself.

The adminstrative standards are those that communicate company's policies in adminstration and personnel matters, concern work measurement, specify working conditions, safety and security, assist in training personnel and finally those that guide financial matters.

STANDARDIZATION IN STEEL PLANTS

In a steel plant organized and formalized standardization work can be done in all technical and adminstrative areas mentioned earlier; however the major areas would be:

Product standards
Raw materials standards
Materials Management standards
Production standards
Quality Control standards
Maintenance standards
Other areas that will lead to economical and streamlined operations.

Product Standards:

The product standards would be useful by covering various aspects of the plant's products with a view to:
- specify exact requirements that will be met by the products right from their designations, properties, chemical composition to specifying methods and conditions of testing
- indicate the rationalized specifications, forms and sizes of the product mix that can be considered for normal manufacture as standard products
- alignment of company's products with industry, national and international standards with a view to meet more customers' needs, encourage export, and assist marketability
- give guidance to customers to assist them in selecting correct materials and ensure their correct use.

Raw Materials Standards

Some of the important coverage by such standards include
- specification of raw materials required by the plant. In addition to the obvious things covered in such purchase specifications they also ensure that requirements are rationalized so that the materials are purchaseable from various competitive sources
- variety reduction in raw materials required in the plant not only for direct production but also for production assisting items.
- specifying attainable and evaluatable properties.

Materials Management Standards

Standards normally issued in this area assist in:
- materials planning
- inventory control
- storage of materials to facilitate retrieval, preservation, easier material handling, and prevent mix-ups.
- codification of materials for facilitating various computerized controls

Production Standards

In this area many types of standards are required. One of the most important ones are the process specifications covering the hundreds of processes used in the plant like (raw material charges w.r.t. type, quantities and order of charging; de-oxidation practices in furnaces and ladles, etc.). These standards assist in maintaining the quality of the company's products as well as reducing quality losses; further they form the basis for research for future improved processes.

Quality Control Standards

Standardization is the the preliminary requirement for a total quality control in design control, materials control, in-process control, finished products control and after-sales service controls. Documented company standards serve as a basis for quality control once the procedures are finalised; also the documentation serves as a basis on which improvements can be investigated and made wherever required.

Actually in addition to Quality Policy statemements, policy standards are required that would indicate what categories of items should be inspscted or tested, by whom, and when and lay criteria for reduced or no inspection based on confidence levels of the vendors and suppliers.

Some other standards that would also be required are:
- standards on measuring instruments and equipments
- standards on procedures for inspection and testing. on expression of results, accuracies of measurement, etc.
- standards on sampling plans and procedures
- standards on acceptance criteria
- standards on uniform understanding of terms and requirements related to QA and QC within the ccompany and with suppliers and customers
- standards on periodic checks and calibration of equipment
- standard conditions/ envoirnment for inspection and testing

Maintenance Standards

In this area preventive maintenance standards as well as standards on maintenace procedures and practices (like lubrication systems, painting specifications, times required for roll changing and other repetetive jobs), on major repairs and over hauls and on maintenance materials are well known.

Another important aspect in maintenance that needs considerable attention, especially in developing countries, is related to that of equipment, maintenance spares and maintenance materials. In the author's own knowledge some steel plants in India and Brazil have applied standardization and rationalization with achievement of considerable benefits. In these plants installed equipment had come from various companies from various countries leading to many problems in maintenance of the equipment and the cost of maintenance. These problems were tackled through rationalization and their adverse effects reduced considerably. An example would illustrate this aspect.

In one Indian steel plant, totally enclosed horizontal foot mounted squirrel cage induction motors installed on equipments were investigated and it was found that the 3787 motors consisted of 288 different horse powers in 111 different brands -mostly imported as only 17 were of indigenous make. Application of standardization and rationalization techniques resulted in a recommendation of future use of 41 motors instead of 288, a reduction of 85%. The steel plant decided to stock some newly rationalized motors and gradually use these whenever a replacement was necessary. Over few years the benefits of this standardization work can be imagined in terms of:
- reduction in downtime
- reduction in inventory of motors and their spares
- better knowledge and experience on fewer motors
- rationalization to fewer motors helped in price reduction
- import substitution helped conserve foreign exchange
- better service from local suppliers
- many other intangible beneficial results

See Fig 1 for overall statistics of this exercise. Steel plants in India and Brazil have successfully conducted many similar programs of standardization and rationalization leading to recommendations that have yielded variety reduction of as much as 60% in many cases. In India, these results had encouraged the steel plants, both private and state owned, to get together along with the national standards body there and formulate *Inter-Plant Steel Standards* that mostly attempted attempted to rationalize their requirements in commonly used items. This may be somewhat close to "Association Standards" available in some countries except that the former were more practical due to the standards being prepared after actual investigation of items required or in stock.

It is appropriate here to sum up the benefits of organised rationlization and variety reduction as being:
- Easy planning in procurement of equipment, spares and maintenance of materials
- Reduced inventory in terms of number and value and inventory carrying costs
- Lower purchase prices and cost
- Lower obsolescence and lower slow- moving inventory
- Improved quality of purchased items due to fewer items to concentrate on
- Better availability of materials and import substitution
- Reduced downtime and easier maintenance
- Possibility of better expertize in maintenance of fewer equipments.

Standardization in Engineering Industry

In the engineering industry the situation in materials is slightly more complex in terms of design of products, complex tooling and use of many raw materials differing only slightly from each other.

In the area of design and development of products, the question is not only of manufactured quality but also of design quality, performance, reliabilty, after-sales service, etc. In this area, the use of standard parts instead of specials, of using existing parts instead of designing new ones require techniques of value engineering, drawing control, parts design retrieval systems and various other means. The need for various standardization techniques and tools in engineering industry becomes very important and varied.

The situation in raw materials (some of them are the finished product of steel plants) is also more complex due to requirement that these materials (such as say steel bars) will be converted into components that will be used with other standard or specially designed bought-out parts to make into sub-assemblies and assemblies and then finished with use of other materials (say like paints). The production materials too are required in many specifications, in various forms/shapes, in various sizes and of different tolerances and surface finishes ; sometimes the same basic specification is required in more than one condition of say heat treatment and the same size may be needed in more than one dimensional tolerance and surface finish (say ground or peeled).

The application of standardization engineering enterprises, like an automotive plant in the area of raw materials, especially steel, is examined in subsequent part of this article.

Standardization of Steels Used in Engineering Plants.

The following aspects of steel products need to be standardized to ensure economy and quality of purchased materials and to to ensure quality and economical production and components and of the finished products of the engineering plant.

- specifications of materials
- rationalization of materials
- inspection and testing
- procurement specifications
- storage and handling
- preservation of materials
- utilization and working of materials
- codification
- import substitution

Specifications of Materials

Some important aspects are,

- requirements/ properties/ composition/ avoidance of brand names
- dimensions/tolerances
- compliance to international/national/industry standards
- inspection, testing, sampling
- packing and marking

Rationalization of Materials

(Variety reduction and control)

Benefits of such standardization work have been mentioned briefly earlier in the article and were also discussed in more detail in an article by the author (see ref. at the end). An example of this work is given below.

In an Indian automotive plant a full fledged standardization department regularly looks after various aspects of standardization including preparation of standards, variety reduction, drawing control, purchase requisition control, metrication, etc. Due to earlier pre-standardization purchases and due to ordering non-standard materials when standard materials were not readily available many materials in specifications and sizes other than those standardized by the company had got ordered that led to a stock of a large variety of materials. Concerted rationalization programs were undertaken to examine some 2000 components -forgings or made from bars, tubes, sheets/ plates. The idea was to study what materials should be rationalized for future to achieve economy, easier purchase, fewer stocked items, reduced wastage, reduced handling, fewer possibility of using wrong materials due to confusion in storage and so on. The initial results of the program achieved the following variety reduction.

Table 1

Types of Steels	Variety before rationalization	Variety after
Hot rolled bars and billets	123	69
Bright bars	128	60
Tubes	87	46
Sheets & Plates	349	101

While recurring monetory savings ran into over few millions, the other results were also extremely beneficial like:

- Some materials were rationalized that would enable energy consuming operations like hardening and tempering, stress relieving, normalizing to be eliminated or reduced.
- Design requirements were ammended to change steel forgings to SG iron to reduce cost (without reducing quality)
- Documented standards reflecting these changes ensured implementation right from the design stage.

As a general information It may bementioned here that varieties in materials normally multiply due to:

- Individual approach to design
- use of brand names or ambiguous specs.
- existence of different systems of measurement due to which materials in both systems get used
- foreign collaborations

In conducting rationlization programs, normally means such as design unification, international preferred numbers series, techniques like ABC analysis, materials codification and other controls at design stage are used as a part of the standardization programs.

Inspection and Testing Standards.

Normally these aspects are adequately covered in national standards and the task of the company standards is to specify the plant's policy on how much inspection and testing it wants to do to ensure that correct material consignments adhering to the company's requirements have been received. The amount of inspection and testing of course has to relate to what QA techniques have been used to assess suppliers and their confidence level with the company, and also whatconfidence the company has in quality of materials certified by others.

Procurement Specifications

These are a company's supplementary requirements to technical specifications to ensure that purchased materials are received in a condition that will assist in their proper identification, handling, inspection, storage , etc. The idea is to ensure economy and quality of purchased incoming materials.

Storage and Handling.

Standards on storage and handling of raw materials in an engineering plant assist in proper and quick retrieval of materials, prevent use of wrong materials in production, ensure first- come first-out use of materials, assist material handling and of course facilitate inventory control. In many plants, rejection of components were finally found to be due to wrong materials getting used in production which happened due to mix-ups because of lack of proper documented and visible systems of storage and identification of materials. Standards on colour coding of steels and their implementation helped reduce many of the rejections due to inadvertent use of a different material than specified.

Stores Preservation Standards.

Supplementary to storage standards, stores preservation standards are very beneficial, especially in plants in developing countries where items get stored for much longer periods. Normally there is a lot of dependence on imported materials and due to this and erratic conditions in availability of indigenous materials and often to meet the minimum purchasable quantities, large amount of safety stocks get kept. This sort of situation is prevalent in many companies in developing countries even though they are well aware of JIT and other inventory control techiques. The possibility of stocked steels or other materials getting damaged, rusty or ageing (as in some steels) are more and preservation standards have been found to be very useful.

Codification of Materials.

In large engineering plants thousands of materials are used and it becomes essential to classify them and allocate them with code numbers, normally in significant codification schemes, so that similar items can be grouped together and duplication of items can be avoided. As mentioned earlier engineering plants use many steels that are different from each other in condition of supply, tolerance, surface finish, etc. and these have to be planned, purchased, stored and identified as different items. This is possible only through use of well designed code numbers. Codification has enabled materials controls to be done more efficiently by use of computers thus ensuring better availability of information for materials management decisions. Introduction of an unified central code by a standardization department in an automotive plant in India that had collaboration agreements with 4 different foreign companies, yielded inventory reductions of as much as 60% .

Import Substitution of Materials.

In many developing countries (and now even in some of the developed countries), where joint ventures with foreign companies is being done, import substitution that will facilitate use of locally made materials is an important aspect of industrial development and growth. In some developing countries, import substitution is an important distinct standardization related activity, both at national and company levels. The standards body along with industry and national laboratories in these countries have special projects to find and develop substitutes for raw materials that are hitherto imported. The idea is to reduce imports, use local raw materials, encourage loca manufacture, reduce costs, and conserve foreign exchange.

In many companies systematic efforts in this area have led to substitution of previously imported steels with expensive alloying elements like Molybdenun and Nickel with other steels that would be more readily available locally.

An example of import substitution by use of rationalization is in an Indian engineering plant manufacturing heavy electrical equipments (at one time in collaboration with many foreign companies from different countries) had to use 180 specifications covering high temperature application. In the import substitution program the first stage was to rationalize and reduce the variety to about 50 specifications. With this done, the company attempted to get the alloy steel industry in the country to develop some of these steels. Some of the steels with revised larger requirements got finally developed, tested and used in manufacturing of some selected components. This would not have been possible before the rationalization efforts of the company as the lack of bulk quantity requirements would have prevented any manufacturer to undertake production of materials in small uneconomical quantities.

CONCLUSION

The application of standardization at company level can considerably assist in economical and quality manufacture of products in steel plants or in engineering enterprises and result in higher productivity in any enterprise if the activty is carried out in an organised and formalised manner. Rationalization of products, parts or materials carried out as a part of organized standardization activity can benefit the companies in many ways and result in overall economy in the individual plants and in the industry as a whole.

VARIETY REDUCTION THROUGH COMPANY STANDARDIZATION IN A STEEL PLANT (IN SQ. CAGE INDUCTION ELEC. MOTORS).

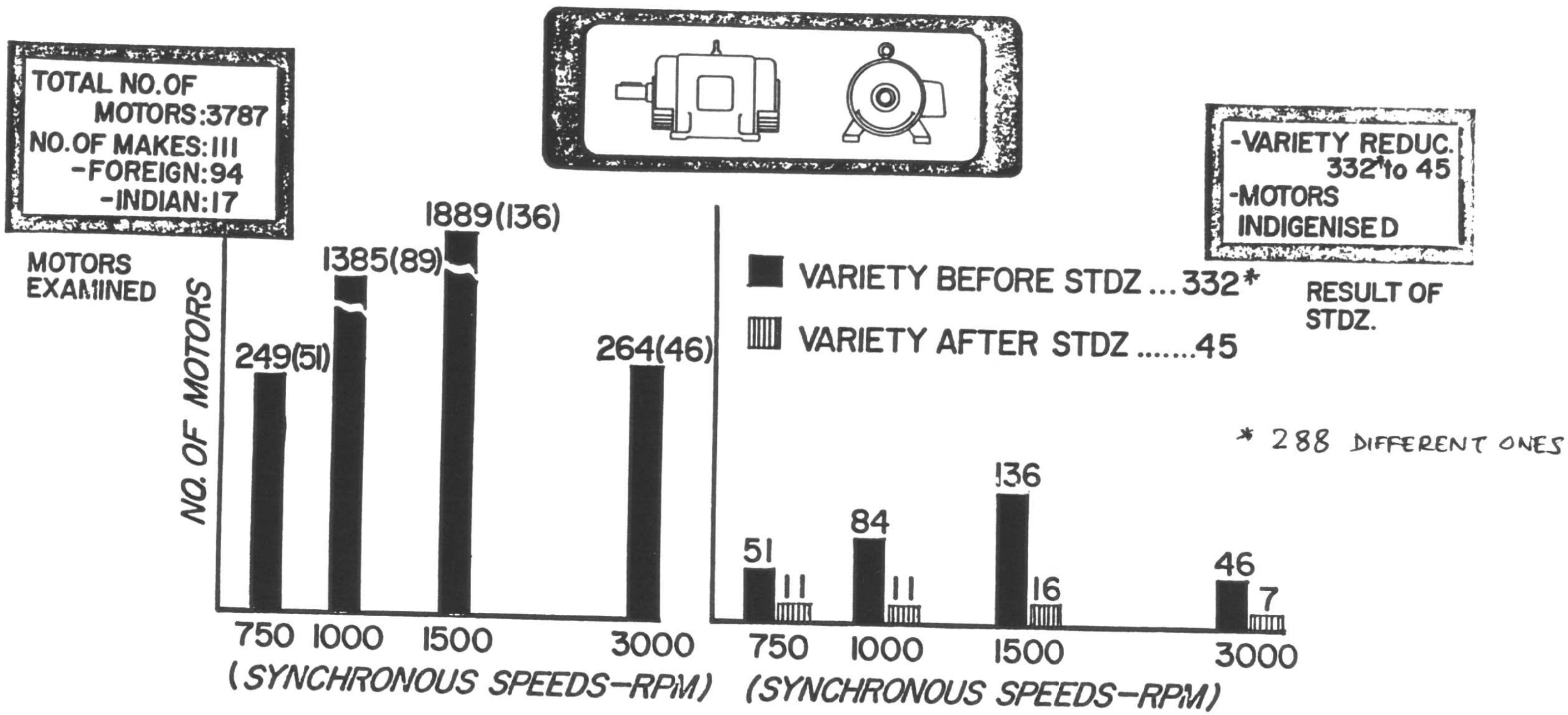

FIG. 1: NUMBER OF MOTORS
A IN THE PLANT
( ) shows variety

FIG. 1: VARIETY REDUCTION
B OF MOTORS (PROPOSED)

Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

Managing Information Technology Investment in the Steel Business

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ABSTRACT

The steel industry, worldwide has seen dramatic changes in the past decade. The next decade promises to be no different. The seeds of change have been planted from a variety of factors and the end results shape the basis for competition. These factors have been reported in various forums and described as follows:

- rebalancing of the materials chain
- relinking suppliers and customers
- improved reliance on decision-making systems
- inter-connected lines of communication
- flexible/responsive organization enterprise

With this renewed focus on information technology, enterprises are seeking to find new ways of investing in methods and concepts that use information as the common denominator. The days of seeking to justify management information systems as an expense are long gone. The focus on expense has been replaced by the notion of value. Value that the enterprise seeks to derive from the investment it makes. This is the basis for the new information paradigm. Timeliness and responsiveness terms have replaced the old adage where the investment was simply measured in terms of percentage of sales. A more effective framework is to use a set of measures that relate information technology investment directly to key business measures and metrics.

This paper will focus on a method that will emphasize the information technology investment process. The discussion will link key industry trends with some key business implications. The discussion will further explore information technology implications and will suggest an investment allocation in technology. The net effect of this planning process is to provide business effectiveness and enterprise responsiveness. From a perspective of global presence, a business enterprise will then be able to assess it's own competitive gap. In the worldwide steel industry, business objectives are being altered by a variety of factors. Among them:

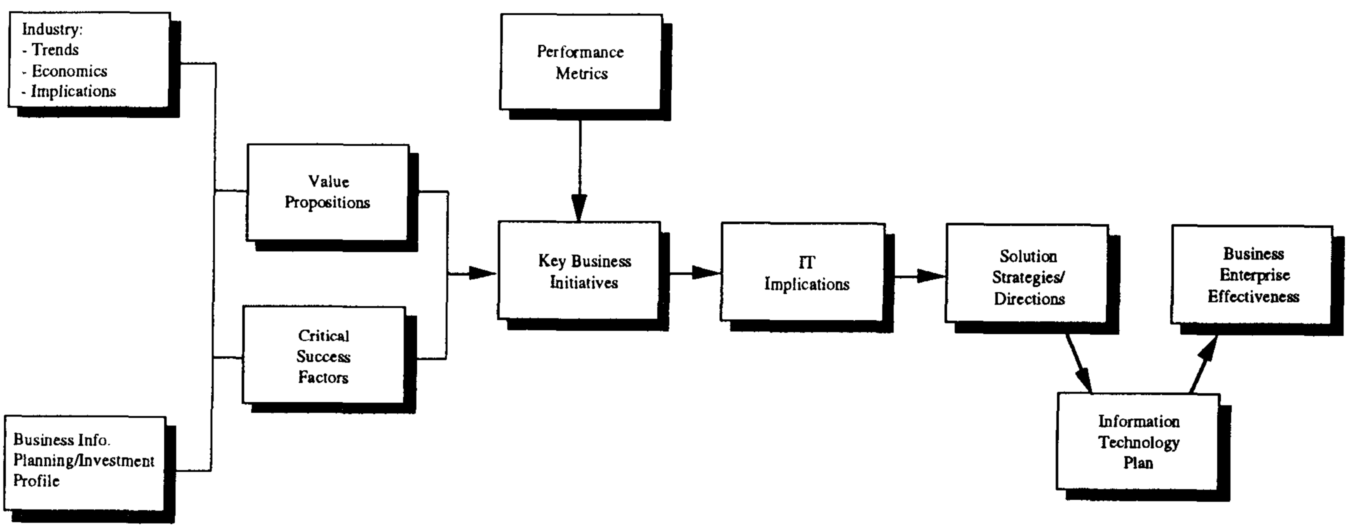
- a new set of infrastructure steel producers and suppliers have emerged
- new customer service concepts are in practice
- quality is a major differentiator
- joint partnerships and ventures have prospered
- technology implementation has accelerated with new and improved processes
- the global economic order has changed as Eastern Europe and other third world nations seek to improve their steel making capabilities.

Within this context, this paper will explore the concepts and issues in a framework described as Business Information Investment (BII).

BUSINESS INFORMATION INVESTMENT (BII)

The BII process is depicted as a sequence of events that are necessary for the analysis process. The series of steps described is largely a method of associations and correlations. The industry trends and business implications are a result of understanding the business characteristics, key factors and futures of the steel industry at large. The derivation of this information is a process of reviewing economic surveys, forecasts and consolidating information from industry analysts and other global organizations such as the World Bank and the United Nations Industrial Development Organization. A set of key business and industry implications can be derived from this analysis. From a business information planning perspective, a high level of correlation can be made between the business objectives of the enterprise and the critical success factors for the enterprise. This step assures the analysis with the idea that the mission and vision as well as the goals of the enterprise will be addressed. The investment profile, also known as chip-charts, becomes a useful method of documenting the current information technology investment of the business. The next step in the process is the concept of creating value propositions. A value proposition is a method of associating a course of action, with an industry trend. The idea of value derived is a necessary step in trying to understand "what" a player in this industry must do in order to be competitive. The discussion presents a useful view of correlating trends with implications on the business functions of the enterprise and its association with a value proposition. The BII process, at this point, creates a set of key high level business initiatives. It is important in this process to associate these initiatives with a set of key performance metrics for the industry at large. It is important to note that these metrics are created at a high level and do not correlate with specific process-related metrics such as blast furnace operating efficiency or other performance characteristics that are unique to a process technology.

BUSINESS INFORMATION INVESTMENT (BII)



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The information technology implications can then be derived to yield a set of solution strategies and directions. The resulting IT plan is a correlation of the technology trend and the potential business impact of the technology platform. The focus of the process is to yield business enterprise effectiveness.

The basic tenet of the BII process is to provide a framework for information technology investment in the enterprise. The primary thrust is to identify how the enterprise derives value, in its industry sector, and to then link the IT investment with business goals and performance metrics.

KEY INDUSTRY TRENDS

From an industry analysis framework, a key set of trends have been identified. Economists and steel analysts generally agree that the nature of the industry is changing, along with the characteristics of the markets they serve. The net result is seen in infrastructure factors such as restructuring, downsizing and cost competitiveness. From a strategic initiatives perspective, it is possible to correlate a set of business impacts with these trends. The following table illustrates this relationship.

Strategic Initiatives Perspective

Key Steel Industry Trends

Trends	Impacts
1. Key industry characteristics are changing • Capital • Labor • Management • Materials • Logistics	• Requires lower break-even costs • Emphasizes valued customer service • Requires fast decision making
2. Aggressive, competitive pricing	• Exit of marginal operations • Rapid rise of single plant companies • Price leadership volatility
3. Volatile industry factors • Market share • *Substitute materials* • Niched products	• Rapid growth of steel scrap substitutes • Continuous cost reductions (2% per year) • *Opportunity to export*
4. Increasing use of computer applications in manufacturing processes	• Focus on process yields • Requires inter-process coupling • Plant and business systems architecture
5. Industry restructuring and shakeout	• Industry/business scale down • Balance sheet impact • Joint venture focus

Source: World Steel Dynamics

As an example, the combined effects of the volatility in the industry and the higher emphasis on logistics and materials, creates a significant impact on steel operations. The implications of these trends lead the steel producer to optimize the use of its production facilities and processes. Further, the emphasis shifts to process improvements and the need to link all of the processes so that information may be shared and problem diagnosis along with fast decision-making can be enhanced. This points to the requirement for coupling inter-related processes and optimizing processing and operations related costs.

From a business enterprise functions perspective, it is useful to associate these key trends with a set of major business implications. The intent of this process is to qualitatively describe the high level impact or implication, of the trend, upon a set of key business functions. The enterprise business model, in this regard, serves as a base of reference for the key business processes. By utilizing a method of evaluating these implications, it thus becomes possible to create a set of value propositions for the business enterprise. The basic idea of a value proposition is to describe "how" the business intends to derive value by reacting to the trend. In this context, the value propositions correlate strongly with critical success factors. From a competitive factors focus, the common set of value propositions rely on a strong focus on cost, quality, and time-oriented responsiveness/effectiveness. To the extent that a business enterprise can achieve these objectives, the competitive gap will be affected. The following matrices are examples of two key trends, the associated business function implications and the resulting value proposition.

Steel Implementation Strategies

Trends	Implications on Sales and Marketing	Implications on Research and Development	Implications on Enterprise Logistics	Implications on Manufacturing Process Technology	Implications on Production	Implications on Management and Business Practices	Value Proposition
• The steel industry is restructuring	• Refocus on market presence, share, and reputation • Rationalize on product mix • Identify niches for specific products that are targeted for growth • Integrators must differentiate product on quality • Mini-mills compete on low-price commodity basis • Rationalize customer base and markets	• Use artificial intelligence to manage production processes	• Justify plant locations • Refocus business along market segments	• Implement well-defined statistical process control systems	• Couple interrelated processes • Improve yield	• Leverage strengths to maintain market presence, share, and reputation • Reemphasize importance on statistical process control and variation reduction processes • Rationalize production capability	• Reduce total cost structure • Partner to reduce business risk and share knowledge • Improve first time quality • Improve organizational effectiveness and flexibility

Steel Implementation Strategies

Trends	Implications on Sales and Marketing	Implications on Research and Development	Implications on Enterprise Logistics	Implications on Manufacturing Process Technology	Implications on Production	Implications on Management and Business Practices	Value Proposition
• Extreme volatility in the industry is forcing integrators to be execution-oriented	• Focus on higher margin products • Establish a global presence • Identify niches for specific products that are targeted for growth • Take advantage of exchange rate variations (increase exports)	• Acquire and transfer proven technology to improve competitive position • Optimize product performance and price tradeoffs • Refocus research and development to support process orientation versus product orientation	• Secure suppliers on a global basis • Refocus business along market segments • Seek opportunities to outsource process technology improvements and production processes	• Optimize processing and operations-related costs • Design simplified processes	• Couple interrelated processes • Increase utilization of production facilities • Improve yield • Reduce breakeven point	• Rationalize marginal operations and processes • Evaluate global opportunities • Restructure business processes to optimize organizational effectiveness	• Reduce total cost structure • Partner to reduce business risk and share knowledge • Partner to assure source of sustained sales • Improve organizational effectiveness and flexibility • Create access to new potential markets with global focus

A simple graphic illustrates the point of associating trends with a set of value propositions that lead to information technology implications. This competitive focus highlights the importance of using the BII process, as a method to link business objectives and goals with IT implications.

Strategic Initiatives Perspective

Competitive Factors Focus

Steel Industry Trends

Aggressive Competitive Pricing

Changing Industry Characteristics

Volatile Industry Factors

Increasing Computer Applications in Manufacturing Processes

Industry Restructuring and Shakeout

Source: World Steel Dynamics

Value Propositions

- Customer Service
- Organizational Effectiveness
- Improved Prime Quality
- Responsive Cost Structure
- Key Product Lines
- Partnerships
- Market Intelligence

Quality
Service
Competitiveness

Key IT Implications

- Shared systems
- Order fulfillment
- Total Quality Management
- Supplier/Customer Partnering
- Enterprise Cost Management
- Enterprise Technical Architecture
- Inter-Process Linkage

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KEY BUSINESS INITIATIVES

In order to manage the information technology investment efficiently, it is critical to have a high degree of correlation between value propositions, IT implications and business initiatives. For it is through the effective utilization of the firm's business processes, that value can be derived. Typically, as in the steel industry, the specific business initiative is usually a function of competitive benchmarking or an organizational effectiveness assessment. With the trends described earlier, it becomes imperative for an enterprise to seek or leverage some competitive advantage and not simply keep pace with others. The main concept here is to emphasize that most enterprises will seek competitive differentiation based on a careful analysis of its status quo and future directions or vision. The following table is a simple listing of a set of key Business initiatives, that a business enterprise may identify.

VALUE PROPOSITIONS
KEY BUSINESS INITIATIVES

1. Optimize processing and operations related costs.
2. Reduce breakeven point.
3. Couple interrelated processes.
4. Acquire/transfer technology
5. Focus on higher margin products
6. Reduce overhead
7. Exceed cost reduction goals
8. Rationalize labor and capital
9. Refocus business along market segments
10. Design simplified processes
11. Justify plant locations
12. Leverage strengths to maintain market presence, share, and reputation
13. Rationalize production capability
14. Streamline business processes supporting logistics
15. Strengthen and improve value chain management
16. Create efficient scheduling processes
17. Establish flexible work rules
18. Create multi skilled workforce
19. Create empowered organization style
20. Couple decision support tools with manufacturing processes

As pointed out earlier, the execution of any business initiative is a function of identifying the primary set of key business activities. The next table is a high level illustration of six key business initiatives and their correlation with primary business activities.

TOP KEY BUSINESS INITIATIVES CORRELATION WITH BUSINESS ACTIVITIES

	Sales/Marketing Intelligence mgmt.	Order mgmt. & delivery perf.	Cust. service management	Business Proc./ Org. Effective.	Cost analysis/ benchmarking	Prod'n plan & Scheduling	Prod'n uptime & maint. mgmt.	Leadtime reduction	Quality perform. & yields	Process tech. ass'mt & practices	Process controls interface
1. Optimize processing and operations costs		X		X		X	X	X	X		X
2. Reduce breakeven point				X	X	X	X		X		
3. Couple Inter-related processes						X		X	X	X	X
4. Acquire/transfer new processes/tech.	X								X	X	X
5. Focus on higher margin products	X		X	X	X				X		
6. Responsive/flexible organization		X	X	X				X			

In order for value to be derived, it becomes necessary to associate these key business initiatives with their impact on performance metrics. The following table is a compilation of a few metrics that are typical in the steel industry. It is important to note, however, that a competitive assessment is usually required in order to benchmark a firm's relative position, and to further identify a set of operational level metrics such as leadtime, prime quality, scrap rates, inventory turns and productive uptime.

STEEL INDUSTRY METRICS MATRIX

	Stages: Noncompetitive	Competitive	Challengers	Leaders
Financial				
Revenue ($)/ton	Less than 356	356-410	411-465	Greater than 465
Net Profit ($)/ton	Less than (52)	(52)-(29)	(28)-4	Greater than 4
Capital Spending ($)/ton	Less than 31	31-38	39-45	Greater than 45
Operating income ($)/ton	Less than (63)	(63)-(39)	(38)-15	Greater than 15
Environmental				
Energy Cost ($)/ton	Greater than 33	33-25	24-17	Less than 17
Production/Quality				
Man-hours per ton	Greater than 5.3	5.3-2.5	2.4-1	Less than 1
Yield percent	Less than 80	80-92	92.1-95	Greater than 95
Capacity Utilization percent	Less than 70	70-79.5	80-83.5	Greater than 83.5
Shipment/Employee/Year	Less than 396	396-629	630-862	Greater than 862
Human Resources				
Labor Cost ($)/ton	Greater than 178	178-128	127-70	Less than 70
Labor Cost ($)/hour	Greater than 33	33-30	29-28	Less than 28

Sources of information for matrix: World Steel Dynamics; Steel Survival Strategies VII, American Iron and Steel Institute; Current Statistics. AUS Consultants; U.S. Mini-Mills Executive Summary; U.S. International Trade Commission; Steel Industry Annual Report

Further, the key business initiatives identified earlier show a correlation with some of the business metrics noted above. This process is noteworthy because it associates the commitment that a firm makes to its business goals with a set of performance characteristics. It is this association that drives the rationalization of an information technology investment strategy. In strictly financial terms, the investment can then be correlated with value and the benefits to be derived.

OPTIMIZE PROCESSING AND OPERATIONS RELATED COST
BUSINESS PERFORMANCE METRICS

Key Business Practices	Net Profit $/ton	Capital Spending &/ton	Operating Income $/ton	Energy Cost $/ton	Man-hours per ton	Yield Percent	Operating Rate Utilization %
Effectively couple order mgmt. w/scheduling	X		X	X	X		X
Commit resources to production plan	X			X	X	X	X
Manage impact of product mix to product plan	X		X	X	X		X
Maximize operations production up-time	X		X	X	X	X	X

COUPLE INTERRELATED PROCESSES
BUSINESS PERFORMANCE METRICS

Key Business Practice	Net Profit $/ton	Capital Spending &/ton	Operating Income $/ton	Energy Cost $/ton	Man-hours per ton	Yield Percent	Operating Rate Utilization %
Reduction of process variation	X		X		X	X	X
Correlate deficient process practices with product specs.	X	X	X		X	X	X
Maximize yield at process step	X		X			X	
Optimize utilization of production resources	X	X	X	X		X	X
Reduce lead time	X		X		X		X

Within the scope of the steel industry, the two examples of key business initiatives can be used to illustrate the BII process. The set of business practices illustrated provides a reference to order management, maximizing uptime, and correlating process practices with specification requirements, as having a strong influence on the performance metrics. From an information technology planning perspective, the major issues to be addressed include, among others:

- customer order planning and provisioning
- equipment/facility maintenance controls
- production downtime
- process controls and monitoring
- process data acquisition and analysis
- inventory planning, etc.

The information technology components required to address these issues could include:

- process monitoring device and alarms
- heat, specifications, chemistry analysis and diagnostics tools
- dispatch systems
- scheduling systems
- network and communications loops
- inventory, customer order tracking, etc.

From this perspective, the BII process yields an analysis of major IT initiatives required to support the business initiatives and the business practices of the enterprise.

The BII process is used to identify a set of key IT implications that forms the basis of developing a business and information technology vision. The vision is typically expressed as a future direction statement that usually describes a future "state" in terms of: flexible organization; effective, value-added business processes; client-server technologies; integrated architectures and systems; executive information systems and others. The methods and tools required to deliver this "state" can then be addressed in terms of hardware, software & network technologies and associated enablers.

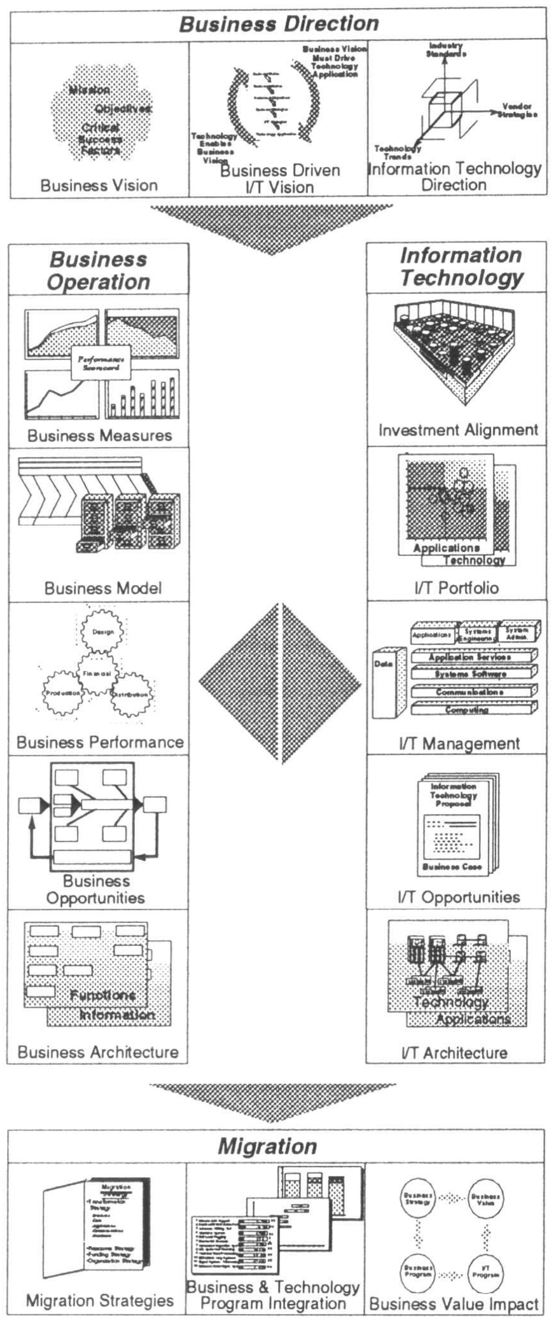
KEY IT IMPLICATIONS

1. Enterprisewide data resource management
   - Interconnected systems
   - Shared systems
   - Interfunction process linking
2. Enterprise level business process consulting
   - Business process reengineering
   - Value chain metrics and benchmarking
   - Organizational effectiveness
3. Enterprise level operations improvement systems
   - Master production planning
   - Finite capacity scheduling
   - Order management and fulfillment
   - Maintenance management
   - Decision support systems
4. Total quality management systems
   - Statistical process control (reduction in process variation)
   - Process practices correlation with product specifications
   - Heat/chemistry/testing/specification compliance (includes NDT testing and sampling)
   - Inter process monitoring and controls
   - First time (prime) yield and process-to-process yield
5. Enterprise partnering with suppliers and customers
   - Quality certification
   - JIT
   - EDI
   - Short interval scheduling
   - Cost-based incentive programs
6. Enterprise cost structure systems
   - Activity based analysis
   - Standard cost/variance accounting
   - Flexible/responsive cost allocation system
7. Enterprise Commercial (sales and marketing) systems
   - Market intelligence and analysis
   - Sales support systems
   - Product strategy management
8. Enterprise support systems
   - Energy/utility management
   - Utilization of steel scrap and byproduct
   - Environmental management
   - Hazardous waste compliance
9. Enterprise technical computing infrastructure
   - Network management
   - Communications media
   - Office/Business automation
10. Inter-process computing architecture and controls
    - SCADA (Level 0 and 1)
    - Process information integration (Level 2)
    - Business information integration (Level 3)

INFORMATION TECHNOLOGY INVESTMENT

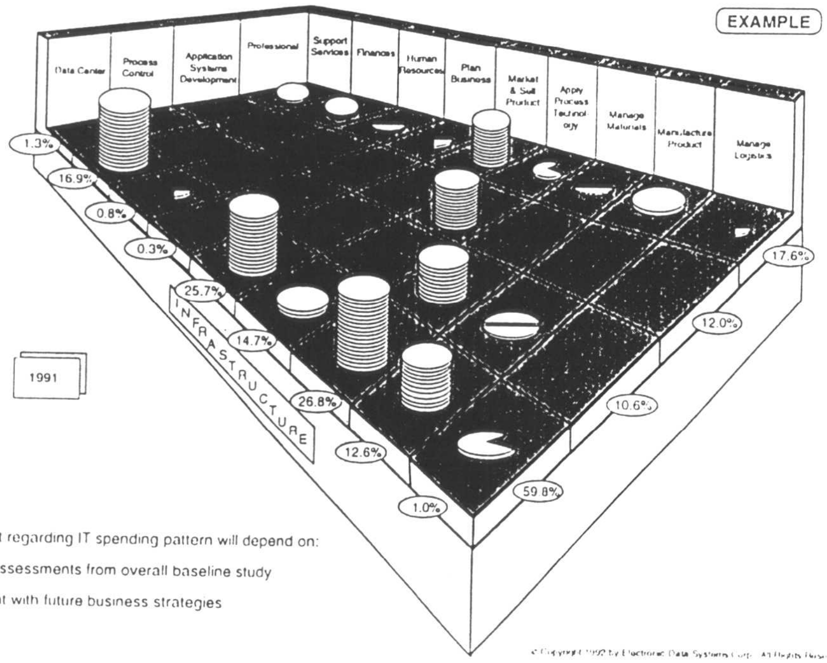
This paper has attempted to develop a process, whereby industry trends, business implications, value propositions, business initiatives and IT implications can be correlated. The process focuses on identifying IT investment as a function of the impact it has on a business metric. The primary linkage is provided from an enterprise/business effectiveness perspective. Within this context, the IT investment is part of the business information planning process.

BUSINESS INFORMATION PLANNING



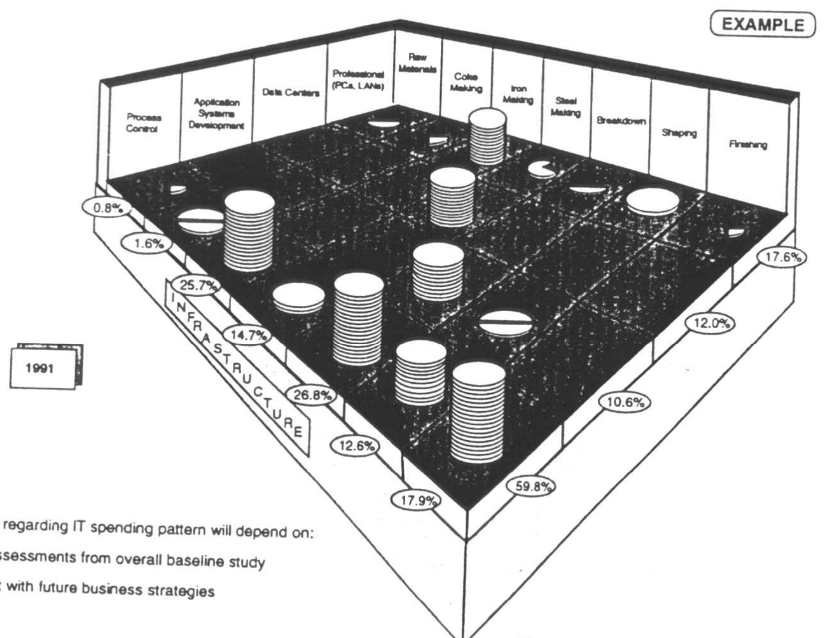
The investment allocation analysis typically starts with a "chip-chart" methodology. The primary intent is to allocate "how" the information technology investment is spread between elements of the infrastructure, processes or by business functions of the enterprise. The following are examples to demonstrate the process.

Information Technology Investment by Function



- Judgement regarding IT spending pattern will depend on:
  - Quality assessments from overall baseline study
  - Alignment with future business strategies

Information Technology Investment by Process



- Judgement regarding IT spending pattern will depend on:
  - Quality assessments from overall baseline study
  - Alignment with future business strategies

The chip-chart methodology provides an opportunity to document and understand "how" the IT investment has been aligned. As business initiatives and business processes are evaluated, the IT planning process correlates the specific IT investment required with an associated business function or line of business. From a management point of view, decisions can then be analyzed in terms of investments required for IT infrastructure, systems planning, IT utilities and data centers etc. As business needs change, the process of correlating trends, value propositions, and business initiatives with IT initiatives becomes a matter of evaluating investment allocations and financial timing.

The steel sector is rich with opportunities for how a proper mix of information technology can provide dramatic results. For example, the technologies required to manage steel processes and couple processes provides a good opportunity to bring dramatic improvements in yield, process variation, and productive throughput. All of these translate directly to reduced inventory, improved customer service and lower operating costs. Information technology and managing its investment remains critical to success.

CONCLUSION

This paper has presented a strategic view of managing information technology investment in the steel sector. The paper describes a process known as Business Information Investment (BII). The BII process focuses on correlating industry trends with value propositions and ultimately suggests information technology initiatives. The method of strategizing information technology investment is an allocation process that correlates the IT investment with the business elements of the enterprise. It is worthy of note that the process described directly supports business process reengineering and business process transformation activities. Within this context, the strategic view of managing information technology is a case of addressing business enterprise effectiveness.

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Controlled Rolling of Hot Strips in the Ferrite Region

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Abstract

Hot strips are usually finish rolled in the austenite region in order to have a uniform and fine ferrite grain structure. Abnormally coarse grain structure occurs in the extra-low carbon steels when the steels are finish rolled at a temperature slightly lower than the austenite/ferrite transformation temperature, which would result in inferior drawability. A new hot rolling process is now under development where hot rolling schedule is controlled so that finishing is mostly carried out in the ferrite region. In the new process, the hot rolling condition can be adjusted so that strips can exihibit uniform grain structure and good formability either in the as-hot rolled condition or in the as-cold rolled and annealed condition. The metallurgical benefits of this new hot rollong process is that, due to a reduction in the slab reheating temperature, the solute contents can be minimized and texture can be controlled more easily. Both laboratory experiments and mill trials were performed in order to see the applicability of the new process. It was found in the laboratory experiment that a uniform and fine grain structure could be obtained if steels were finished rolled in the ferrite region with a high degree of deformation and were coiled at a relatively high temperature. The r-values of cold rolled and annealed strips were sensitive to the chemical composition as well as the microstructure of hot bands. Higher r-value was observed when the solute carbon content was lower during hot rolling in the ferrite region. At a given steel chemistry, r-value was increased by improving the uniformity of fine hot band grain structure. In addition, the difficulties and the advantages expected when the process is practiced in the hot strip mill are discussed.

EXTRA-LOW CARBON STEELS have recently found wide industrial applications such as automobiles, home appliance, beverage cans, and so on. In the conventional hot rolling process for extra-low carbon steels, strips are recommended to be finish rolled in the austenite region in order to have a uniform and fine ferrite grain structure. Abnormally coarse grain structure appears in the extra-low carbon steels when the steels are finish rolled at a temperature slightly lower than the austenite/ferrite transformation temperature (Ar_3)[1]. This non-uniform grain structure in the hot bands has been known to cause a deterioration in the drawability when the hot bands are cold rolled and annealed. Hence, the hot rolling condition should carefully be controlled to keep the finish delivery temperature (FDT) higher than the transformation temperature.

A new hot rolling process has recently been suggested where the hot rolling schedule is controlled so that finish rolling is carried out in the ferrite region[2-8]. In the new process, called often 'ferrite rolling' or 'transformation controlled rolling', the processing condition can be adjusted so that strips can exhibit uniform grain structure and good formability either in the as-hot rolled condition or in the as-cold rolled and annealed condition. The primary benefit of practicing this new hot rolling process is that the energy cost can be reduced. This is due to the fact that the slab reheating temperature is significantly lower than the reheating temperature presently employed in the conventional process. In addition, the process is expected to decrease the scale loss, to improve the formability and to improve the productivity.

Numerous laboratory investigations have been carried out in order to analyze how hot rolling conditions influenced the microstructure and formability of strips manufactured by ferrite rolling[2-8]. These investigations can be classified into two groups: one for hot bands with good formability[2-5], the other for cold strips with excellent drawability[6-8]. Applications of the laboratory results have been practiced in the hot strip mills to find the feasibility of the new process. The present paper summerizes the salient features of the ferrite rolling process and the recent progress in research and application of the process.

CHARACTERISTICS OF FERRITE ROLLING

Fig. 1 shows schematically the processing scheme of ferrite rolling compared with the conventional rolling process. Since rolling is carried out at lower temperatures in the new process, the slab reheating temperature can significantly be reduced, which would result in a reduction in the energy cost.

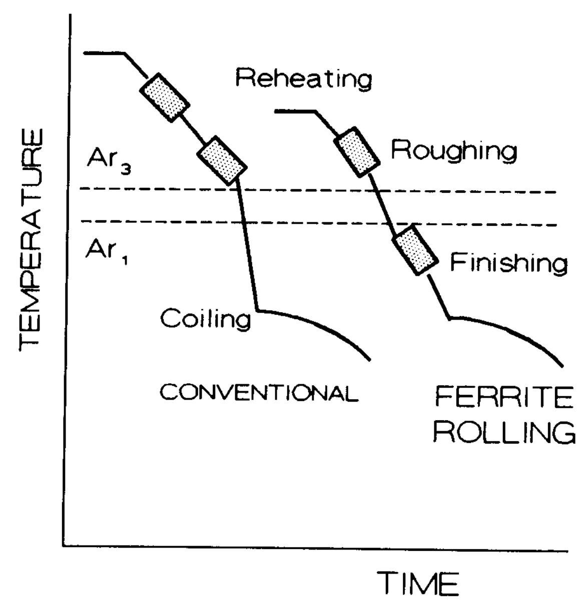

Fig. 1 Schematic diagram showing the processing scheme of ferrite rolling compared with the conventional rolling process.

The strong {111} texture observed either in hot strips or in cold rolled and annealed strips is known to improve deep drawability[9]. Hot strips finish rolled in the austenite region exhibited random distribution in the grain orientation[10]. Deformation texture is developed during hot rolling, but the texture becomes random after transformation due to the numerous orientation variant in the Kurdjumov-Sachs relationship. However, strong deformation texture occurs in the strips finish rolled in the ferrite region. This deformation texture can be controlled during heat treatment in order to have the strong {111} texture. The r-value of a strip hot rolled in the conventional method is usually lower than 1.0, but that in the ferrite rolling process ranges from 1.0 up to 2.0[2-5].

Another metallurgical benefit of ferrite rolling is that the solute content which is a critical factor determining formability can be reduced. It has been reported that solute carbon and nitrogen were detrimental to the development of {111) texture[9,11]. Reduction in the solute content occurs either by coarsening of carbo-sulfides during reheating or by strain-induced precipitation of carbonitrides during finish rolling or coiling. Since the solubility of carbon or nitrogen is smaller and the diffusivity is greater in ferrite than in austenite, the formation of carbonitrides is promoted[12]. Therefore, the lower solute content is expected in the strips processed by ferrite rolling.

HOT STRIPS WITH GOOD FORMABILITY

According to the previous investgation on ferrite rolling on hot strips, the following conditions should be met to obtain good formability in hot bands[2-5]; 1) the microstructure is as homogeneous as possible; and 2) the contents of solute carbon and nitrogen are minimized (less than 10 ppm, according to Senuma et.al.[2]).

The homogneity of the microstructure could be improved by properly selecting the hot rolling condition. The friction coefficient during hot rolling ranges between 0.2-0.4, higher than that during cold rolling. This usually causes the grain orientation at the surface differnt from that at the mid-thichness section. As a result, the recrystallization texture at the surface is {110}<001> and that at the mid-thickness is ND//<111>[2]. The thicknesswise change in the drawability of the strip is shown in Fig.2. It was concluded that a reduction in friction by lubrication rolling improved the homogeneity of texture and increased the r-values[2-5]. Matsuoka et.al. analyzed the effect of strain rate on the texture formation in hot strip[13]. According to this study, as the strain rate was increased, the accumulation in the strain energy preferentially occurred in the {111} planes and the drawability was improved due to relatively rapid recovery and recrystallization on {111}. It was reported, in this case, that lubrication rolling was not important and the r-value was as high as 1.5. Heavy deformation either at about the transformation temperature or at a temperature lower than 750℃ was recommended to improve drawability[5]. In any case, it is believed that the homogeneity was improved either by dynamic transformation and recrystallization or by static recrystallization during post annealing, respectively. However, the absolute value of r was higher in the latter case.

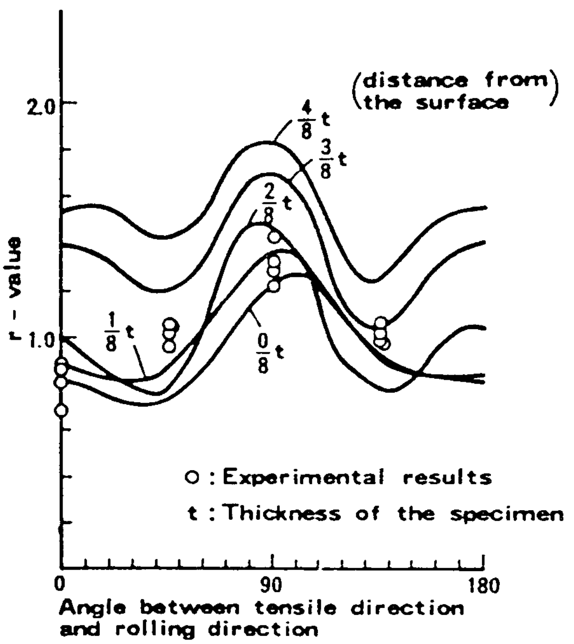

Fig.2 Variation of r-values calculated from texture intensities(after Senuma et.al.[2]).

Titanium and niobium are usually added to fix carbon and nitrogen, which is also effective for retarding recrystallization and refining the grain size. A detailed analysis of the orientation of recrystallized grains using the ECP (electron channeling pattern) suggested that carbon and nitrogen segregated to the {110} planes in the vicinity of the grain boundary hindered slip on the {110} planes as compared with that on the {112} planes, resulting in heterogeneity in texture[14]. The effect of solute carbon is shown in Fig.3, which clearly indicates that the r-value increased as the solute content decreased. It was also found that, since the precipitation kinetics of TiC was faster than those of NbC, the addition of Ti was more advantageous[3]. The precipitation of TiC was closely related with the nitrogen and sulfur contents. The titanium nitrides and sulfides which usually formed at a relatively high temperature acted as the nucleation sites for carbide precipitation. Therefore, lower temperature heating in ferrite rolling promoted the precipitation of nitrides, sulfides and carbides and reduced the solute contents.

Hot strips manufactured by ferrite rolling could either be used as-coiled condition or further be post-annealing treated after coiling. The former process is clearly cost effective, but may cause non-uniformity in microstructure and drawability in a strip. Post annealing treated ferrite rolling strips has been known to improve not only drawability, as explained above, but also ductility of hot strips. This has been shown by Hashimoto et.al[15]. The elongation of a strip ferrite rolled under the controlled condition was as high as 60%.

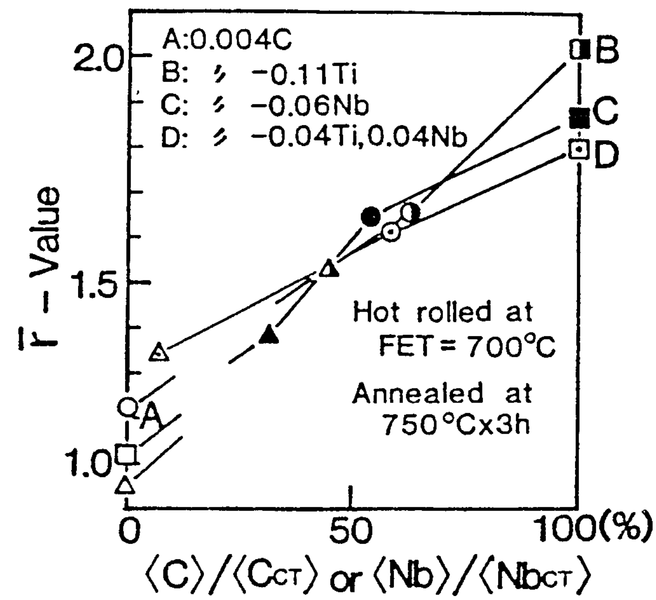

Fig.3 Relationship between r-value and precipitation ratio of TiC or Nb(C,N) which corresponds to solute carbon content(after Hashimoto et.al.[3]).

⟨C⟩ : calculated C as precipitates
⟨C_{CT}⟩ : calculated C as precipitates of furnace cooled steel
⟨Nb⟩ : calculated Nb as precipitates
⟨Nb_{CT}⟩: calculated Nb as precipitates of furnace cooled steel

COLD STRIPS WITH EXCELLENT DRAWABILITY

The important processing parameters influencing the drawability of cold strips were the type and amount of alloys and the hot rolling schedule. Generally speaking, the effects of these parameters appeared to hold for the case of cold strips. Some specific details of the effects are described as following.

An early investigation on ferrite rolling was carried out by the present authors, proposing a new hot rolling process called TCR (transformation controlled rolling)[6]. In TCR, the hot rolling condition was controlled so that austenite-ferrite transformation took place when rough rolled bars were transported on the delay table. The r-values of the TCR treated cold strips are shown in Fig.4. The strips, analyzed to be 0.0035C-0.14Mn-0.077Ti, were cold rolled and continuously annealed after hot rolling. It was found that the hot strip microstructure was either fully recrystallized (closed marks) or partially recrystallized (open marks) depending on the finish rolling and coiling temperatures. The drawability of cold strips hot rolled in the fully recrystallized condition was superior to those in the partially recrystallized condition.

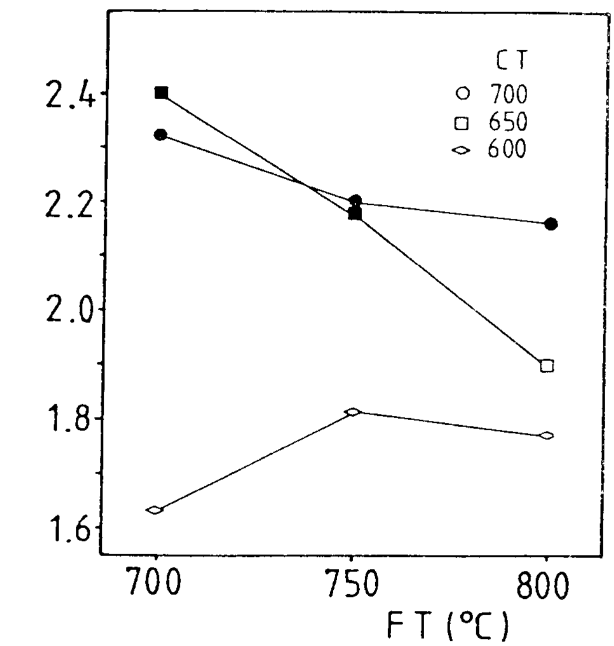

Fig.4 Effect of FT and CT on average plastic strain ratio in cold strips.
Closed symbols : complete recrystallization in hot-rolled ferrite
Open symbols : partial or no recrystallization in hot-rolled ferrite

Similar results have been reported by Senuma et.al. for strips cold rolled and batch annealed[8]. The results are shown in Fig.5. Strips hot rolled in the ferrite region exhibited similar drawability to those in the austenite region. In addition, the lubrication condition strongly influenced the drawability; the lower was the friction coefficient, the better was the drawability.

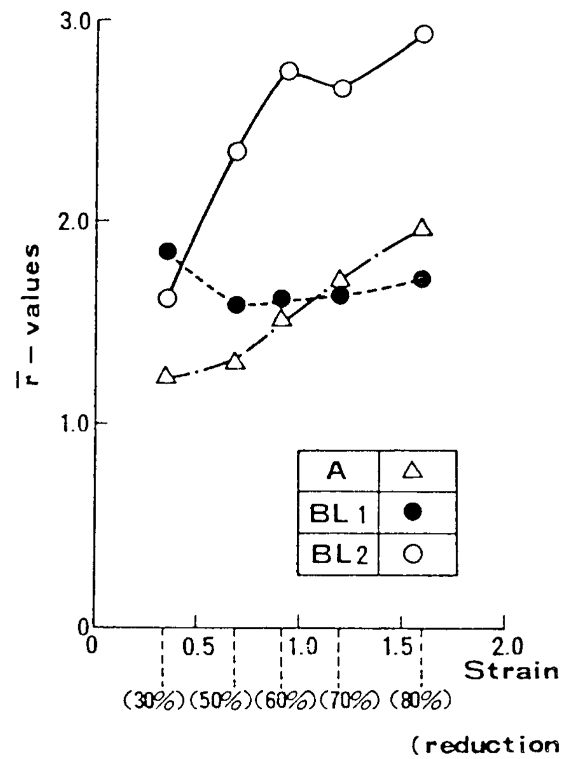

Fig.5 r-values of cold rolled steel sheet which was hot rolled in ferrite region in a lubricated condition, compared with a usual cold rolled sheet(after Senuma et.al.[8]).
A ; hot rolled in austenite region
BL1 ; hot rolled in ferrite region
BL2 ; hot rolled in ferrite region and annealed for recrystallization before cold rolling

The effects of finish rolling temperature and cold deformation were analyzed by Hashimoto et.al.[7], as shown in Fig.6. The steels were directly cooled to room temperature after hot rolling, followed by cold rolling and continuous annealing. In this case, the r-value was increased as the finish rolling temperature was lowered when the amount of cold deformation was relatively small. However, when the amount was greater than 90%, the drawability was not changed significantly.

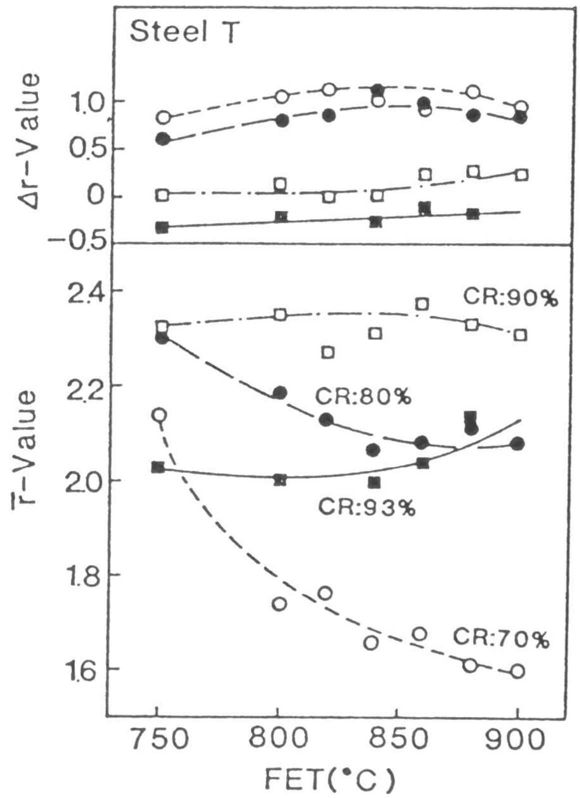

Fig.6 Effects of hot rolling temperature and cold reduction on r-value of 0.0020% C - 0.032% Ti steel(after Hashimoto et.al.[7]).

CONCLUDING REMARKS - APPLICATION

The difference between the conventional hot rolling process and the new ferrite rolling process was on the hot rolling schedule. In the new process, the processing condition was controlled so that finish rolling was carried out in the ferrite region. Therefore, the reheating temperature in ferrite rolling could be lowered by about 200℃, which would result in save in the energy cost, reduction in the scale loss, reduction in the solute content and better control of the texture formation. These are the advantages of the new process, but there are some disadvantages, too; i.e., difficulty in scheduling, greater roll force and hetrogeneity in lengthwise microstructure.

A trial production has been made in the hot strip mill to ascertain the laboratory results. The processing condition of the mill trial is shown in Table 1 and the resuting mechanical properties were displayed in Fig.7.

The drawability of the mill trial steel was slightly lower than that of the laboratory steel, but was equivalent to that of the conventional steel. A greater roll force was required during roughing. However, the roll force during finishing was about the same when compared with those in the conventional process. This followed from the fact that the intrinsic hot strength of ferrite was low. The above mill trial results clearly indicated that the new process was feasible in the technical point of view.

Table 1 Processing conditions for mill trial.

Slab size	; 248^t x 1320^w mm
Coil size	; 3.2^t x 1303^w mm
SRT	; 1050℃
RT4	; 910℃
FT7	; 750℃
CT	; 700℃
Cold Rolling Reduction	; 75%
Annealing	; 830℃, 32sec

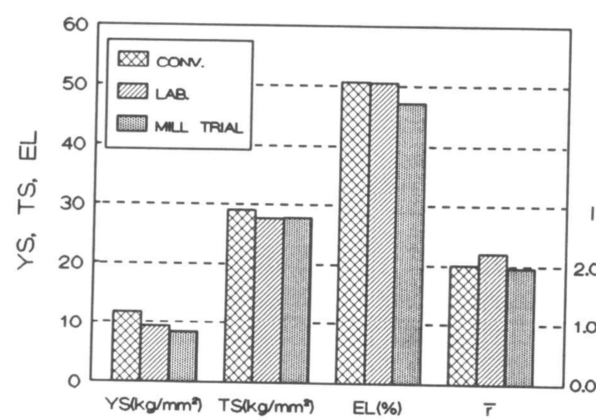

Fig.7 Mechanical properties of cold rolled and annealed strips manufactured using various hot rolling processes.

An industrial application of the concept of ferrite rolling was carried out at Arbed ADu in collaboration with CRM and Cockerill-Sambre[16,17]. Investigations done by this group confirmed productions of extra-low carbon DDQ hot and cold strips both in the laboratory and in the mill trial. However, the commertial application was made for an economic production of low carbon CQ cold strips in the reversing-type cold mill. It was reported that the productivity of the cold rolling mill was increased by 30-40%. This productivity increase was attributed to softening of hot strips finish rolled at 750-800℃ and coiled at 650-700℃. The hot strips presumably exhibited coarser grain structure and bigger precipitates.

Although ferrite rolling is not widely practiced in industry at present, the technology appeared to have very good future. This is due to the fact that the ferrite rolling process has many advantages over the conventional one, as explained in the former paragraph. Some of the disadvantages could be solved without much difficulty in the near future. In addition, ferrite rolling will be even more effective when the process is combined with thin slab casting and hot direct rolling, preferably for manufacture of ultra-thin gage hot strips[18].

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Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

Bimetallic Bushings by Isostatic Pressing

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Abstract

The manufacturing process for internal coatings of steel bushings using a Fe base powder is described. The process includes the stage of cold isostatic pressing, followed by sintering in vacuum and heat treatment, getting a wear resistance coating when the bushing works under cyclic axial motion. A diffusion layer is obtained when the sintering temperature is above of the melting point of copper.

COATINGS ARE DESIRABLE or necessary for a variety of reasons including economics, materials conservation, unique properties, etc., which can be obtained by separating the surface properties from the substrate properties.

The behavior of the coating/substrate depends not only on the properties of the two components, i.e., the coating material and the substrate material, but also on the interaction between them, i.e., the structure and properties of the coating-substrate interface . The common processes to obtain coated metallic parts include: electrodeposition, welding, plasma spraying, brazing, chemical vapor deposition, physical vapor deposition, roll bonding, etc. Hot isostatic pressing is a process where the metallic part is loaded into a metallic can and the remainder of the container is filled with powder of desired composition and sealed. During the hot isostatic pressing cycle, loose powder is compacted and bonded to the metallic part. An important drawback of the process is its high cost.

Presently, valve seats (1) and valve guides (2) made from Fe-base alloys by PM are used, being in these pieces the wear resistance a very important requirement.

This paper deals with self-lubricating coatings using Fe base powder using cold isostatic pressing and sintering, showing not only the coating but a diffusion interface due to the solubility of the copper into the substrate.

Experimental procedure

The material employed in the present research was a powdered ferrous material used in internal combustion engines valve guides (2,3). This material is a Fe - 4.5 Cu - 2 C - 0.4 Sn - 0.3 P, which includes free graphite and phosphorus as ferrophosphorus. Powdered Cu-base alloy (4,5) was tried before; showing wear and metallurgical bonding problems on the coatings.

The raw materials (Cu, -325 mesh; Sn, -325 mesh; graphite, -325 mesh; ferrophosphorus, -325 mesh; iron, -140 mesh and acrawax) were mixed in a ball mill during 1 hour .

The mixed powders were compacted over the internal area of the steel bushing (6150 steel) at 15000 psi by means of a cold isostatic press using a dilating wet bag tooling (fig. 1). The coated bushings were sintered in a vacuum furnace at a heat rate of 20° C/min and a 60 minutes hold. During the cooling, fast cooling was applied in order to get hardness in the steel bushing (37 RC). That is to prevent distortion of the bushing when it is press fit at the wear test. A hardness testing machine was used in the Rockwell B scale (1/8" ball indentor, 100 kgf) for hardness measurements. The porosities were measured using a mercury intrusion porosimeter. The wear testing of the coated bushing was carried out by IEM quality control department after oil infiltration using a SAE mineral oil.

The apparatus used in this test consisted of a spring mounted "flotation" base in which the bushing was placed. This allows free yet contained motion of the bushing. The rear side of the floating base is attached to a die spring and a rod which in turn is attached to the upper plate (containing the guide pin). As the press goes downward, the die spring is depressed by the attaching rod, thereby creating an increasing load. An air gauge to measure the wear on the bushing was used. The accuracy of this instrument is calibrated to be +0.000001 / -0.000001 inches.

The test is terminated under one of the three conditions.

*Because of wear, the bushing inner diameter has increased 0.0012 inches.

*Wear or scoring of the coating increases to the point that the coating can no longer be considered acceptable.

* The test bushing completes 105 000 cycles..

Sintered microstructures were characterized by means of optical and scanning electron microscopy.

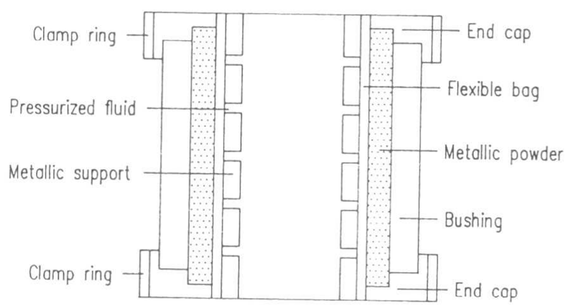

Fig. 1. Dilating bag tooling for cold isostatic pressing of bushings.

Results

The obtained properties of the coating using Fe base powder are indicated in the table 1.

Table 1

Sintering temperature	1050°C	1100°C
Porosity (%)	20	16
Density (g/cm³)	6.3	6.5
Hardness RB	48	56

The table 2 shows the obtained properties of the coating using a Cu-base powder [Cu - 11 Al - 4 Fe], -140 meshes and free graphite, being the sintering temperature 1020°C and a 60 minutes hold.

Table 2

Graphite (by weight)	0%	1%
Porosity (%)	17	21
Density (g/cm³)	6.2	5.7
Hardness HR 15T	78	68

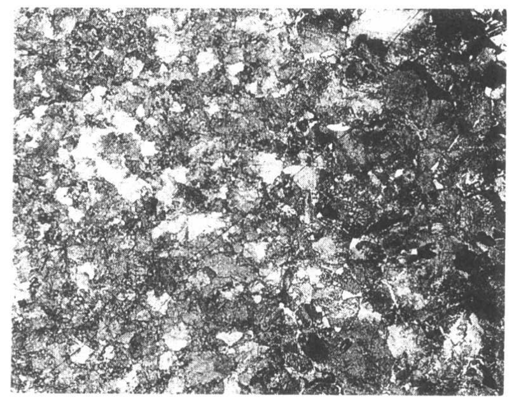

Fig. 2. Sample using Fe base powder sintered at 1100°C.

The fig. 2 shows the interface between the steel bushing and the coating sintered at 1100°C, where it can be noted the metallurgical bonding due to the sintering treatment as carried out above the melting point of copper. Scanning electron microscopy indicates copper, iron and tin in the interface. At 30 microns depth into the steel bushing copper is found, being the solution of copper into the iron the mechanism of the metallurgical bonding. The structure of the substrate is a fine lamellar pearlite matrix and ferrite; the structure of the coating is pearlite matrix, ferrite and copper dissolved in the pearlite.

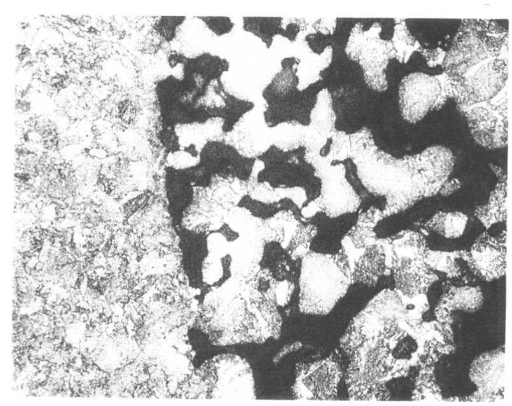

Fig.3. Sample using Fe base powder sintered at 1050°C.

The fig. 3 shows the metallurgical bonding at 1050°C with poorer bonding, noticing the pearlite matrix, ferrite and free copper in the coating. The fig. 4 shows the bushing wear test, having the highest wear resistance for the Fe-base coated bushing sintered at 1050°C. The test was ended due to the bushing started to get hot, seeming to lose all lubrication at around 100 000 cycles.

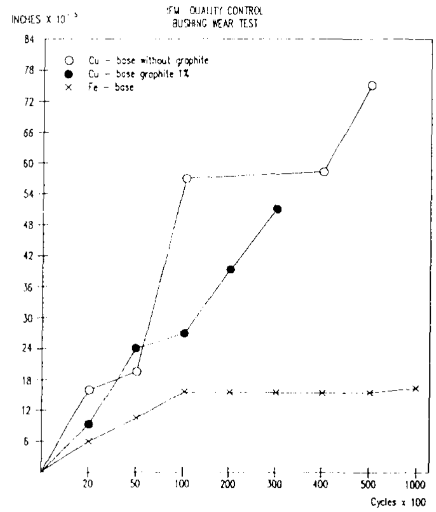

Fig. 4. Wear test.

In order to test the valve guide alloy bushings in a "real world" by means of increasing the period of inspection and relubrication, IEM is modifying its test fixture in order to allow insertion of temperature probes.

Conclusion

Fe-base powder and steel bushing show a good metallurgical bonding when the sintering temperature is above the melting point of copper.

The coating wear resistance using Fe-base powder is higher than the Cu-base powder.

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1991 Conference

Emerging Technologies for New Material and Product-Mix in the Steel Industry

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Proceedings of the Emerging Technologies for New Materials & Product-mix of the Steel Industry, 1991 Materials Week, Cincinnati, Ohio, USA, 21-24 October, 1991

Production of SG Iron Using Elemental Magnesium Treatment of Melts Prepared from Sponge Iron

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Introduction

Spheroidal graphite iron is usually produced by treating a low sulphur base metal with Fe-Si-Mg or/and Ni-Mg alloy. The treatment of the base metal using pure magnesium is not commonly practiced for SG iron production, since the high vapour pressure of magnesium results in a violent reaction as soon as the elemental magnesium metal comes in contact with the molten iron. George Fischer converter, however, makes use of the elemental magnesium with the help of a specially designed converter and magnesium chamber.

The base metal when prepared from the Indian pig iron and coke, contains unacceptably high phosphorus. Since high quality raw materials such as sorel pig is not readily and inexpensively available from the indigenous sources in India, the base metal for SG iron production is prepared from the steel scrap as a feedstock. On the other hand, the DRI is low in tramps and impurities and could be used as a feedstock to prepare the base metal.

Accordingly, production campaigns were run for several weeks at National Metallurgical Laboratory (NML), Jamshedpur, India to produce appropriate base metal for SG iron production using DRI as the feedstock. The base metal so produced was subsequently treated using elemental magnesium to produce SG iron.

This paper reports the results of the experiments conducted at NML. Some of the results obtained were verified through trials in an industrial plant.

Experimental Procedure

Three campaigns each lasting for 10 to 20 days were carried out in a 500 kVA submerged arc furnace at NML to produce base metal for SG iron production using 100% DRI. The analysis of raw materials used in the campaigns is reported in Table I. The base metal produced was tapped after every 3 hours (one ton batch) and was subsequently treated by plunging elemental magnesium in an open ladle with the help of a device specially designed for this purpose (patented). The use of the device resulted in a very safe, completely controlled and reliable magnesium introduction in the metal. As a result SG iron could be consistently produced.

The trials at the plant used steel scrap and return as feedstock, which were carburized using graphite. Ferro-silicon was added to raise the silicon level of the iron. The melting of these raw materials was carried out in a 5 T induction furnace to produce the base metal of requisite chemistry. Subsequently, the base metal was treated by elemental magnesium using the device specially designed for the purpose.

Table I: Preparation of base metal in NML's 500 kVA submerged arc furnace

Three campaigns: 17, 10 and 20 days

Raw materials:

- Sponge iron (DRI) analysis (wt.%)

Fe(T) :	84-89	C :	0.4-1.3
Fe(M) :	65-72	S :	0.02-0.08
FeO :	18-28	P :	0.03-0.08
SiO_2 :	1.6-5.3	O :	4-6
Al_2O_3 :	1.3-4.2	CaO:	0.15-0.7

- Size fraction of the sponge used:

Fines:	1 mm below	50%
	1 to 5 mm	50%
Lumps:	5 mm below	20%
	5 to 20 mm	80%

- Pet coke:
  - Fixed carbon : 91 to 96%
  - S : 0.5 to 0.7%
  - Quantity used : 80 to 120 kg/T

- Quartzite:
  - SiO_2 : 95%
  - P : 0.03%
  - Quantity used : 30 to 60 kg/T

- Slag:
  Basicity: 1.2 to 2.1 (100-140 kg/T)

- Hot metal:
  - Temperature: 1330°C to 1450°C (ladle)
  - Production : 8 to 10 T/day
  - Tapping : Every 3 hours
  - Analysis : (wt.%)
  - C : 3.4 to 4.1
  - Si : 0.5 to 2.1
  - S : 0.005 to 0.04
  - P : 0.03 to 0.065
  - Mn : 0.03 to trace

- Power consumption (kWh/T):
  1090 (18% FeO) to 1450 (28% FeO)

- Recovery: 95 to 99% Fe

Results and Discussion

Results of the experiments conducted are summarised in Table II. The magnesium treatment process developed, has been successfully scaled up to treat batches of 2.5 tonnes of base metal during the plant trials and the comparative parameters and results are shown in Table III.

Table II: Typical tensile properties of SG and CG iron produced at NML

	FG	CG	SG
Tensile strength (MPa)	140	260-340	380-460
Elongation (%)	Nil	2-5	12-14
Hardness (BHN)	150	158	160

Table III: Elemental magnesium treatment trials

	at NML	at PLANT
FEEDSTOCK:	DRI	Scrap and Return
FURNACE:	500 kVA SAF	5 T Induction
BATCH SIZE:	500 to 1000 kg	2.5 T
MAGNESIUM ADDED:	0.4 to 1.0 kg	2.5 kg
BASE METAL ANALYSIS (%):		
C :	3.4-3.9	3.4-3.5
Si:	1.4-1.9	1.6-1.8
S :	0.02-0.04	0.02-0.04
P :	0.03-0.05	—
Mn:	0.03-Trace	—
Ni:	--	1.5-2.4
Cr:	--	0.25-0.40
Mo:	--	0.30-0.55
CARBON EQUIVALENT:	3.9-4.1	3.9-4.1
TEMPERATURE (°C):		
Tapping :	1420-1450	1500-1515
Treatment:	1350-1400	1410-1465
Pouring :	1280-1350	1340-1380
TIME ELAPSED, MINUTES:		
Between tapping and casting:	10 to 15	27 to 31
Between treatment and pouring:	5 to 10	18 to 20
MICROSTRUCTURE:	95-100% SG	95-100% SG

Several benefits would accure if DRI (HBI or sponge iron) substitutes pig iron or steel scrap as a feed stock and processed in a Submerged Arc Furnace (SAF). First, the harmful tramp elements which adversely influence the toughness, ductility and performance at high temperature, of the SG iron produced, are present only in traces in the DRI. Second, the low sulphur and low phosphorus base metal can be produced since both these impurities can be decreased during the smelting of the DRI in a SAF. Whereas, the desulphurization of the iron is not unexpected, a decrease in the phosphorus content of the metal in the reducing condition such as is encountered during smelting in the SAF, is rather unexpected. The reason for this observation is being studied. Third, the cost of production of metal would decrease if DRI is used as a feedstock. The inherently low manganese content of the DRI, offers flexibility in controlling the level of manganese in the iron and in addition can facilitate production of the as cast ferritic grade SG iron.

The treatment using elemental magnesium was accomplished using a special plunging device (patented). This not only provides a safe, high reliability, controlled reaction with a slow release of magnesium but has several other advantages. First, the cost of magnesium treatment is significantly decreased due to the nominal capital investment in fabricating the plunging device and due to the very low cost of the spherodizer. Second, the treatment process produces very little fumes, flash or metal spillage, when compared to that during the treatment by NiMg/FeSiMg alloys. The process is capable of desulphurising even a 0.06% sulphur base metal. The lower treatment temperatures adds to the energy savings requiring less superheat. The plunging treatment provides greater flexibility in the amount of post inoculant that can be added. The recovery of magnesium is excellent. The nodule counts are higher and the nodules are smaller and exhibit much better sphericity.

Conclusion

The experiences gathered through these experiments at NML as well as the upscaled inplant trials, lead to the following conclusions.

(1) Sponge iron(DRI) when used as a feed-stock to prepare the base metal in a submerged arc furnace to produce SG iron can results in the following advantages:

- S, P, Mn and also Si level in the base metal can be controlled conveniently.
- Whenever the steel scrap is expensive and scarce and suitable pig iron for making SG iron is not available, the DRI can be used as a substitute feedstock resulting in a lower cost of production of base metal.
- In view of lower Mn level in DRI and in subsequent base metal, as cast ferritic grade SG iron can be produced.

(2) A safe, reliable controlled reaction of elemental magnesium with molten cast iron using a very simple pluging technique in an open ladle demonstrated that good SG iron can be produced with the following potential advantages:

- Use of elemental magnesium decreases the treatment cost.
- The drop in metal temperature due to treatment is less and consequently lower superheat is required, resulting in savings in energy.
- The flashes, metal spillage and fume generation are much less and consequently the process is characterised to be less pollutive compared to the conventional process based on the conventional spheordizer.
- The amount of ferro-silicon added as post-inoculant can be varied over a wide range.

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Model Study of Impact Stress Distribution Along the Bottom and Lining of the Combined Blown Converter

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ABSTRACT

A model study of the impact stress distribution along the converter bottom and the furnace wall with the straight tube, slit type, annular slit type and multitubed type nozzles were carried out under the same condition of gas flow rate. Experimental results show that the impact stress on the converter bottom reaches its maximum near the nozzle and declines drastically with the increase of radical distance from the nozzle. The effective scope of the impact stress on the converter bottom is R/d =10-13, beyond which the impact stress along the converter bottom drops substantially to an invariant. The impac stress on the furnace wall increases with the increase of furnace wall height from the bottom and reaches its maximum near the liquid surface under the slag line.

INTRODUCTION

The liquid melt of the combined blown converter moves violently due to the reinforcement of blown jets from the converter bottom and stirring. Therefore, the life of the furnace lining and bottom decreases sharply. The frequent replacement of the furnace lining effects not only the index of econamy but also the rate of operation in the production process. The relationship between the impact stress distribution along the converter bottom and operation parameters for the straight tube, slit, annular slit, or multitubed nozzles was investigated in present experimental study. The model study was simulated to a 50-ton top-bottom combined blown converter of Wuhan Iron and Steel Cooperation.

MEASURING SYSTEM AND PRINCIPLE

The nozzle arrangement and measuring points distributed on the furnace bottom are shown as Fig.1a. The ZBF-1 combined step-by-step scanivalve consists of a main body of the scanivalve and a control power supply shown in Fig.1b. The main body of the scanivalve is conposed of four valve heads, each of which has 48 measuring pressure tubes. Four pressure transducer are installed in the valve head, which is a critical part to carry out sweep measurement. The scanivalve contains a driver, an encoder and a cotrol disk. A microcomputer was used to control the stepping and reset of the scanivalve. When an impulse of about 10 volt and zero potential from the D/A converter was transmitted to the control power supply through 2 wires, the control power supply would switch on the driver and the control disk and complete a stepping and a reset.

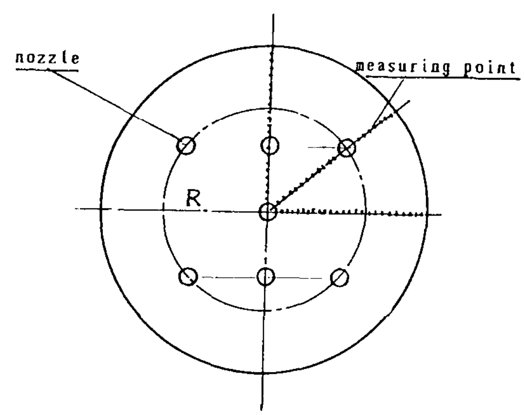

Fig.1a Nozzle and measuring points arrangement

1.driver 2.valve head 3.code device
4.valve holder 5.controller

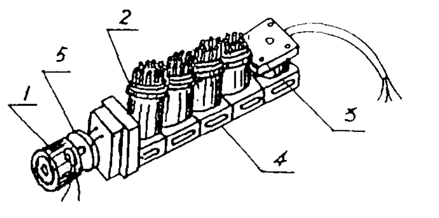

Fig. 1b Scanivalve for measuring multipoint pressure

The driver was used to make an encoder carrying out the scanning pressure measurement, and a stepping switched on a pressure probe in turn. The pressure signals were transmitted to the pressure sensors, where they were changed into voltage signals. Then, the voltage signals were fed to the amplifiers and converted into digital signals by an A/D converter. Thus, automatical data acquisition and real time processing were achived, which led to saving of the transducers and lightening of onerous transducer calibra-tion. Only three transducers were used in the present model study. One was used for impact stress distribution measurement, the others for measuring the exit velocity of the nozzle on the converter bottom. The measuring system is shown in Fig. 2.

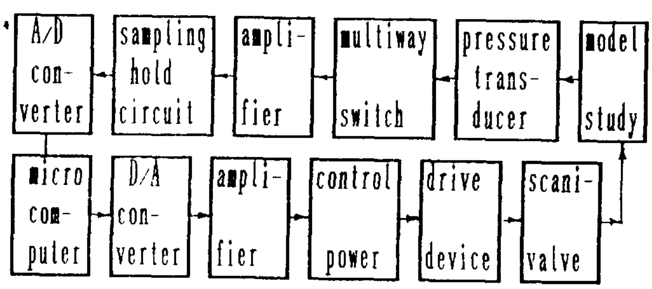

Fig 2. Scheme of impact stress measurement system

EXPERIMENTAL RESULTS AND DISCUSSION

IMPACT STRESS ALONG THE CONVERTER BOTOM

Gas was injected from the nozzle of the converter bottom, and bubbles were foremed at the nozzle exit. The bubble formation, enlargement and disengagement were the three steps of the bubble behaviar. While a bubble was disengaging to float from the nozzle exit, a subsequent bubble was not formed. The cavity formed due to floating of the bubble was certainly filled up by the surrounding liquid. So a reaction force of bubble (which was called the recoil of bubble) on the nozzle was formed and an action force made up of fill-up by the surrounding liquid[1], acted on the nozzle. As a result of continuous injection of gas from the nozzle, a reaction force of melt on the nozzle was also formed due to liquid surface fluctuation of the melt. Therefore, the measured impact stress on the converter bottom was the vector sum of the three action forces described above. When the impact stress distribution along the furnace bottom was investigated, for convenience, the action force formed due to liquid surface fluctuation of the melt was ignored in the present model study. So that, the impact stress measured in the present experiments was the vector sum of the recoil of the bubbles and the reaction force of gas jet on the nozzle.

IMPACT STRESS DISTRIBUTION ALONG THE RADIUS OF THE CONVERTER BOTTOM

Figure 3 shows the dimentionless distribution of impact stress along the radius of the converter bottom with straight tube nozzle with diameters of $d=5\times10^{-3}$m. As it can be seen, the impact stress near the nozzle declines drastically with the increase of the distance from the nozzle, and remains basically unchanged when it reaches a certain value. The effective action radius is 10-13, beyond which the impact stress keeps substantially invariant.

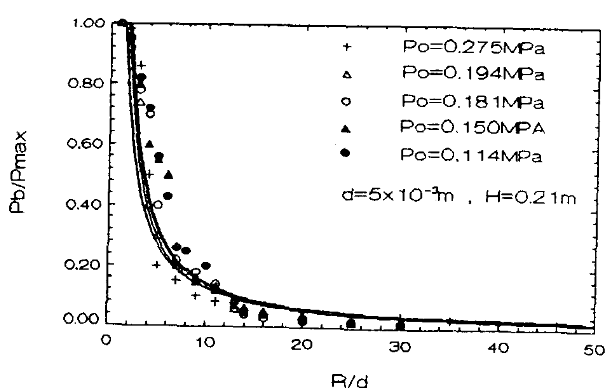

Fig. 3 Radial distribution of Pb on the bottom for d=0.005m

As indicated above, the effective action scope of impact stress is about R/d=10-13. Therefore, the bigger the diameter of the nozzle is, the wider action scope of the impact stress is. Pb/Pmax decreases with the increase of R/d for a constant stagnation pressure Po, and declines with the increase of stagnation pressure Po for a constant R/d. Both Pb and Pmax increase with the increase of stagnation pressure Po, and the latter increases more quickly than the former. Although the entrainment of the gas jet on the surrounding melt enhances with the increase of Po, bubbles either breaked down at a higher position from the nozzle exit or not breaked down so that there is a gas jet mechanism existed. Therefore, the cavity resulting from breaking down and floating of bubbles was filled up by the surrounding melt at a higher position from the nozzle exit so that the impact stress on the converter bottom was decreased. The facts presented above explain why Pb/Pmax decreased with the increase of stagnation pressure Po. It can be seen from the experimental results that the recoil of bubble decreased with the increase of Po, and the continual impact of bubble due to the recoil of bubbles on the converter bottom also attenuated with the increase of stagnation pressure Po, which was thought as the criterion determining whether the recoil of bubbles vanished or not.[2-4]

Figure 4 indicats the radical dimensionless profiles of the impact stress with the annular slit type nozzle of inner diameter 6×10^{-3}m, and slit outer diameter of 7.8×10^{-3}m and equivalent diameter 4.984×10^{-3}m. As it can be seen, when the effect of static pressure and surface fluctuation of the liquid melt on the nozzle is ignored, the impact stress is almost zero near the center of the annular slit. The cavity of the liquid melt caused by the entrainment of the surrounding gas jet was not filled or hardly filled by the surrounding melt within the annular slit. A gas zone was formed because of the mutual entrainment and aggregation of the surrounding gas jet. So that the local pressure inside the inner diameter of the annular slit was smaller and approximately equal to the static pressure of the gas jet at the nozzle exit. Therefore, the inner part of the annular slit was hardly deteriorated by the impact stress. As it can be seen from Fig. 4 the decreasing trend of Pb/Pmax beyond the inner part of annular slit is the same as in Fig.3.

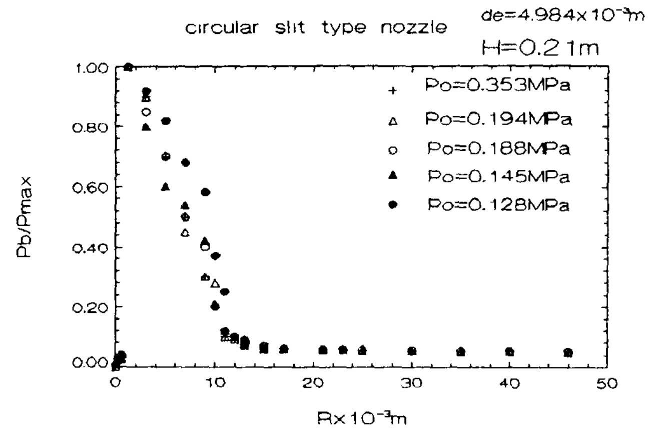

Fig.4 Radial distribution of Pb on the bottom for the annular slit type nozzle de=4.98×10^{-3}m

Fig.5 shows the dimensionless impact stress distribution along the radius of the converter bottom with the straight slit nozzle of slit area having $3\times6.6\times10^{-6}m^2$ and equivalent diameter of 5.02×10^{-3}m. It can be found that the decrease trend of impact stress with the nozzle described above is similar to that with straight tube nozzles having a diameter $d=5\times10^{-3}$m.

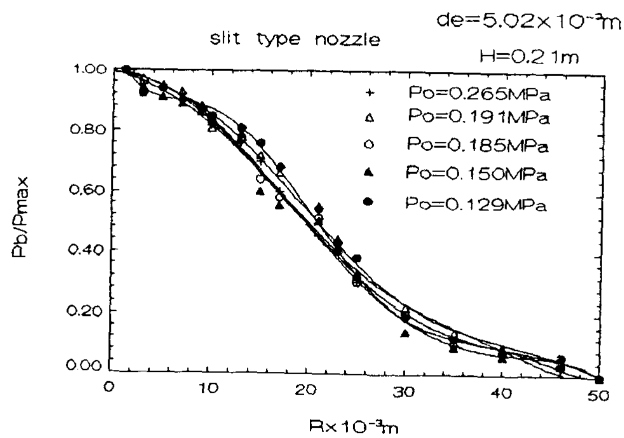

Fig.5 Radial distribution of Pb on the bottom for the slit type nozzle de=5.02×10^{-3}m

Figure 6 illustrates that the distribution of the impact stress along the radial direction on the furnace bottom was obtained through experiments under injection condition of six fine tubes of multitubed nozzle were evenly arranged over the furnace bottom, pitch diameter of 8×10^{-3}m, tube diameter of 2×10^{-3}m and equivalent diameter de=4.9x10⁻³m. This figure demonstrates that Pb/Pmax is less than 0 when R/d is between 0 and 1. This case is similar to that appeared with the annular slit nozzle. All the above figures can be explained why the Pb/Pmax value decreases rapidly with the increase of R/d value near the nozzle, but is hardly affected by R/d value where R/d is more than 10-13. The impact stress on the furnace bottom near the nozle is mainly caused by gas jet which forms a reaction field against the nozzle. In this field, the force distribution is not definitely perpendicular to the furnace bottom. Therefore, the impact stress is determined by the amount of force and its direction.

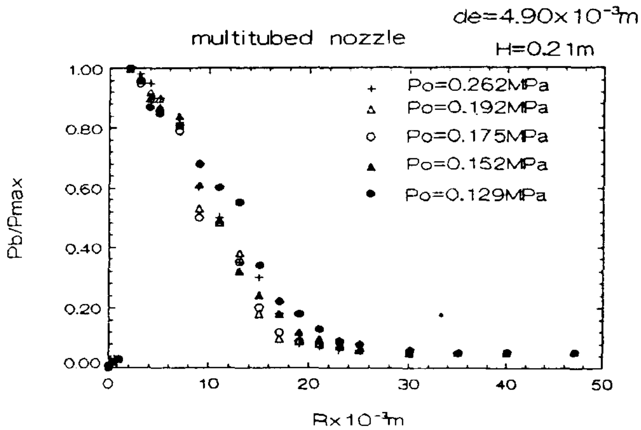

Fig.6 Radial distribution of Pb on the bottom for the multitubed nozzle de=4.9x10⁻³m

Figure 7 shows the effect of different shape of nozzle with similar equivalent diameter on the impact stress. As shown in this figure, the equivalent diameter de=5.02x10⁻³m for slit type nozzle, de=4.98x10⁻³m for annular slit type nozzle and de=4.9x10⁻³m for multitubed nozzle. The exit area of all the above nozzles are basically equal to the area of straight tube nozzle of de=5x10⁻³m, but the equivalent diameters are slightly different. In other words, the four kinds of nozzles are nearly same in equivalent diameter and gas exit area. This figure demonstrates that the Pb increases with the increase of the equivalent diameter and is also affected by the nozzle shape under conditions of a definite gas fed pressure and a definite liquid depth.

Bubble band near the gas exit expands with

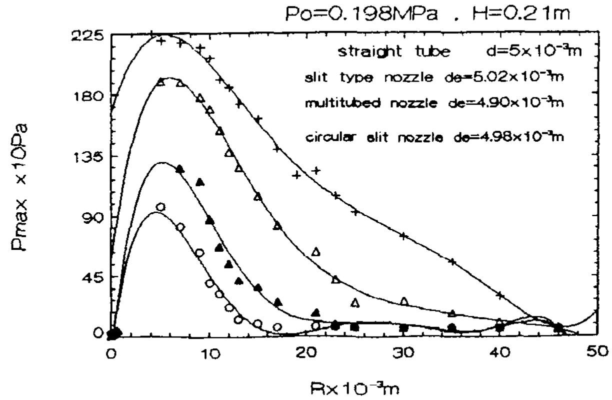

Fig.7 Radial distribution of Pb on the bottom for the different shape of nozzle

the increase of the equivalent diameter under the same supplied gas pressure Po. More liquid is needed to occupy the space of the bubble when the bubble breaks out from the gas exit. Thus, the impact stress of the liquid on the furnace bottom increases and the affective range also expands. In addition, the liquid, which occupies the space above the nozzle resulted from the bubble break-up, brings about an abrupt impact on th enew bubble formed at the gas exit. So that the new bubble changes into an oblate form. In this case, the oblate bubble moves abruptly down to the furnace bottom. Obviously, the larger the nozzle diameter is, the larger the effective range of the bubble recoil is. It clearly shows that the effect of nozzle diameter on the impact stress isopiestics is very notable in addition to the effect of supplied gas pressure Po on Pmax. Figure 7 also shows that the annular slit type nozzle is the best one and the multitubed nozzle is the second one for decreasing the impact stress on the furnace bottom under the same supplied gas pressure Po, and that the slit type nozzle is a bit better than straight tube nozzle. The effective range of the impact stress for the slit type and straight tube nozzle are all considerable. Therefore, the annular slit type nozzle is the optimal one theoretically. But it is very difficult to make an accurate annular slit nozzle in practice. If an annular slit nozzle has a little dissymmetry, the gas flow through the nozzle slit would also have dissymmetry, so that the nozzle would be damaged quickly. Therefore, the multitubed nozzle has been widely developed due to its higher life duration in practice.

IMPACT STRESS ALONG THE FURNACE WALL

Figure 8 and 9 indicate the impact stress distribution along the furnace wall with straight tube nozzle of diameter $d=5\times10^{-3}m$ and multitubed nozzle of equivalent diameter $de=4.98\times10^{-3}m$ respectively under the different supplied gas pressure. The impact stress acted on the furnace wall is mainely caused by the flow of melt. It can be seen from Fig. 8 and 9, that the impact stress acted on the lower part of furnace wall changes unremarkable but it increases with the increase of supplied gas pressure. On the upper part of the furnace wall,

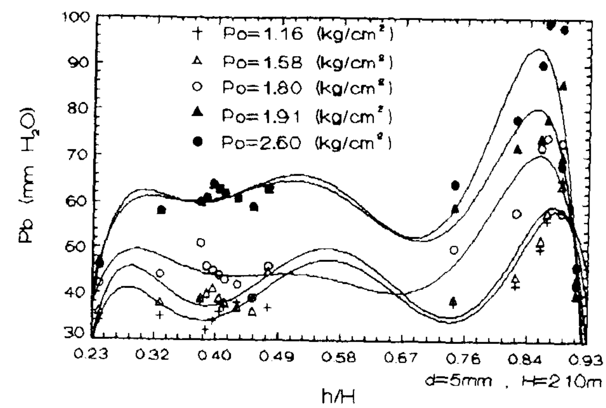

Fig.8 Impact stress distribution along the furnace wall for straight tube nozzle of $d\ 5\times10^{-3}m$

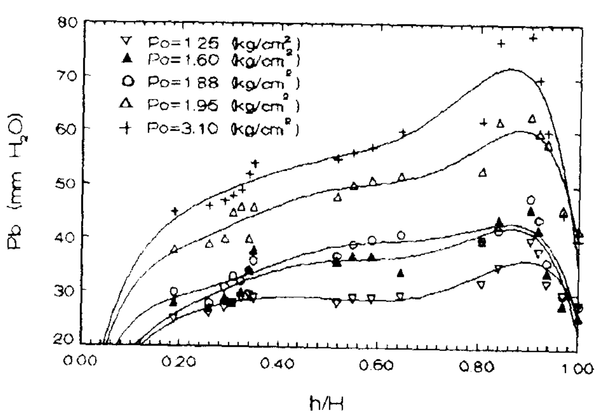

Fig.9 Impact stress distribution along the furnace wall for multitubed nozzle of equivalent diameter $de=4.9\times10^{-3}m$

the impact stress increases with the increase of wall hight and reaches its maximum value near the liquid surface. The muximum value is caused by the larger liquid surface velocity and fluctuation. We have fund the same situation in the production furnace, that is the serious erosion of furnace lining appears at the upper part of furnace wall under the slag line in the combined blown converter.

CONCLUSIONS

Acording to above analyses, the conclusions for the impact stress distribution acted on the furnace bottom and wall can be expressed as follows:

1), The impact stress acted near the nozzle is the largest and decreases rapidly with the increase of the distance from the nozzle. The dimensionless effective radius of the impact stress on the furnace bottom is notable as $R/d=10-13$.

2), The impact stress increases with the increase of the supplied gas pressure Po.

3), The effect range of the impact stress, acted on the furnace bottom, increases with the increase of the equivalent diameter of the nozzle under the condition of the same supplied gas pressure Po.

4), Under the condition of the same gas flow rate, the optimum nozzle is the annular slit or multitubed nozzle, which may not only decrease the impact stress acted on the furnace bottom but also uniformly distribute the bubble in the vessel, resulting in favorable effect to the stirring of the bath.

5), The maximum impact stress acted on the furnace wall appears at upper part of the furnace wall under the slag line, and increases with the increase of supplied gas pressure Po.

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A Strategic View of Managing Information Technology in the Steel and Metals Sector

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ABSTRACT

As we begin the last decade in this century, a common theme that emerges is one of change. This decade holds an alluring promise of exciting transformations in the world economies and the possibility of dramatic changes in business philosophies. In the world economic order, business relationships and the emergence of new steel making technologies have created a fresh set of paradigms for performance and success. Information technology has evolved to the point where enabling technologies are being routinely exploited. The steel industry is in a state of change and a strategic investment in information technology will prove to be a key factor for success. The widespread use of computers and information systems from the plant to the board room is becoming the basis for competitive differentiation.

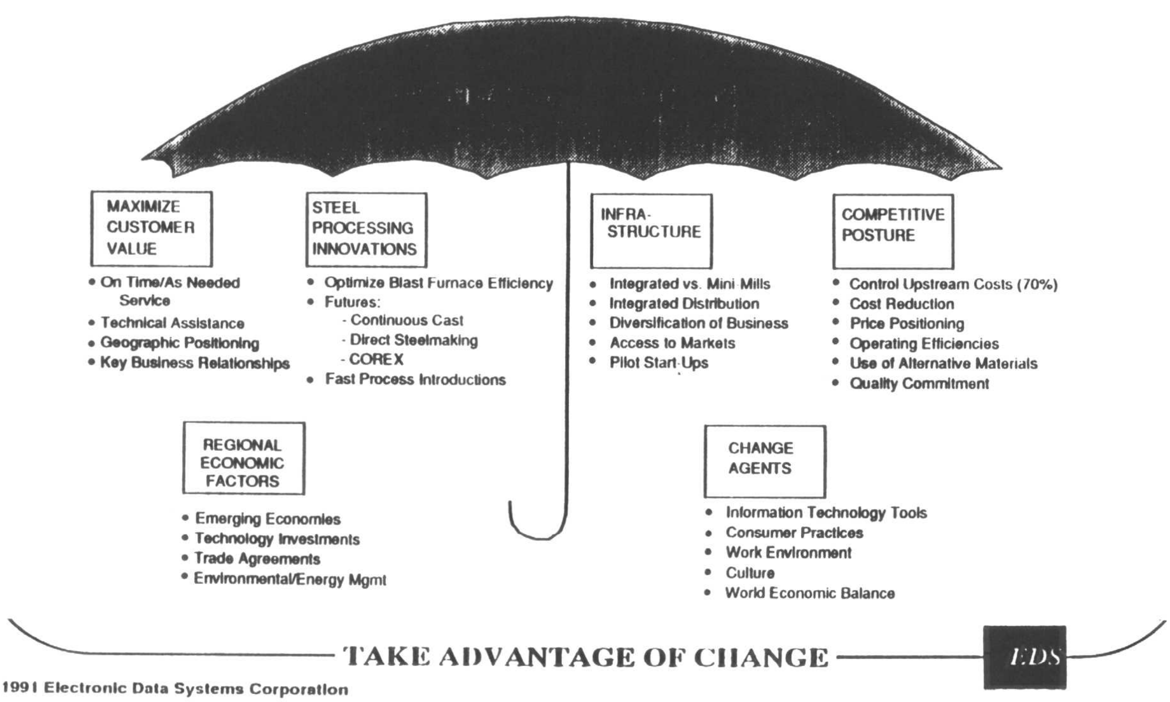
GLOBAL COMPETITION IS HEATING UP and with the rate of technological change, coupled with man's ability to harness that change, information may very well be the true currency in a global marketplace. The major changes that have occurred are a result of several factors. The market has shifted so that the specifications and requirements are more exacting. Capital formation tied with capital availability has constrained many business entities and producers to be more selective in their investments. The industry infrastructure is witnessing a dramatic growth of minimills and reconstituted mills. Alternative materials such as plastics and composites and aluminum are making inroads into market share. The exchange rate phenomena and the rapid emergence of free trade zones is affecting the export-import relationships as well as causing extreme volatility in pricing and availability of capital for technology investment purposes. Global competition is also being directly affected by government regulations and environmental concerns. In efficient steelmaking processes has forced an evaluation of cost efficient operations.

This paper will address the need for managing the new information paradigm. The emphasis on using information technology as an enabler and a differentiator will be discussed. The concept of a structured information management planning process will be reviewed in the context of a manufacturing business vision. It will thus be possible to understand how specific information technology drivers and initiatives can provide the competitive edge.

STEEL INDUSTRY - MARKET INFLUENCERS

The strategic view of managing information technology can be addressed from an umbrella perspective. There are six major market influencers within this broad perspective. A business group or a steel producer can thus assess its competitive gap and focus on the opportunities that are available to it. The role of information technology is to provide the linkage through these influencers. The focus on maximizing customer value emphasizes the concepts of just-in-time deliveries and effective order management practices. The aspect of providing technical assistance as well as post-sale collaboration and key problem resolution are linked. Plant location and delivery logistics play a very important role as well. Innovations in steelmaking processes require the ability of steel producers to move processes from a pilot or R&D stage into production effectively. The availability of raw materials and proper grades of iron ore, coke, and other materials can influence the choice of an appropriate technology. The efficiency with which producers bring these processes online and the capability to manage process variation quickly, often affects the ability of a producer to manage cost and retain market share. The use of information technology tools in this context include process controls, statistical analysis and quantitative modelling of the process. The impact of the industry infrastructure are often factors of competition provided by minimills, market access, and business diversity. The relevant impact of information technology is best identified via management practices, cost structures that are responsive to changes and realtime decision making capabilities. Regional economic factors include energy and environmental systems, joint ventures, and trade agreements that affect operations. The information technology perspective thus focuses on information exchange, monitoring systems and simulation capabilities. In the final analysis, steel industry players have to identify their own competitive posture in terms of metrics that it can manage and control. Operating rates and the efficiency of its operations

STEEL INDUSTRY - MARKET SHARE INFLUENCERS



are a key to correlating costs, leadtimes, prime yields, inventory levels, and the effective use of its productive assets. The final set of influencers lies in the ability of a steel producer to harness external change agents and to rely on its own internal ability to change. Such change is often introduced via business and management practices. The process of managing change has been described as business process reengineering. It is clear from research findings and literature, that there are a variety of market influencers in the steel industry. The opportunity to succeed lies in the ability of a steel player to simultaneously harness business issues and the effective use of information technology tools.

THE ENVIRONMENT OF THE STEEL SECTOR

In order to appreciate how information technology can be useful, it becomes necessary to develop a simple, but comprehensive view of the environment that the steel industry players find themselves in.

Steelmaking practices are continually evolving. The use of steel scrap substitutes materials, coke alternatives, BOF practices, pulverized coal injection methods and trends in ladle metallurgy processes have all changed the efficiency of ironmaking and steelmaking methods. Cost efficiencies gained here provide a substantial advantage to steel producers. The rapid growth of continuous casting facilities and the focus on thin slab cast ing has opened up opportunities for producers to make significant operational cost improvements. Rapid advances in hot rolling and cold rolling practices have introduced a variety of techniques such as tandem rolling, cross rolling, edging and reversing capabilities. And in recent times the growth of galvanizing facilities to meet the needs of the automobile industry has introduced a strong focus on quality. The net result of this technology is a strong commitment to quality, yield improvements and cost improvements due to an efficient application of practices.

The competitive nature of the market place is changing at a rate whereby the traditional measures of performance have given way to a market-driven focus. Even though price is an important factor, much more emphasis is being placed on customer service. The elements of this focus lie in the concepts of supplier responsiveness. These, in addition to meeting quality requirements, include delivery systems, joint production planning, order management and fulfillment, and reaction to changes in market requirements. The impact of these factors on a steel producer are felt in having flexible manufacturing capability, managing a dynamic product mix, and relying on competitive benchmarking that goes beyond traditional cost measures. The age of the discriminatory consumer is here to stay.

The intense competition for markets and niches between integrated mills and minimills, and reconstituteds, has put an intense pressure on cost improvements and an in-depth understanding of overhead and allocated costs. The dramatic impact of these influences are being felt in management practices, organization structures, and decentralized/autonomous mode of operations. Thus a focused, participative, and committed workforce becomes a key means of differentiation. This has increased the emphasis on identifying and maintaining core competencies and technical expertise, at a time when technology-critical skills are in high demand, and short supply.

With respect to the information technology arena, the key issues have evolved to systems integration perspectives and not the technology itself. The computing infrastructure has become a competitive differentiator. The reliance on realtime information, the emphasis on moving decision making to the lowest levels, the need for process control systems that facilitate inter-process coupling are all examples of areas where information systems are being speedily deployed. The extent to which a steel player can move boldly ahead to make strategic investments in information technology, will dictate the competitive gap that will exist among them. Decision support systems, such as artificial intelligence, process modelling and simulation and process design aids are all making a significant impact in this industry today.

In the final analysis a steel enterprise is a 'manufacturing' organization. Every manufacturer utilizes a business value chain that focuses on the primary and support functions of the business. The winner is often the one that is able to maximize the utilization of this value chain and focus on continuous improvement. In real terms this is the issue of reducing lead time for all functions and processes in the enterprise.

There are a number of examples in the steel industry that focus on strategic information technology investments. The basic concepts that are found in these examples include :

* lead time improvement
* quality management
* inter-process linkages
* production monitoring
* order management
* performance management
* inventory management
* decision support tools
* executive information systems
* synchronous practices

As the steel producers and industry players implement these practices, it becomes important to rationalize the organization's business management practices and processes. For example the I/N TEK strategy calls for the use of computer integrated methods to link its operations in a continuous process: pickling, tandem rolling, annealing, temper rolling and inspection. The steel operations at Weirton has a strategic plan to link realtime systems that integrate the functions of order entry, scheduling, tracking and on-time delivery. At other steelmakers, there exist strategies that link the caster with the steelmaking process and the blast furnace. At others, the caster is linked to downstream hot rolling processes. In Japan, the trend towards process automation and synchronous process is focused on the reduction of lead time and elimination of bottlenecks. There are similar experiences being recorded in Brazil and in S. Korea. Recent literature points to the use of networking, electronic data interchange and expert systems in the steel operations at POSCO.

The current environment of the steel sector is filled with examples of dynamic change that is introduced by the market, world economies, process technologies that are designed to provide significant advantage, and an information paradigm that is moving the industry into a realtime mode of operations. The aspect of information being the real currency in this industry may very well be true.

STRATEGIC VIEW OF MANUFACTURING

The manufacturing business vision is a three-tiered model that is supported by a platform of competitive advantage enablers. The core business culture and values acts as the pipeline that integrates all levels of this model. The model suggests that in order to be a responsive enterprise one must have leadership while focusing on integrating technologies with the competitive advantage enablers. Information thus becomes the common link and provides a seamless view of how the plant floor processes are linked with the business systems so that the whole enterprise is optimized. The real value then comes from converting realtime data into formats for realtime decision-making information. The business functions of the enterprise are then identified as nothing more than a series of interlinked business processes. It is within this framework that the management of information technology must be viewed. In order for a steel industry player to be effective, it must focus on three specific initiatives :

* develop a business model framework
* link key business drivers to the information requirements
* link information technology investments with organizational effectiveness objectives

The business information model depicts the enterprise value chain and captures two fundamental perspectives of the information architecture: the business processes; the data management processes.
By completing an affinity analysis, that groups data entities and processes, an architecture model can then be created. From this a useful view of a systems integration model links the business functions of the enterprise with the data, computing,

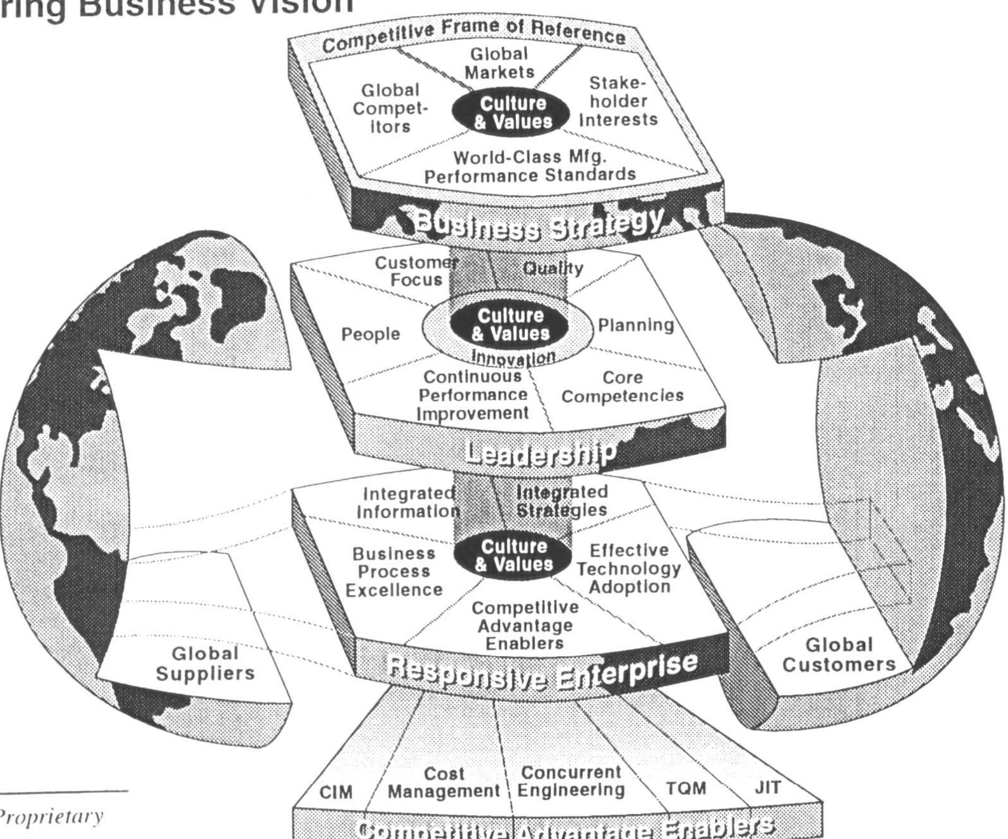
and communications infrastructure.

The business information management planning framework provides a useful view of correlating business directions, vision and opportunities with information technology architecture and investment. The business model framework for information technology planning provides a useful view of a culture based organizational model. Thus a strong management focus and leadership vision **is critical** in an age where time-tested norms are in a state of change. The focus on decentralized vs centralized role concepts provides an insight into the culture of the organization. The ability to use information technology tools by moving decision**s** lower into the organization is directly affected. With the rapid increase in process automation, there is a tendency for the worker to be often dis-empowered from the job functions. The leadership paradigm therefore needs to focus on workforce recognition and support so that the firm's competitive advantages can be maintained. From this perspective, information technology is facilitating new organizational forms. Some of the key characteristics that are often noted include :

* fewer layers of staff/management
* small inter-disciplinary teams
* customer focused organizations
* empowered and creative environment

The competitive advantage enablers that are noted provides a view of how information technology could be exploited. CIM or computer integrated manufacturing focuses on an enterprise architecture to link plant floor processes to business planning and related functions. TQM or total quality management links the statistical process control activities with process design and improvements in prime yield. JIT or just-in-time manufacturing focuses on schedules, order management and productive operations utilization. Concurrent engineering allows a systematic process for manufacturing process design, pilot production and shop floor process quality improvements. It is in this manner that the strategic intent of the business is achieved.

Manufacturing Business Vision



EDS Proprietary

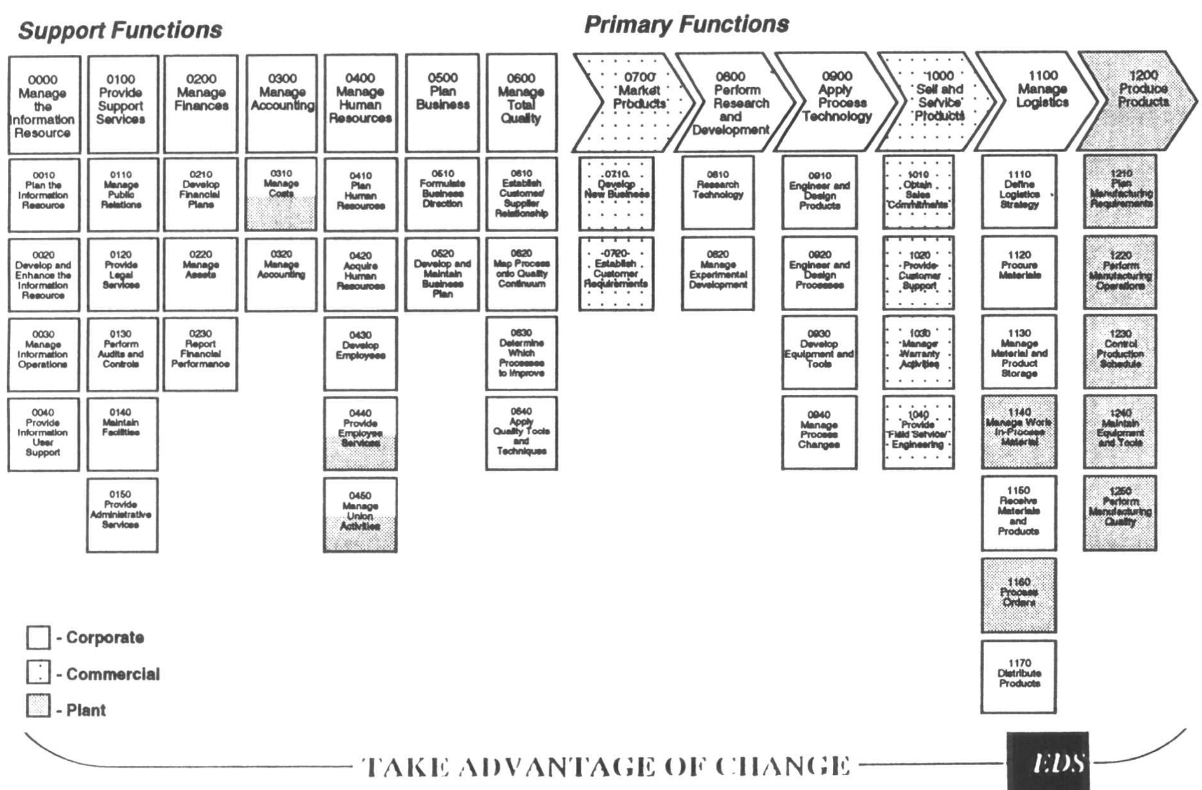
KEY ENABLING TECHNOLOGY DRIVERS

In the steel industry time is indeed money and survival. To the extent that the information technology investment directly affects time related performance measures, the business will prosper. The primary areas where ' time ' becomes a major determinant include ;

* decision support systems
* process controls and automation
* inter-process logistics
* productive operating rate
* electronic data interchange
* communication networks
* people skills and core competencies

Decision support systems, including the use of simulation and artificial intelligence systems are primarily used to model operations, processes and aid decision making. Thus resources are optimized, and the total quality program is enhanced. The focus is on improving throughput and reducing operating expense. In the area of process controls and automation, the driver is yield management and reduction of process variation. Conformance to specifications, heat chemistry management, and timely problem resolution are the areas of focus. Inter-process linkages, in this regard, will provide the opportunity to link process steps, thereby allowing more efficient use of the productive time available. In order to

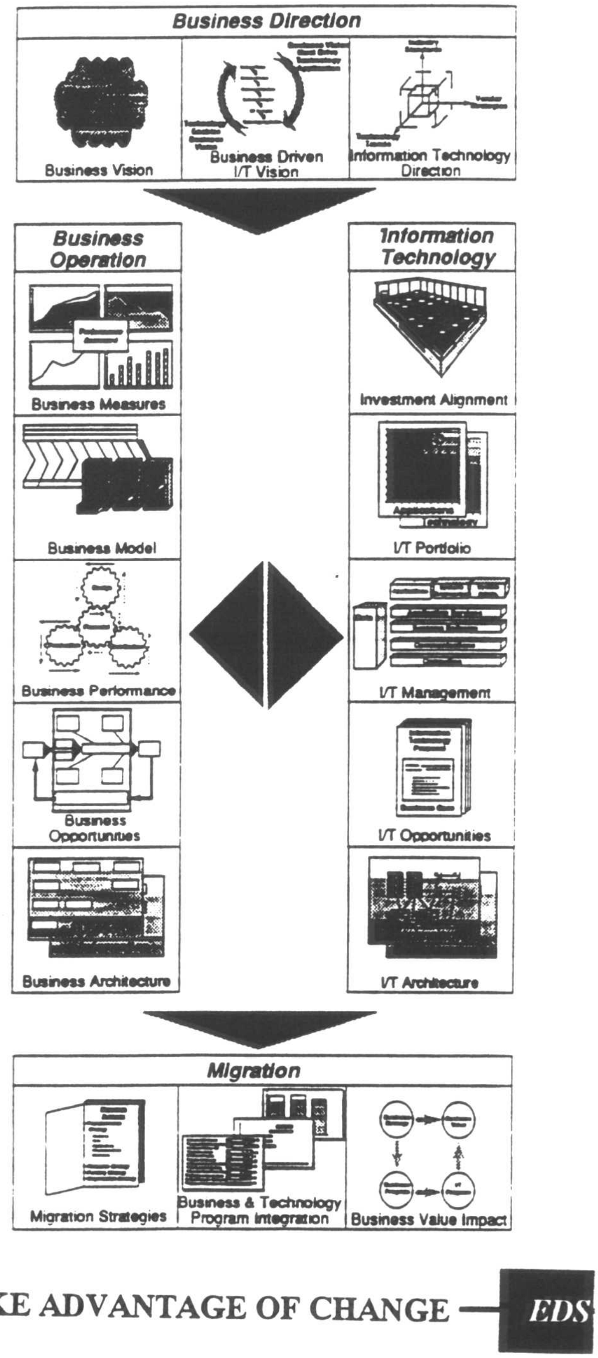
Business Model



maintain a responsive cost structure and maintain a high operating rate, steelmakers will continue to focus on those tools that enable them to do so. Among these will be tools using finite capacity scheduling methodologies, process diagnostic tools, machine diagnostic tools that are linked to maintenance management strategies and programs, and process improvement methods. The use of electronic data interchange as a method to link with customers, suppliers and vendors will be an important key for an organization that is using time as a common denominator. The EDI linkage is critical to becoming a fast cycle company. The communications and network architecture in this environment serves as the backbone for connecting all aspects of the business enterprise. The primary driver is to move rapidly towards realtime autonomous decision making in the enterprise. And finally, people skills and core competencies remains a powerful dirver. Ultimately, the most effective use of information technology is in decision making. While the technology enablers aid, they do not replace bodies of intrinsic knowledge.

CONCLUSION

This paper has presented a strategic view of managing information technology in the steel sector. The central theme is that change is inevitable. The steel sector is faced with a wide variety of market influencers. The discussion suggests that steel players will need to develop a broad and comprehensive information technology strategy that is designed to provide it with a significant business advantage. The winners will clearly comprehend the information paradigm as information being the true currency of global competition.



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Physical Metallurgy of Micro-Alloyed High Strength Low Alloy Steels

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Abstract

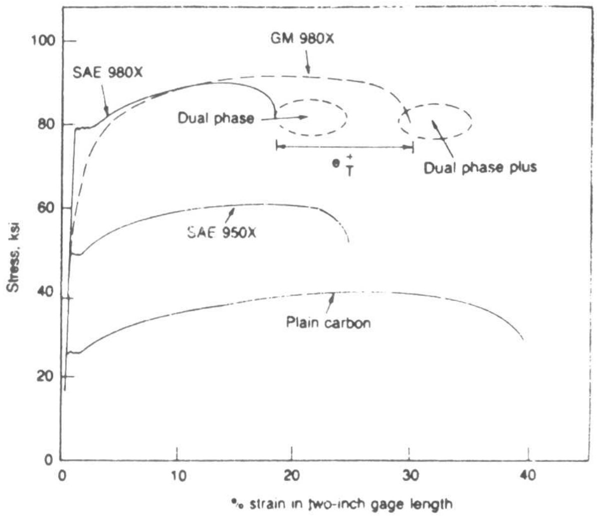
In the last three decades microalloyed high strength low alloy (HSLA) steels have become established as the preferred engineering materials for a wide variety of structural applications. In the present paper physical metallurgy of these steels is discussed from structure - property - processing aspects.

MICROALLOYED HIGH STRENGTH LOW ALLOY (HSLA) STEELS can be defined as low C-Mn steels containing very small amounts (usually < 0.1 wt% singly or in combination) of microalloying elements (MAEs) such as niobium, vanadium, and/or titanium to attain yield strengths > 275 MPa (40 ksi), and good fracture toughness and weldability. The modern microalloyed steels can now achieve yield strength of 650 N/mm^2, CVN of 80 J at -60°C with 40 % tensile elongation. The processing methods of these steels include: (a) hot rolling at high reheat and finish-roll temperatures, (b) conventional control-rolling (CCR) at high reheat and low finish -roll temperatures, and (c) recrystallization-control rolling (RCR) at low reheat and high finish-roll temperatures to produce desired microstructures and properties (1-3).

Microalloyed HSLA steels are successfully used as strip, plate, bar, structural section and forged bar products; they find applications in several diverse fields such as in oil and gas pipelines; automotive, agricultural, and pressure vessel industries; as off-shore structures and platforms; and in the construction of crane, bridges, buildings, shipbuildings, railroad tank cars, power transmission and TV towers. As-rolled microalloyed steels exhibit properties similar to or better than normalized or highly alloyed quenched and tempered steels. They are more economical than the quenched and tempered high alloy steels because of their cost effective combinations of MAEs addition and elimination of multi-step heat treatment and straightening operations (1-5).

The main purpose of addition of MAEs in steels is twofold: (a) to produce precipitation strengthening and (b) grain refinement. During controlled rolling, both of these phenomena are caused by the precipitation of extremely fine dispersion of very small and stable microalloy carbides (NbC, VC, TiC), nitrides (NbN, VN, TiN) and/or carbonitrides [NbCN, VCN, TiCN, (Nb,V)CN, (Nb,Ti)CN] (6). These stable second phase particles form: (i) during reheating to the austenitic temperature; (ii) during and after transformation of ferrite; (iii) during and after accelerated cooling; and (iv) in transformed martensite during tempering to provide secondary hardening. The unique strength and toughness properties of microalloyed HSLA steels arise from the precipitation and interaction of these precipitates with the process of recrystallization and grain growth of γ and of transformation from γ to ferrite (7). Typical stress-strain curves for C-Mn (or mild) steel, HSLA steel, and Dual Phase steel in Fig. 1 show that yield strength of HSLA steel in the 350-700 MPa (50-100 ksi) range is double that of C-Mn steel (8)

The role of MAEs in controlled rolled plate steel is different from that in hot rolled strip steel. For example, in plate steel, Nb is employed to stop or significantly delay the recrystallization of γ in the early stage and allow further deformation to produce fine austenite 'pancakes' that transform to very fine ferrite grains. Thus, here, lower reheat temperature is beneficial. In hot strip rolling, Nb is used to stop γ recrystallization late in the rolling process and to permit water cooling to produce very fine grains, which can be precipitation strengthened at lower temperature by Nb after the steel has been coiled. Thus, it is advantageous to prevent extensive precipitation of Nb in austenite (9).



(a)

Fig. 1. Stess-strain curve for plain carbon, HSLA, and Dual phase steels (8).

Controlled Rolling

An important difference between hot rolling and controlled rolling is that roughing and finishing steps are continuous and the nucleation of ferrite occurs primarily at austenite grain boundaries in the former, whereas there is a delay between the roughing and finishing stages and the nucleation of ferrite occurs in both the strain hardened grain interiors and at grain boundaries in the latter, resulting in more grain refined structure (10). The controlled rolling or conventional controlled rolling (CCR), performed on strip, plate, and bar mills, is increasingly applied to microalloyed HSLA steels with specific compositions to achieve a very uniform ferrite grain size causing an increase in both the yield strength and toughness properties. The CCR process involves the following five steps, as shown in a schematic temperature/time profile in Fig. 2 for the rolling of HSLA steel plate (11): (1) reheating the steel plate or slab to the austenitizing temperature and soaking it at this temperature to produce uniform γ- grains; (2) a series of high temperature rolling (roughing) passes to continually refine the γ-grains by sequential recrystallization (in the γ recrystallization temperature range); (3) holding (or a time delay of) the steel components to lower temperature to allow a temperature drop below recrystallization to produce a static recrystallization of γ-grains; (4) incorporating a series of low temperature finish-rolling passes in the austenite non-recrystallization region to break -up and flatten (or pancake) the recrystallized γ-grains, completed above or below Ar_3 temperature

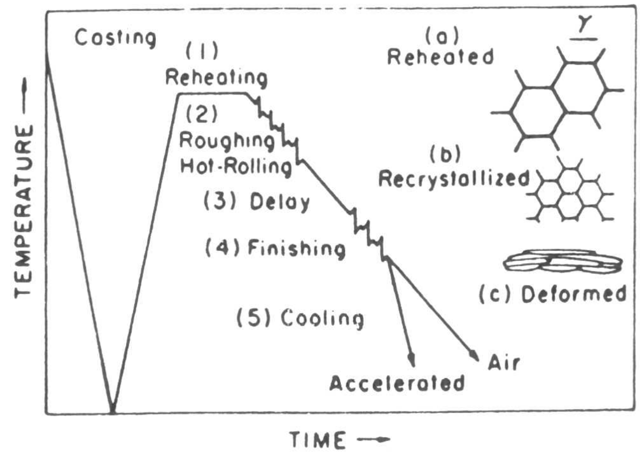


Fig. 2. Controlled rolling process.

in the two-phase austenite-ferrite region; and (5) finally controlled cooling to form ultrafine ferrite grains from such deformed (pancaked) γ-grains (Fig. 3) (12). The optimum conditions for each of these steps depend on the fundamental physical metallurgy of steels, but whether they can be achieved in practice is ascertained by the availability of suitable processing equipment and by economic considerations (13).

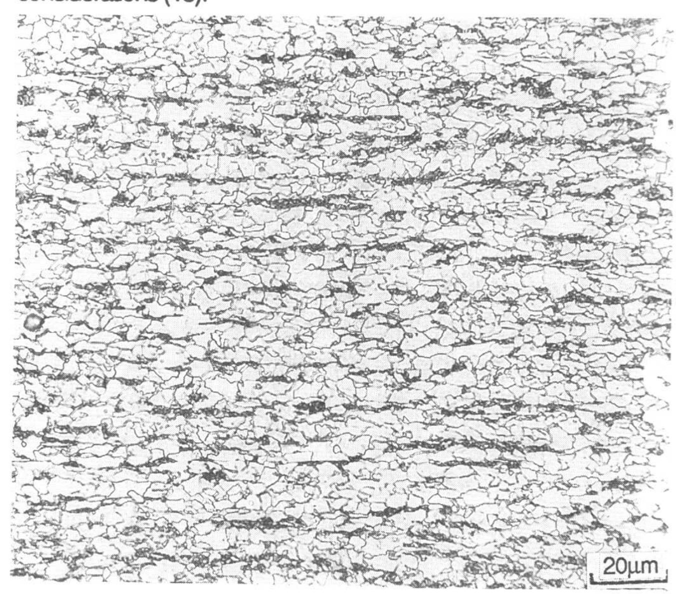


Fig. 3. Ultrafine-grained ferrite produced from flattened unrecrystallized austenite (12).

It is noted that the resulting microstructure assoaciated with deformation below Ar_3 consists of deformed γ-grains with deformation bands and deformed ferrite grains with a subgrain structure, The former transform to polygonal ferrite whereas the latter exhibits the same structure (10). The grain structure is finer and more uniform in controlled rolled and accelerated cooled HSLA steel plates than in controlled rolled and air cooled HSLA steels (14,15).

The success of the CCR process lies in its ability to promote the occurrence of recrystallization in the high temperature region and to avoid it during the low temperature finish rolling. The CCR process is sometimes applied to modern plate and strip mills to produce very fine as-rolled ferrite grain sizes in the flat-rolled products (16)

Nb is the most effective MAE for grain refinement by CCR. During the rolling reductions at < 1040 °C (1900 °F), Nb in solution suppresses recrystallization by solute drag or by strain induced Nb(CN) precipitation on the deformed γ and slip planes. A useful amount of precipitation strengthening is possible in control-rolled Nb steels. Nb is most effective MAE in raising T_R temperature (Fig. 4). Ti, Al, and V are not so effective in raising the T_R temperature (17). It has been shown that the absolute value of T_R depends on grain size, strain and composition (13).

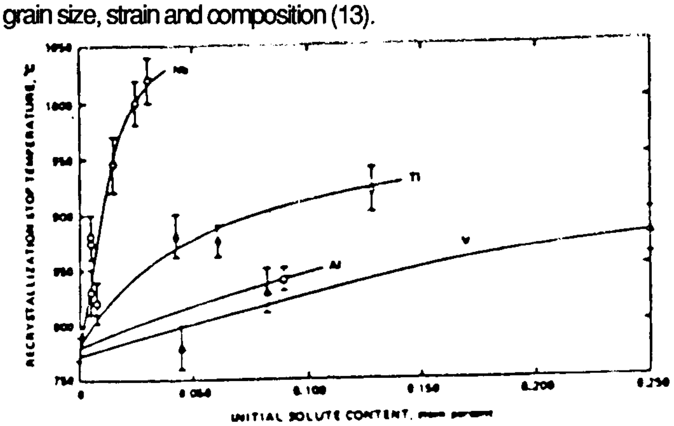


Fig. 4. Effect of various additions of microalloying elements on "Recrystallization stop temperature"(T_R) (17).

The serious shortcomings of CCR process are the following :

1. Hold period necessary to reach T_R temperature after the high temperature roughing passes, causes excessive processing time which decreases mill productivity. However, application of accelerated spray cooling during the delay/hold period at the roughing stand exit temperature for 10-15 sec has resulted in the improvement of productivity up to 300% in X65 and X70 line pipe steel plates and upgrading of yield strength range and notch toughness, when compared to conventional control-rolled plates of equivalent thicknesses (18).

2. High roll separating forces (due to low finish-roll temperature) are often above the design loads of the mill. That is, CCR is difficult to use with older, less powerful plate and strip mills, as well as modern high speed bar mills because of the incorporation of a low finish-rolling temperature region. Moreover, low temperature controlled rolling is hardly suitable for fast mills designed for rolling long products (17).

STAGES OF CONTROLLED ROLLING

1. Reheating. The reheating conditions determine the amount of MAEs taken into solid solution and the initial γ grain size for thermomechanical processing. Solution of MAEs depends on two factors: (a) thermodynamic stability of carbonitrides and (b) the kinetics of dissolution for the size distribution of particles present (13). *Reheated austenite* refers to the austenite at the solution temperature (above Ac_3) after casting and ready for the hot-rolling operation. It consists of annealed, equiaxed grains associated with high angle boundaries, with some grains containing annealing twins.

Solubility of Microalloyed Precipitates. It should be noted that the solubility of carbide particles in the austenite increases in the order NbC, TiC, VC, while the nitrides with normally lower solubility increases in solubility in the order TiN, NbN, AlN, VN. It is thus apparent that NbC and TiN are the most stable particles, the most effective grain size refiners, and are more resistant to coarsening by effectively particle pinning of grain boundaries and dislocation arrays. However, Al, V, and Ti are more effective in high-nitrogen steels, by forming comparatively stable AlN, V(CN), and Ti(CN) in austenite (18), which may be potent in preventing grain coarsening on reheating, but not effective in preventing recrystallization (19).

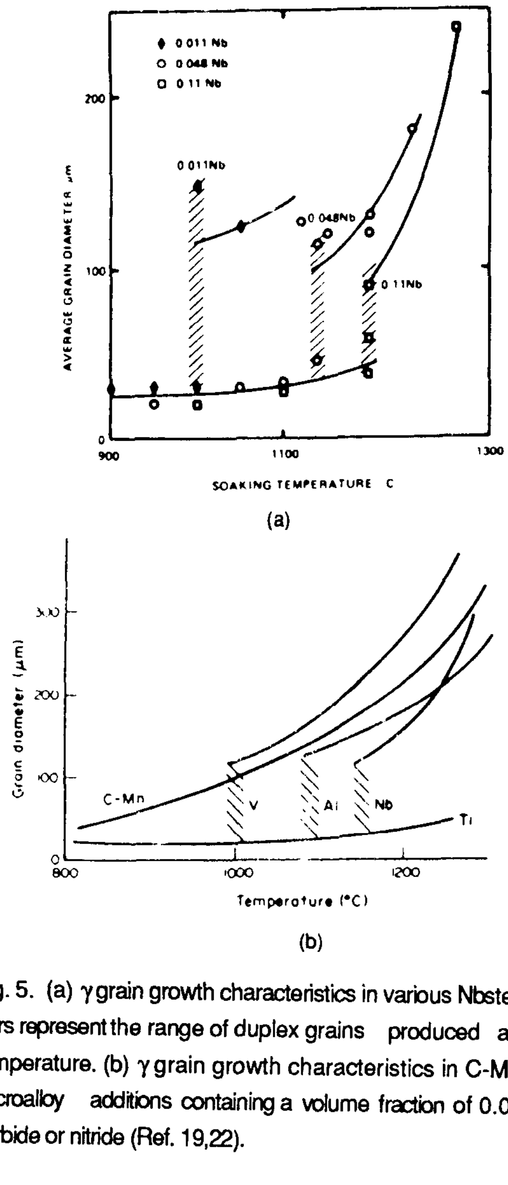
Sulubility data for the carbides and nitrides of Nb, V, and Ti in γ provide a guide to precipitation bahavior during CCR. Precipitation of carbides and carbonitrides occurs during the γ/α transformation in several modes.: planar and non-planar interphase precipitation and fibrous carbide growth (20). The precipitate solubilities in ferrite are much smaller than in austenite, but follow the same general trends.

Grain Coarsening Temperature (GCT). During reheating of the slab austenite, grain growth occurs either continuously or discontinuously with time, temperature, and heating rate, depending on the type, size, and volume fraction of the second-phase microalloy carbides and/or nitride particles. Grain coarsening in C-Mn steels during reheating between 800 and 1300°C obeys a well-established continuous grain growth law expressed by

$$\bar{d} = K.t^a .\exp(-b/T) \qquad (1)$$

where $\bar{d}$ is the average grain diameter, t is the time, T is the temperature in absolute scale, and K, a, and b are constants (21).

Grain coarsening in microalloyed and Al - killed steels in the temperature range of 900-1300°C is, however, characterized by continuous growth at low and high temperatures; between thesetemperature regions is a narrow temperature range where abnormal grain growth comprising a duplex distribution of austenite grain size occurs (Fig.5) (19,22). This figure illustrates the grain coarsening behavior during reheating in C-Mn steels with MAE additions that form with a volume fraction of ~ 0.0005 of alloy carbides and/or nitrides. It also illustrates that γ-grains grow very



(a)

(b)

Fig. 5. (a) γ grain growth characteristics in various Nbsteels. Hatched bars represent the range of duplex grains produced at the coarsening temperature. (b) γ grain growth characteristics in C-Mn steels with microalloy additions containing a volume fraction of 0.0005 of alloy carbide or nitride (Ref. 19,22).

little with increasing temperature during continuous grain growth, while grain growth becomes very rapid during abnormal or discontinuous grain growth. It is thus apparent that steels containing microalloyed second phases are susceptible to grain coarsening in a particular temperature range. The GCT may be defined as the temperature beyond which grain growth is very rapid; this depends on composition, initial γ grain size, and particle size distribution. Abnormal grain growth is largely controlled by grain boundary-particle interactions (23). When a critical area-fraction of grain boundary is covered by particles, boundary pinning commences Boundary pinning is promoted by high volume fraction and finer-sized particles. If the reheating temperature is too high, the particles tend to coarsen or dissolve. As a result, some boundaries can be released which would lead to abnormal grain growth.

The simplest approach to achieve high strength in HSLA steel plates is through vanadium additions which provide precipitation strengthening by the formation of vanadium carbonitride precipitates (generally smaller than 300 Å in diameter) in the ferrite below 700°C, i.e., during transformation of austenite to ferrite. The strengthening can be further increased by raising nitrogen content, but not at the expense of precipitation in austenite. In addition, vanadium stabilizes ferrite. Increased amounts of vanadium above 0.14% refine the γ-grain size at temperatures up to ~ 1000°C and do not contribute any marked effect above 1100°C (24) due to appreciable solubility of VCN in austenite.

The AlN particles prevent grain growth in normalized steels and in, some cases, in bars during forging (6). The grain coarsening temperature in Al-killed steels is above 1050°C (25).

For thinner plates and low-strength grades, where finish rolling temperatures are low, Nb can be used to provide strength by grain refinement. However, in thicker plates and higher-strength grades, the strength from grain refinement in controlled rolled steels often has to be supplemented by the V addition to provide some precipitation strengthening. HSLA steels produced with Nb addition alone or together with V is normally cheaper than steels with larger V addition alone.

Since thicker plates cool more slowly and the finishing temperature is higher, some strengthening can take place through precipitation of NbCN. However, there is a likelihood of bainite formation with a high Nb level; both of these tend to cause a loss in toughness, but the bainite content increases the tensile strength. Carbonitrides of niobium precipitate at temperatures below about 1000°C when the steel is austenitic. In rolled steels, niobium prevents recrystallization of austenite that results in the formation of pancake-shaped grains and fine grained ferrite, which, in turn, leads to increased strength and toughness. Niobium carbide precipitates also prevent grain coarsening of austenite during normalizing; thereby, increasing its strength and toughness. Nb also serves as a ferrite strengthener.

The effective use of niobium as grain refining and precipitation strengthening agent depends on the use of a quite high temperature (up to 1200°C) during reheating for rolling (7). Nb-bearing steels have sufficiently higher grain coarsening temperature than the V-bearing steels and Al - killed steels. The grain refinementof austenite by Nb addition is more effectively accomplished (relative to the Ti, V, and Al addition) on both the reheated grain size and recrystallized grain size when the Nb content is up to 0.1 wt% and the temperature is up to 1200°C. The precipitate formed over a range of temperature during hot rolling and responsible for grain boundary pinning is $Nb_x(C_yN_{1-y})$ (26). Nb addition can decrease the stability of TiN and produces a lower GCT. Rapid austenite grain growth arises from the solution of fine (< ~15 nm) TiN or TiNbN particles and the consequent increase in mean grain size and decrease in volume fraction of these particles.

The starting austenite grain size on reheating after solution treatment or hot rolling, is also a factor which can affect the GCT (27). Ti addition up to 0.04% causes the formation of stable nitride, which raises the GCT to about 1300°C during both isothermal soaking and hot deformation. The stable precipitates formed during soaking and responsible for grain boundary pinning in high temperature austenite, thereby restricting austenite grain growth are TiN and TiNbN. Carbides or carbonitrides of titanium can form and result in precipitation strengthening in strip and thin plate steel during fast cooling. Titanium is also the most effective element for scavenging nitrogen from solution in ferrite in strip steels (6).

In plain carbon steels recrystallization is sluggish at low temperatures in the γ-region (above 900°C = Ar_3); hence a finishing temperature should be above 750°C and preferably 800°C. Nb has a powerful retarding influence on γ-recrystallization. It has been observed that the retardation of recrystallization due to Nb is more effective when an appreciable amount of Nb remains in solution in austenite prior to the start of rolling (28). In Nb-steels, the finishing temperature is above the temperature range of 850-900°C.

When more than one MAE are present in a steel, the cumulative benefits can be achieved in combination with some interactions which, in some conditions or compositions, can decrease the individual effectiveness of each element. When two MAEs are used in a steel, the element which usually precipitate at lower temperature will always has a tendency to precipitate together with the element that precipitates at higher temperature. For example, in steels containing Ti and V or Ti and Nb, V and Nb will be associated with the precipitates of TiN which forms above 1300°C. This may influence the function both of the Ti and of the V or Nb. This precipitation of V or Nb with the Ti in the nitride can increase the TiN particle size, making them potent in preventing grain growth of the austenite. Conversely, when V and Ti are present in steels, the the latter removes N from the system which reduces the precipitation of VCN in ferrite (VCN) (7).

2. Rough Rolling. The roughing stage, comprising repeated deformation and recrystallization in the austenite-recrystallization region produces a uniform and fine γ grain size. A certain minimum strain rate is necessary, if recrystallization is to result in grain refinement, as shown in Fig.6 (13). The lines show the limit of rolling strain required for recrystallization. Strains below these lines produce grain coarsening, whereas strains above these lines the grain refinement. The extent of refinement increases with the increase in total reduction and percent reduction per pass, reaching a limiting value, and to a lower extent with a decrease in rolling temperature (Fig. 7) (19).

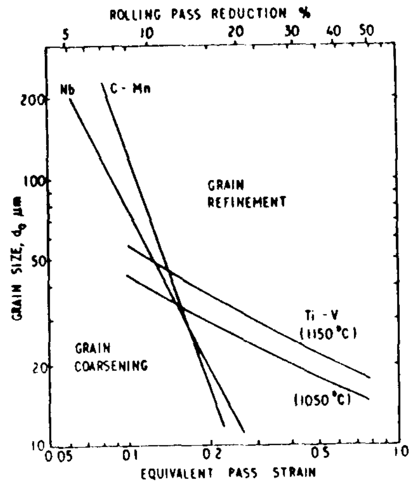


Fig. 6. Critical strains for grain refinement by recrystallization calculated from the relationship for recrystallized grain size in C-Mn and Nb steels and in Ti-V steel (13).

The effectiveness of common alloying elements (normalized to 0.1 wt% additions) in retarding γ recrystallization, in increasing order, is : Si, Cr, Mn, Ni, V, Mo, Cu, Ti, Nb. Multiple alloying additions lead to greater retardation of recrystallization than the arithmatic sums of the individual effects (29).

Dynamic Processes: During rolling of austenite at elevated temperature, dynamic softening or restoration processes occur that comprise dynamic recovery and dynamic recrystallization. The term dyanmic is employed to distinguish them from the *static recovery* and *static recrystallization* processes that occur either between intervals of hot-working or on heating, after the completion of cold-working. Both these dynamic softening processes are thermally activated and cause a strong temperature and strain rate dependence of flow stress, but they lead to different characteristic microstructural changes (30).

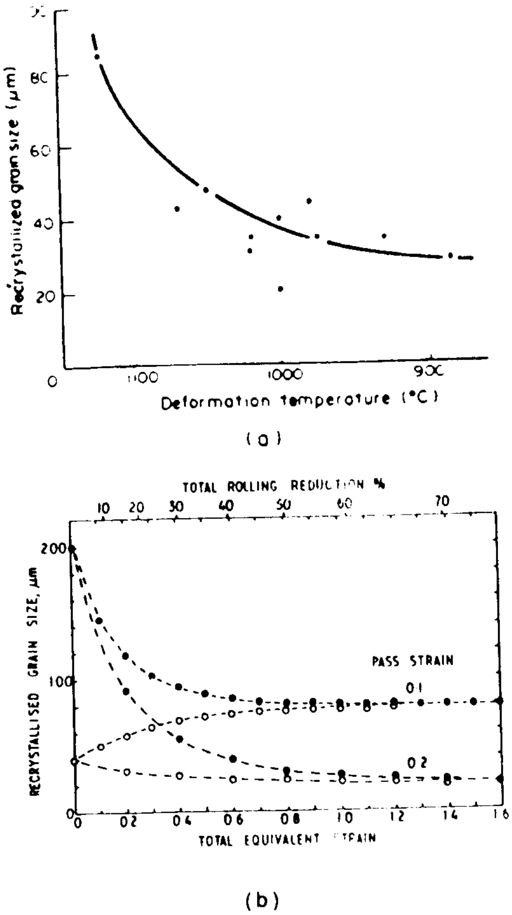


Fig. 7. Effect on recrystallized grain size: (a) in 0.05 Nb steel of deformation temperature and (b) of Nb steel during multiple pass rolling with equivalent pass strains of 0.1 and 0.2, calculated fromthe relationships for recrystallized grain size (13)

Dynamic recovery occurring during high temperature deformation appears to lower the dislocation density by the cross-slip of screw dislocations and the climb of edge dislocations, which lead to the annihilation of dislocations of opposite sign and the rearrangement of dislocations to form well-developed and delineated cells or subgrain structures containing low dislocation densities in their interiors (30). These substructures are equiaxed in nature, even at large strains (because of their continuous break-up and reformation during hot deformation), and are present within the considerably elongated and flattened grains (31). A subgrain size d_{sg}, characteristic of the temperature and strain-rate conditions, can be related to the creep stress or to the steady-state flow stress σ_S by the equation:

$$\sigma_s = K.\, d_{sg}^{-n} \qquad (2)$$

where K and n are constants, and n, according to Twiss, has a value of about 1 for many materials (30). Fig. 8 is a schematic $\sigma(\varepsilon)$ curve representing restoration by dynamic recovery only (31).

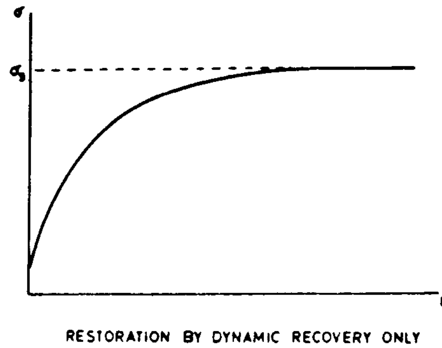


Fig. 8. Schematic curve representing restoration by dynamic recovery only (31).

Dynamic recrystallization commences only when a *critical strain* (also called *incubation strain*), ε_c is reached during hot deformation. The recrystallization start time t_{rs} for dynamic recrystallization may be determined from the relation:

$$t_{rs} = \varepsilon_p / \dot{\varepsilon} \qquad (3)$$

where ε_p is the maximum (or peak) strain, associated with this process and $\dot{\varepsilon}$ is the testing strain rate (29). This process leads to an initial increase of flow stress to the peak value and then a decrease of flow stress to a steady state. These flow curves are either periodic (multiple peak) or continuous (single peak) (32,33) (Fig. 9) (33). The former curves appear at low strain rates and high temperatures. This indicates that discrete cycles of grain coarsening are occurring. The latter curves occur at relatively high strain rates and low temperatures and is associated with the grain refinement and with the operation of "necklace" mechanism of dynamic recrystallization (29). This is of commercial significance, as in extrusion and planetary hot rolling, where large strains are accomplished in a single operation (34).

In dynamic recrystallization, nuclei form preferentially at or near the pre-existing grain boundaries but may also occur at deformation bands, twins, or inclusions within the grains, particularly in coarse-grained materials and at high strain rates. In the case of dynamic recrystallization during constant strain rate deformation

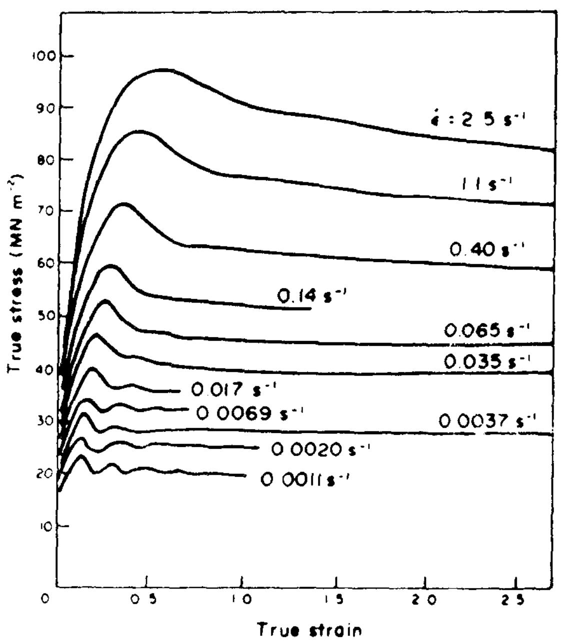


Fig. 9. Flow curves derived fromtorsion data for plain 0.25 % C in the austenitic condition at 1100°C (0.76 T_M), showing the influence of strain rate (33).

the recrystallization curve for single-peak flow condition, can be represented by the Avrami expression:

$$f(t) = 1 - exp[-K.(\varepsilon-\varepsilon_c)^n] \quad (4)$$

where $f(t)$ is the volume fraction recrystallized; ε is the strain; ε_c is the critical strain for the onset of dynamic recrystallization; K is a constant, dependent on composition, grain size, temperature, and strain rate; and n is a constant (usually 1.2–2). The dynamically recrystallized grain size d_{dr} is uniquely related to the temperature-corrected strain rate (also called Zener-Hollomon parameter) Z and is given by an equation of the form (35):

$$d_{dr} = BZ^{-p} \quad (5)$$

where $Z = \dot{\varepsilon} \exp(Q/RT)$ (6),

$\dot{\varepsilon}$ is strain rate, Q is activation energy, R is gas constant, T is temperature in absolute scale, B is a constant, mostly dependent on materials' composition, and p is a constant about 0.3-0.4 for all steels (35).

The occurrence of dynamic recrystallization during controlled rolling is favored by the following conditions: relatively high temperature and low strain (deformation) rate; large accumulated strains; reduced concentration of solute elements; and decreased rate of dynamic precipitation of carbide, nitride, and carbonitride particles. Dynamic recrystallization produces both texture and grain size distribution that is different from that of static recrystallization (36).

3. Delay or Hold Period. Since the structural changes obtained by dynamic restoration are thermodynamically unstable, holding at temperature in the interstand period, particularly during roughing passes modifies them by the static restoration process. These structural changes play an important role in determining the final microstructures and properties of HSLA steels (37).

Static Processes: The static restoration process involves three different types of softening; namely, mode I is static recovery, mode II, classical (static) recrystallization, and mode III, metadynamic (i.e., post-dynamic) recrystallization (38,39). Static recovery starts as soon as deformation is complete and extends into the incubation period of static recrystallization. Static recovery causes a loss or reduction of dislocation density within the subgrains, which, in turn, leads to a small decrease in yield strength or flow stress. This does not produce any detectable microstructural changes under optical microscope.

In the case of classical (static) recrystallization, recrystallized nuclei start to form after the completion of straining and a large number of dislocations are simultaneously annihilated. Here, the recrystallization kinetics are described by the Avrami equation. The distribution of recrystallized nuclei is highly localized and inhomogeneous, occurring predominantly at triple junctions of deformed austenite grains and grain boundaries (38,40); the other nucleation sites being pinned stationary unrecrystallized-recrystallized interfaces and deformation bands or deformed annealing twin boundaries (41).

The retardation of recovery and recrystallization processes are primarily attributed to the solute drag of dissolved MAEs or pinning actions of fine, stable microalloy carbide, nitride, and/or carbonitride precipitates (formed during hot rolling) on migrating grain boundaries., which hinder the rearrangement of dislocations (during the formation of a recrystallization front). The criteria to be fulfilled for pinning action include:

1. Particle size and spacing should be smaller than critical value.
2. Adequate volume fraction to maintain critical spacing.
3. Low rates of coarsening.

The presence of boron has also been found effective in retarding recrystallization of γ during and after high temperature deformation above 950 °C (1742 °F) by solute drag and precipitate pinning (or grain boundary segregation) in Nb- and Nb-Ti HSLA steels (42,43).The combined addition of B and Nb or Ti suppresses markedly the γ/α transformation and increases the T_R temperature more than the addition of individual Nb, Ti or B only (44). However, retardation of recrystallization produced by Al addition in Nb HSLA steels is much weaker than by Nb (45). This is mainly attributed to the greater electronic difference between Fe and Nb as compared to that between Fe and Al, although Al and Nb have similar atomic sizes (46).

The statically recrystallized grain size d_{sr} in a Nb-Ti steel with a relatively coarse starting austenite grain size for a particular rolling reduction level has been found to be independent of rolling temperature as accurately predicted by Seller's equation:

$$d_{sr} = D' d_o^{0.67} . \varepsilon^{-0.67} \qquad (7)$$

where $D' = 0.80$, d_o = starting γ grain size, ε = rolling strain.

Metadynamic recrystallization does not exhibit an incubation period, which implies that nucleation has taken place during deformation. Consequently, it is about an order of magnitude faster than classical static recrystallization. It also produces finer grain structures as compared with the classical mechanism, primarily due to the formation of higher density of nuclei by dynamic nucleation (34,39).

4. Finish Rolling. A series of low temperature finish rolling passes in controlled plate or strip rolling of microalloyed austenite carried out in the non-recrystallization temperature range above or below Ar_3 (intercritical rolling), breaks-up and flattens (pancakes) the (recrystallized) γ grains (47). The conditions of finish rolling differ extensively for plate,strip and rod and the resulting microstructures depend on relative kinetics of recrystallization and precipitation.

Effect of Deformation on Nucleation Rate: The nucleation sites in deformed austenite are: in order of decreasing significance, austenite grain boundaries, incoherent annealing twin boundaries, deformation bands, second phase particles, and subgrain boundaries (48). Researchers have found that high ferrite nucleation frequency at the austenite grain boundaries is due to high energy at boundaries (48).They indicate that the effective γ interfacial area /unit volume, S_v, which is the sum of the two interfacial areas (such as grain boundaries and deformation bands) per unit volume, may be interpreted as indicative of small "effective" γ grain size. The "effective" grain size is slightly smaller than the actual grain size of austenite because of the incorporation of the influence of deformation bands on ferrite nucleation. An increased S_v, obtained by producing large rolling reduction and highly elongated grains, favors large ferrite nucleation rates (i.e., finer ferrite grain sizes) within γ grains, while a small S_v causes low nucleation rates and coarse ferrite grains (Fig. 10) (49). Thus, an increase in deformation below the recrystallization temperature significantly augments the ferrite nucleation rate per unit boundary area of austenite (50) and moves the TTT curves to shorter times.

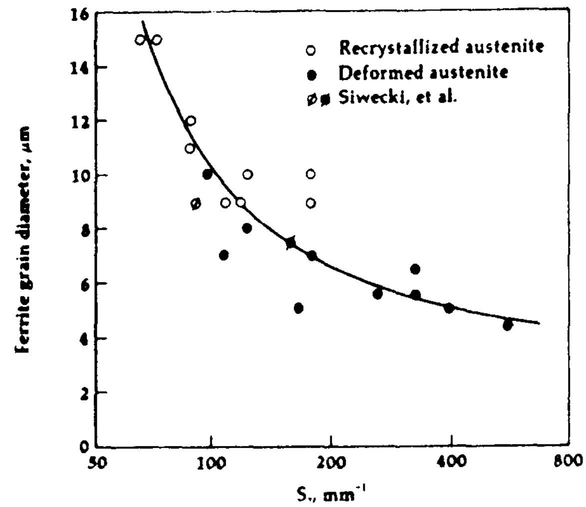


Fig. 10. A relationship between ferrite grain size and S_V (49).

Several mechanisms of increase of nucleation rate of ferrite by deformation have been put forward. These include an inter-relation between the increased nucleation rate of ferrite with the: (a) bulges formed by local austenite grain boundary migration (51), (b) formation of subgrains near the deformed austenite grain boundaries (52), (c) strain energy of the dislocations stored in deformed austenite (53), and/or (d) degree of saturation Ae_3 - T (47).

It is pointed out that the ferrite grain refinement is mostly the result of austenite deformation below the recrystallization temperature and accelerated cooling after deformation; both processes increase the nucleation of ferrite phase (54). For a certain S_v, ferrite grains produced from transformation of deformed γ are smaller than those formed from fully recrystallized grains (54). For a given cooling rate, the ferrite grain size is a unique function of S_v. (55). The formation of resultant polygonal ferrite grain size is a function of nucleation and growth rates of ferrite, the austenite grain size and the degree of austenite deformation (56). However, the nucleation rate is more effective compared to growth rate for controlling the ferrite grain size (47).

5. Cooling. It has long been understood that the transformation temperatureand cooling rate have profound effects on the transformation structures. A simple relationship between ferrite grain size (d_α, μm), austenite grain size (d_γ, μm) and some of the process variables has been given by (57):

$$d_\alpha = a + b.\dot{T}^{-1/2} + c[1 + \exp(-1.5 \times 10^{-2} d_\gamma)].(1 - 0.45\,\varepsilon^{1/2}) \quad (8)$$

where $\dot{T}$ is the cooling rate (°C/s), ε is the strain applied during finish rolling below the recrystallization temperature of γ and a, b and c are constants, dependent on the composition of steel and, perhaps, on the processing parameters determining the degree of strained induced precipitation.

Accelerated cooling lowers the transformation temperature and increases the density of effective nucleation sites, which provides both the ferrite grain refinement at all γ grain sizes and finer carbonitride precipitation during or after transformation to ferrite, thereby further improving room temperature strength at the expense of toughness (13).

Recrystallization-Controlled Rolling

To overcome the above shortcomings of CCR method, attention was directed toward recrystallization controlled rolling (RCR) method of producing very fine ferrite grain size of the order of 5 to 10 μm (0.2 to 0.4 mil). This process involves a relatively low reheating temperature, repeated high temperature finish rolling above T_R (i.e., up to 1050°C), and retardation of austenite grain growth during and after rolling. In the RCR operation, recrystallization must go to completion within times available between rolling passes. After the last rolling pass, the fine recrystallized austenite grains transform to very fine ferrite grains. The RCR process, in combination with controlled accelerated cooling is often used to optimize the ferrite nucleation rate and higher precipitation strengthening increment. The RCR process has the inherent advantage of rapid processing, energy savings, and easy implementation within existing plants (58).

To successfully utilize the RCR approach, it is necessary to determine the relationship between recrystallization behavior (time for static recrystallization and recrystallized grain size) and rolling parameters (strain, temperature, and interpass time) (59). The RCR process is especially suited to high-speed, high-finish-temperature bar and section mills, as well as plate and strip mills which are not designed for high mill loads produced at low temperature conventional controlled rolling. (CCR).

The RCR is well-suited to V-N and V-N-Ti steels. V steels with increased N contents (0.01-0.02% N) exhibit austenite grain refinement during high temperature rolling, as well as increased VN precipitation strengthening when compared to low- nitrogen vanadium steels. The negative influence of Nb at higher finish rolling temperature and the need for a low T_R prevents its use in RCR steels.

A small Ti addition (0.015%) to V-N steels causes a fine distribution of stable TiN particles, which effectively impede austenite grain growth during reheating and rolling, enhances the uniformity of grain size upon transformation, and contributes to a higher final S_V by hindering growth of recrystallized grains (Fig. 11). Fig. 11 shows the microstructural evolution of austenite grain size in C-Mn and V-Ti-N steels during RCR (4). This illustrates the occurrence of a significant grain growth in C-Mn steel after the last rolling pass with respect to V-N-Ti steel (4). Properties of low-carbon V-Ti-N steels, processed by RCR, in combination with controlled cooling, are considered as available alternative to steels

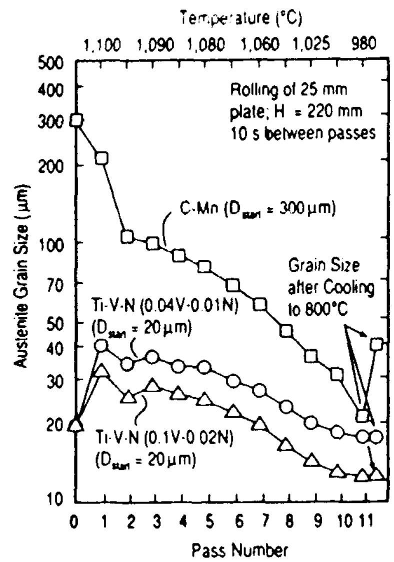


Fig. 11. Microstructural evaluation of C-Mn and Ti-V-N-austenites (4).

processed by low-temperature CCR. High N content in these low-carbon steels does not adversely affect weldability, in terms of HAZ toughness, provided proper welding parameters have been chosen (60).

MECHANICAL PROPERTIES

Strengthening Mechanisms. The major strengthening mechanisms in controlled rolled microalloyed HSLA steels include: grain refinement; precipitation hardening by strain-enhanced interphase precipitation of microalloyed carbides and carbonitrides at semicoherent and incoherent α/γ interfaces; solid solution strengthening from Mn, Si, and uncombined N; dislocation substructure (including dislocation tangles and cell walls) strengthening; and texture hardening.

The observed lower yield stress of a polycrystalline controlled rolled microalloyed HSLA steel can be expressed by the following Hall-Petch relationship:

$$\sigma_y = \sigma_o + k_y d^{-1/2} \quad (9)$$

$$= (\sigma_{lh} + \sigma_{sh} + \sigma_{dh} + \sigma_{ph} + \sigma_{texh}) + Ck_s l^{-1/2} + k_y d^{-1/2} \quad (10)$$

where σ_o is the internal or lattice friction stress opposing dislocation motion; $Ck_s l^{-1/2}$ is the subgrain or substructure strengthening term (61); k_y is a pinning constant measuring the degree to which dislocations are piled up at the barriers ; d is the mean grain size (diameter); $k_y d^{-1/2}$ is the contribution to strength by the ferrite grain size. σ_o is divided into several terms: lattice hardening σ_{lh}, solid solution hardening σ_{sh}, dislocation hardening σ_{dh}, precipitation hardening σ_{ph}, and texture hardening σ_{texh}. However, the relative contribution of any individual mechanism presumably varies with the change in steel composition and rolling practice (62).

Ductile-Brittle Transition Temperature: Like the strength equation, the ductile-brittle transition temperature Tc is related to grain size; the only difference is that Tc decreases with the increase of $d^{-1/2}$. This relationship can be written in the form:

$$Tc = To - k d^{-1/2} \quad (11)$$

where To is a function of the lattice friction stress σ_o and k is a measure of the effectiveness of refining the grain size in order to lower Tc.

According to related theories of Cottrell (63) and Petch (64), increased σ_o to dislocation movement provided by solutes, precipitates, and other dislocations raises the yield stress and, thereby increases Tc. For a given design stress, the beneficial effect of controlled rolling for improved toughness is attributed to the combined effects of friction stress reduction and grain size refinement.

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Direct Reduction/Sponge Iron Under Hungarian Conditions

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Abstract

This report is based on information obtained from M/S Vaskut and Dunai VasMu Meaf during the visit made to Hungary and Sponge Iron India Limited in India from January 24, 1985 to March 10, 1985. This information was primarily obtained from average annual production reports and annual raw material consumption records and these data were furnished by the Hungarian authorities. Based on these data, the cost analysis of hot metal using Sponge Iron was formulated. (Table 1,2,3, and 5)

Background

Sponge Iron India Ltd. (SIIL), a government of India undertaking, made a bench scale test of Hungarian raw materials. (See tables 5 and 9) The raw materials supplied to SIIL were low and medium grade iron ore and brown coal. The test results indicated that the raw materials are suitable for sponge iron production. According to the suggestion of the Government of Hungary, SILL engineers visited and studied the feasibility of modified cement kilns at Tababanya to produce Sponge Iron. The SIIL report concludes that these cement kilns at Tatabanya can be modified for Sponge Iron Plant. From the SIIL report it is apparent that with minimum cost and effort, these cement kilns can be modified into Sponge Iron making plants.

Introduction

In the past years the world's production of pig iron and steel has steadily increased. At the same time, there has been continuing improvement in existing iron making technology and facilities. Most of the steel companies have made extensive investments in iron making facilities. The average blast furnace hot metal production rate has increased almost 50 percent. Some individual furnaces have made more than 6 to 7 tons per day/100 cu foot of working volume. At the same time, the coke rate has dropped to 1300 pounds per net ton of hot metal (LB/NTHM) i.e. liquid pig iron, and in Japan few furnaces consume less than 900 pounds NTHM.

The major reasons that contributed to this increase in production and decrease coke rate are:

- *The decreasing of coal ash content.*
- *The enrichment of the blast air with O_2.*
- *The use of high furnace top pressure.*
- *The use of high hot blast temperature.*
- *The use of improved burden practice by using screened ore and coke. Also, in several places, very large size blast furnaces with daily capacities of more than 10,000 mt HM (11,025 NTHM) have been put into operation.*

At many of these plants, the normal hot metal demand is not high enough to justify such a high capacity blast furnace with their capital investment. But demands of hot metal vary. During high demand periods, it is profitable to boost blast furnace production by using high metallized burden (Sponge Iron). Recent tests have proved that a major improvement of production in blast furnace operations can be achieved by the use of Sponge Iron as part of the burden, (i.e., raw materials for blast furnace). This serves the purpose of increasing production, as well as decreasing coke rate. (See Tables 10 and 6, Figure I).

Previous Test Results

Several tests have been conducted using Sponge Iron in the blast furnace burden. These tests are listed below: (See Table 10 and 4)

- *The U.S. Bureau of Mines conducted its tests in experimental blast furnace in 1965, using oxide pellets and Sponge Iron.*
- *U.S. Steel conducted a trial in a 1.2 meter furnace with sinter and HIB (high iron briquettes) with only 57.7% metallization in 1966. (Table 7)*
- *U.S. Steel conducted commercial blast furnace tests in 1978 using HIB in their Fairless Works. Test results on table.*
- *The test conducted at Stelco Hilton Works blast furnace of 5.5 meter hearth diameter, with oxide pellets and Sponge Iron. Natural gas was used, (1964 test). See test result table.*
- *Nippon Steel conducted its trials in a commercial blast furnace in 1965 with sinter, size ore, pre-reduced iron low metallization. Oil was used as extra fuel.*
- *Kawasaki Steel trial was run in (1966) a larger blast furnace of 10.5 meter hearth diameter. Pre-reduced sinter of 95% metallization was used. Also fuel oil, high hot blast temperature and O^2 enrichment was included in the test program.*
- *In April 1978, Altos Hornos de Mexico, conducted a test using 43,000 tons of HYL-DRI in the burden.*

All test results were consistent (See Fig. 1). The results show that for each percent burden metallization, a 0.8% increase in hot metal production and 0.7% decrease in coke rate were obtained.

USE OF DRI IN BLAST FURNACE BURDENS* IN EXPERIMENTAL BLAST FURNACE

U.S. Bureau of Mines

	BASE PERIOD	TEST I	TEST II	TEST III
Oxide Pellets,%	100	70	40	15
Sponge Iron (or DRI)	0	30	60	85
Hot Metal Production Rate, metric tons/Hr (MT)	1.55	1.99	2.41	2.71
Coke Rate, (Dry) Kg/MT Hot Metal (HM)	574	441	352	306

In the blast furnace burden with 100% iron oxide feed, about 45% of the total energy of the furnace is used in reduction. Therefore, in simple terms, lowering the amount of oxides in the burden (i.e., raw material charged to furnace) would lower the thermal requirement, i.e., specific coke rate: Coupled with this lowered coke is an increase in blast furnace production/productively.

Reduction in Blast Furnace

To determine what benefits can be obtained from Sponge Iron (or highly metallized directly reduced iron), a brief analysis follows:

Let us assume that 100 pounds of naturally occurring ore are to be reduced to produce iron. Approximately 25 pounds of oxygen must be removed from this 100 pounds of ore depending upon the impurities contained. In the upper stack zone of blast furnace, 1/3 of the oxygen is removed and hematite (Fe_2O_3) is reduced to Fe_3O_4 (magnetite) and then reduced to FeO (ferrous oxide). This removal can be done easily with only small excess of reducing gas. However, the removal of remaining 2/3 oxygen is more difficult when FeO is reduced to Fe. The latter's reduction rate is slower than reduction from Fe_2O_3 to Fe_3O_4 and also the reduction requires a larger excess of reducing gas. Only 60 percent of this 2/3 oxygen is reduced at temperatures below 1500°F. The remaining oxygen (in the form of FeO) is removed at higher temperature by the chemical reactions as shown in equations one and two.

$FeO + CO \rightarrow Fe + CO_2$ (1)

$CO_2 + C \rightarrow 2CO$ (2)

The sum of equation one and two gives the equation:

$FeO + C \rightarrow Fe + CO$ (3)

Equation three is called direct reduction or endothermically gasified carbon reaction (EGC). The EGC reaction is highly endothermic (equation 3) and besides requiring carbon as reductant, requires 6200 BTU for every pound of carbon used in reduction.

With conventional burden materials about 25 percent of total energy requirement for the blast furnace process is for the EGC reaction.

If we add Sponge Iron, in which most of the iron has already been metallized, the amount of endothermic reduction is decreased, or one can say that the energy and carbon requirements are decreased because of lower fuel consumption. In addition, the iron production rate will increase. The situation of each blast furnace practices is different. The quantity of Sponge Iron in furnace burden depends on (a) hot metal requirement, (b) necessity of coke saving and (c) cost of burden material.

It is necessary to explain a few terms that will not be ambiguous.

(i) Amount of metallic iron in burden
(ii) Metallization
(iii) Amount of gangue

Metallic iron - This is the iron that is in the metallic state (Fe^o) which is determined by a method of chemical analysis.

Metallization - The degree of reduction terms for DRI or Sponge Iron is expressed by percentage of metallization. This is the ratio of metallic iron to total iron. (i.e. % Fe^o/% Fet)

Amount of gangue - Is the quantity of SiO_2, Al_2O_3, CaO, MgO, etc. The coke consumption in the blast furnace depends not only on the pound of metallic per THM (ton of hot metal), but also on % FeO to be reduced by EGC (Eq. 3).

As the amount of metallic in the blast furnace burden increases, then the amount of FeO (to be reduced) decreases. Hence, the heat required for EGC becomes a smaller percent of total heat.

If the amount of FeO reduced by EGC reaction is 50%, the coke rate (consumption rate) will be decreased by 0.40 to 0.45 pound per one pound of metallic added to the burden. (Relationship established by U.S. Steel between 330 pounds to 760 pounds metallic. Between 760-1465 pounds, the coke rate decrease is 0.30 pounds/pound of metallic). Burden with higher gangue content will require additional fuel for heat.

COMPARISON OF PROPERTIES CONVENTIONAL BURDEN VS SPONGE IRON (PRE-REDUCED) BURDEN

1. The iron (Fe) content in Sponge Iron is higher by 20% to 30% than the conventional Fe content in the iron ore.
Fe content of sinter is 48.4%
Pellet (made by SIIL) 65.7% —From Hungarian ore
Hungarian Sponge 90.7%
To deliver one unit of iron only 1.10 unit of Sponge Iron to be handled where as conventional burden requires 1.55 units. There is considerable saving if Sponge Iron is used.
2. About 2/3 of Sponge Iron contains iron in metallic form. This does not require any chemical reduction in the furnace.
3. The density of Sponge Iron is 70% (Pct) higher than conventional burden. This means lesser area is required for storing and stocking.
4. Sponge Iron made from Hungarian raw materials show a lesser gangue-to-iron ratio and sulphur-to-iron ratio than in the case of convention sinter used at present in Hungary.

	CONVENTIONAL	SPONGE
SiO_2	15.0	5.4
Al_2O_3	1.55	1.13
CaO	14.10	—
MgO	1.95	—

SUMMARY OF RESULTS USING SPONGE IRON IN BLAST FURNACE BURDEN:

These results specified here are typical test results of various commercial and experimental blast furnace. It is necessary to take into consideration (a) the difference between small and large furnaces (b) the variation of operating parameters and (c) raw material composition all of which influence the results.

1. Coke, the most important single item in blast furnace conversion costs shows marked reduction. Significant coke saving can be obtained by using 600 lb. (pound) Sponge Iron per NTHM. Approximately 9.40 pound coke are saved per pound of sponge in the burdens (Fig. I)

2. There is significant increase in the production of hot metal. Using 500 lb. (pound) of Sponge Iron in the burden, the hot metal production rate increases about 30% compared to conventional burden practice.

3. Sponge Iron in burden permit a significant reduction of the weight of materials which must be transported.

4. With materials compacted (Sponge Iron) after reduction, there is a significant decrease in the volume of material to be handled. This will permit savings in handling equipment.

5. Materials with high-iron content and low-gangue content are preferred as starting material for

Sponge Iron.

6. Lesser wind is blown in the blast furnace per NTHM (net ton of hot metal) because of the decrease in coke rate. This represents a savings in the energy for blowing. Also use of Sponge Iron in burden permits a higher production rate with same blowing equipment.

7. Fairly high sulphur content coal can be used for making Sponge Iron. But the sulphur input to blast furnace per NTHM decreased because of the large coke savings.

8. Use of Sponge Iron in the blast furnace burden become highly desirable from the standpoint of operating plan strategy and overall flexibility, particularly for easing production trouble-spots or during periods of iron making capacity deficiencies.

9. Sponge Iron use permits substantial elimination in capacity requirements for coke works and blast furnaces. But use of Sponge Iron must be evaluated in terms of the total capital cost required for given hot metal capacity.

COST ANALYSIS PER NEW TON OF HOT METAL

excluding fixed charges

	NewBlast Furnace	Conventional Burden for No. 2 Blast Furnace			Coventional Burden (No.2 Blast Furnace) with Sponge Iron Added		
	Capital Cost, Fixed Cost, & Burden Cost	PCT,%	Quantity Kg/ NTHM	Cost, $ U.S.	PCT,%	Quantity, Kg/ NTHM	Cost, $ U.S.
SINTER		88	1825	45.42	76	1304	32.7
SCRAP		4.3	84	3.01	—		
ORE		7.8	162	5.6	DRI Sponge	400	30.8
COKE		—	783	80.64		540	55.60
LIME STONE Dolomite		—	91	0.28		86	0.2
TOTAL	152.73*			134.95			119.3
DIFFERENCE							(15.5)
PRODUCTION, NTHM/DAY		967 NTHM/DAY			ESTIMATED 1257 NTHM/DAY		

(From Table)

*Cost of Hot-Metal From Newly Built Blast Furnace $152.73/NTHM "Use of HYL Sponge Iron in Blast Furnace" ,AISE 1979 Convention

1) Savings due to Sponge Iron uses =$15.56 x 1257 NTHM/Day x 360 Days = $7,041,211.00

CONCLUSION

Each situation involving the uses of Sponge Iron in blast furnace burden is unique and their economic analysis must be considered individually. The data contained in this paper, however, provide only preliminary cost analysis. For detail analysis following points to be examined:

1. Location of direct reduction (Sponge Iron plant) relative to its sources of raw material and blast furnace, cost of production, cost of transportation, cost of raw materials.
2. Location of coal, and coal quality.
3. Infra-structure
4. Cost per man hours, etc.

TABLE 1

ANNUAL PRODUCTION DATA

DUNAI VASUM BLAST FURNACE

	NO.1 FCE ACTUAL	NO. 2 FCE ACTUAL	TOTAL ACTUAL
Production	393329	254527	647856
W. Days	348.5	263.0	305.7
Down Days	16.5	102.0	59.3
Working Vol	960.0	950.0	1910.0
DIA	7.3m	7.3m	
Production/day	1128.6	967.8	2119.2
Coke rate, kg/THM	634	783	692
THM x 100 Ton Metallic-dust	51.34	50.24	50.90
Coke rate w. H_2O, kg	634	783	692
Coke rate dry, kg	610	755	667
Gas injection, m3	22.002	6.22	28.22
Hot Blast Temp., °C	959	838	
Burden/Coke	3.37	2.82	3.12
Top Gas CO_2	13.1	12.3	
O_2, K m3	3.733.372	27.460	
O_2, m3/THM	9.49	0.11	

TABLE 3

DUNAI VASMU BLAST FURNACE

		COKE ANALYSIS	
Fixed Carbon	-	81.78	% C
Ash	-	11.84	
H_2O	-	3.78	
S	-	1.30	
Stability	-	78.1	

TABLE 2

DUNAI VASMU BLAST FURNACE

HOT METAL ANALYSIS

647.856T	
606.062	T (Fe)
93.554	% Fe
1.04	% Mn
1.03	% Si
4.19	% C
0.29	% S
0.11	% P
0.04	Cu
0.07	Cr
0.008	Ni

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TABLE 4

(TYPICAL) - EXPERIMENTAL BLAST FURNACE TEST RESULTS -

With Sponge Iron

Item	Unit Measure	Test Period				
		Base	I	II	III	IV
Burden Materials						
Sinter	Pct	100	60	77	—	40
High-Iron Briquettes	Pct	—	40	—	100	—
Scrap	Pct	—	—	23	—	60
Metallic Iron	Lb/ NTHM	—	588	600	1306	1310
Production Rate	NTHM/ Hr	1.26	1.56	1.58	1.94	2.04
Coke Rate	Lb/ NTHM	1024	803	801	599	599
Wind Rate	SCFM	943	950	969	954	965
Hot Blast Temperature	°F	1998	2005	1915	1956	1964
Blast Moisture	Grain/ SCF	15.5	13.0	7.0	7.0	7.0
Slag Weight	Lb/ NTHM	602	403	395	407	410
Raw Flux Stone	Lb/ NTHM	70	111	43	310	244
Top Gas Composition						
CO	Pct	24.3	27.2	25.2	31.0	30.5
CO_2	Pct	18.3	14.7	16.0	9.6	10.4
H_2	Pct	2.1	2.3	1.4	1.7	1.7
FeO Reduced by EGC	Lb.Moles/ NTHM	14.2	10.4	10.1	4.2	5.2

TABLE 5

COST & CHEMICAL ANALYSIS OF BURDEN MATERIAL FOR DUNAI VASMU BLAST FURNACE

(To Produce One Ton Hot metal (THM))

Name	Quantity kg/THM	Fe%	SiO_2 %	CaO %	MgO %	Al_2O_3 %	MnO%	Price/ ft/T
Pig Iron	1.000	94,02	0,94	—	—	—	0,68	7444
Slag Tip Iron	145,65	60,50	6,50	12,50	4,00	6,50	2,00	1800
SM Slag	13,04	19,76	12,07	39,27	12,10	2,30	5,57	500
DV Roll Scate	17,39	81,40	4,22	0,76	0,09	2,30	0,75	2274
OKU Roll Scate	14,35	73,29	2,61	0,20	0,19	4,10	1,06	2070
OKU Scrap	6,09	69,54	0,88	0,09	0,05	0,23	1,12	1180
LKM Scrap	10,87	72,50	1,50	0,50	0,20	1,00	0,84	1450
LKM Roll Scate	21,74	96,18	1,10	—	—	—	0,89	2420
DV Sinter	521,74	48,456	11,514	12,666	2,993	2,16	0,17	1242
BEM Sinter	1.304,88	46,964	15,004	14,103	1,95	1,555	0,28	1280
Lime stone	78,10	—	0,67	54,04	0,98	0,37	—	160
Dolomite	12,52	—	0,72	30,57	20,05	0,38	—	200
Coke	666,357	1,56	4,60	0,35	0,18	2,42	0,04	5270
Mn ore	16,30	6,71	5,72	1,99	0,35	9,33	47,18	1450

2829 Kg

Gas 55,002m^3/T.H.M Gas Cost =4,002 ft/m^3

Oxygen 14,66m^3/T.H.M. O_2 Cost=1,602 ft/m^3

Basicity: 1.CaO/SiO = 1,11 2.CaO+MgO/SiO_2= 1,284

Blast air T = 973°C

CO_2 = 13,1%

TABLE 6

EFFECT OF PREREDUCED BURDEN MATERIALS ON BLAST FURNACE PRODUCTION RATE

Using Dunai Vasmu #2 Blast Furnace

Present Burden Practice

ITEM (1)	UNIT MEASURE	PRESENT BURDEN	PRESENT BURDEN & SPONGE IRON
BURDEN MATERIAL:	(2)		
Conventional Sinter	Kg/NTHM	1825	1305
Scrap	Kg/NTHM	83.4	83.4
Ore	Kg/NTHM	162	162.0
Sponge Iron (DRI)	Kg/NTHM	——	400
Production Rate	NTHM/Day	967	1257
Production Rate Increase for Burden with Sponge Iron	NTHM/Day		290
Coke Rate	Kg/THM	783	548
Decrease in Coke Rate	Kg/THM		235
Slag Volume	Kg/THM	720	474
Sulphur Input	Kg/THM	11	6.4

TABLE 7

USE OF DRI IN BLAST FURNACE BURDENS EXPERIMENTAL BLAST FURNACE

U.S. STEEL CORPORATION

	BASE	TEST I	TEST II	TEST III	TEST IV
Burden					
Sinter, %	100	60	77		40
HIB, %		40		100	
Scrap, %			23		60
Fe°/Total Fe X 100	0	32	32	70	70
HM Production Rate, mt/hr	1.14	1.41	1.42	1.76	1.85
Coke Rate, dry, kg/mtHM	498	403	400	300	300
Solution loss C, kg/mtHM	88	62	61	25	31

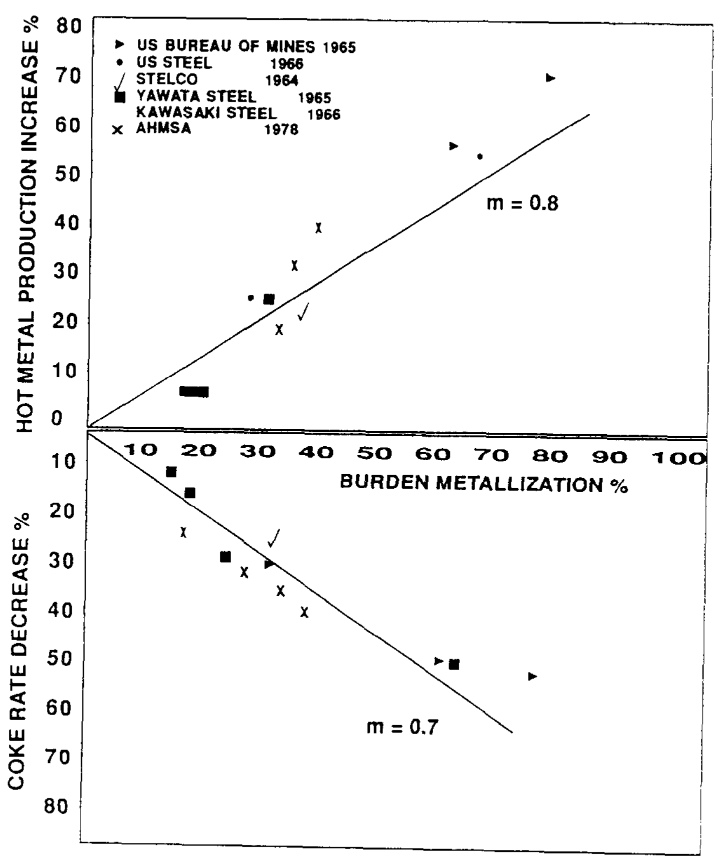

FIGURE 1: RESULTS IN TRIALS USING PREREDUCED MATERIAL AS PART OF THE BURDEN IN EXPERIMENTAL & COMMERCIAL BLAST FURNACES

Proceedings of the Emerging Technologies for New Materials & Product-mix of the Steel Industry, 1991 Materials Week, Cincinnati, Ohio, USA, 21-24 October, 1991

Secondary Steel Refining for Cleaner and Special Steel Product-Mix

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Abstract

In this paper, a review has been made of the successive developments of secondary Steel making and ladle metallurgy processes / operations outlining their characteristics and results claimed. Some typical and specific cases have been furnished to illustrate the process developments and technological trends.

Every country and each plant have to formulate their process configurations to suit their product requirements and resources available.

WHILST WORLD STEEL production figures have not kept pace and fulfilled world steel forecasts made during the last decade and more by multiple agencies, in meeting the steel quality requirements in terms of clean steel and homogeneous chemical composition, the world steel has made remarkable progress mainly through secondary steel making/steel refining and ladle metallurgy processes and innovations.

Important secondary steel making processes developed during the last few decades are vacuum degassing, vacuum oxygen decarburization, vacuum circulation and the ladle metallurgy operations. So revolutionary have been the developments leading to a diversity of multiple operations, their permutations and combination and multiplication of their nomenclature and trade names, that one tends to lose all perspective and attempts to standardize and rationalize the technology. Here the theme is everyone for himself and the concepts of secondary steel making processes and plants are based on local conditions, market demands and quality control specifications.

Not only have vacuum degassing plants and ladle furnace equipment and plants been designed and set up but also combinations like VD, VOD and LF plants and a host of other titles signifying breakthroughs, are leading the trade.

Shifting of metallurgical technologies to secondary refining processes with logical plant and equipment related developments the world over, have led to the general connotation of Secondary Metallurgy or secondary steel making/steel refining.

Secondary Metallurgy

Metallurgical criteria of second metallurgy are based on to meet the following demands:

- Upgrading the degree of purity to highest standards
- Lowering the impurity and metalloids contents
- Uniform molten temperature control
- Fully homogeneous chemical composition
- Upscaling the yield figures
- Downscaling the energy consumption figures
- Relieving the primary melting units of doing final refining and finishing operations

The objectives of secondary steel making including ladle metallurgy operations are:

- Effective quick desulphurization, decarburization and deoxidation with minimum metallic and alloying elemental losses
- Effective degassing of hydrogen, oxygen and nitrogen
- Optimum alloying and recovery figures
- Final homogenization of the melts and resultant finished products

To achieve the above requirements, ladle metallurgy is applied based on:

- Gas stirring by argon/nitrogen lances
- Scrap and alloying elements additions
- Aluminum wire injection
- Powder injectants of Ca, Si, Cao, CaF2, Ca c_2, etc.
- Top slag additions
- Temperature and oxygen activity measurements

The list is hardly complete. The options cover newer technology and treatment schedules such as degassing of pouring stream, casting under vacuum, and induction stirring.

There is a justification for each process as a link in the overall production chain.

The most suitable process and the optimum and efficient plant configuration in each and specific case has to be determined in the planning phases by combining appropriate plant modules and technological expertise.

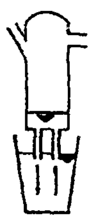
Historical Perspective

The historical developments have been depicted in the attached tabulations. 1/

Historical Perspective

Table 1

Process	Time of introduction	Brief characteristics	Effects of the process (primary and secondary)
Vacuum degassing  ladle throughput degassing vacuum ingot casting tap degassing	1950/55	Degassing By the vacuum acting on a liquid metal surface as large as possible (drops)	- Reduction especially of the hydrogen favouring flake cracking to less than 2 ppm → among other effects, by-passing of the expensive homogenising with forging ingots - Increase of the degree of cleanness vection under vacuum - Disadvantage: temperature loss → tapping temperature increased by up to 50°C

RH

	1955/58	Degassing
		By the vacuum acting on parts of the heat, which change rapidly. With RH: Increase of the degassing effect by a great number of small inert gas bubbles in the metal flow; ideal precondition for alloying.
			- Rapid reduction of the hydrogen content to less than 2 ppm (forged pieces, rail steel, thick plate, ball bearing steel, etc.)
			- Alloying under vacuum:
			  - rapid charging (even great amounts)
			  - rapid homogenisation (~1-3 min after addition)
			  - excellent yield (especially oxygen-affine additions)
			- Increase of the degree of cleanness by intensive material flow upon exchange of the partial flow and/or by vaccum-carbon deoxidation (forging steel

DH

	1955/58	Under vacuum → convection, no oxygen and slag. Due to the design of vacuum chamber, deoxidation and/or secondary decarburisation can be convientlly accomplished via CO-formation	- Vacuum deep decarburisation (down to less than 0.005 % C) (electric quality sheets, enamelling steel, ULC steel)
			- Removal of nitrogen under vacuum (down to less than 40 ppm) (tyre cord steel)
			- Light treatment: combination of
			  - high yield with deoxidation and alloying
			  - rapid homogenisation
			  - Increase of the degree of cleanness
			- Disadvantage: temperature loss (50 - 100° C)

Table 2

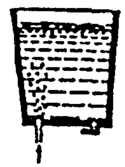
Process	Time of introduction	Brief characteristics	Effects of the process (primary and secondary)
Ladle stirring 	1955	Stirring of the heat in the ladle by inert gas bubbling up from the ladle bottom	- Homogenisation of the heat ⟶ precise analysis and temperature adjustment - Addition of deoxidation and alloying materials - Addition of cooling scrap - Stirring to degree of cleanness - Convection upon ladle stand degassing and other heating and degassing processes - Disadvantage: - alternating contact with atmospheric oxygen - negative effect of the furnace (converter) slag
Ladle degassing 	1955	Degassing By the vacuum acting on the heat surface in the ladle, which is located in a vacuum (tank) or closed by a vacuum cover. Low-lying parts of the heat have to be transported to the bath surface by means of a stirrer. Possibility of combining degassing with desulphurisation by charging of synthetic slag. Vacuum-carbon deoxidation and/or vacuum deep-decarburisation by sensitive vacuum control.	- Reduction of the hydrogen content to less than 2 - 3 ppm (prolonged degassing period as compared to RH/DH) - Increase of the degree of cleanness (ball bearing steels, forging steel, ...) - Alloying under vacuum: - high yield, also oxygen-affine additions - Vacuum-carbon deoxidation - Vacuum deep-decarburisation - Additional desulphurisation by means of synthetic slag ⟶ low S-values (less than 50 ppm) and high degree of cleanliness - Disadvantage: - high temperature loss (50 - 100°C - increased ladle wear - great freeboard in the ladle required - dependence on the efficiency of stirring

Table 3

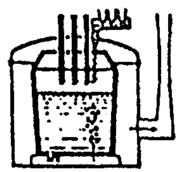
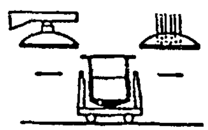
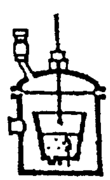
Process	Time of introduction	Brief characteristics	Effects of the process (primary and secondary)
VAD  ASEA SKF 	1965	Electric heating of the convected heat outside the primary melting unit in the ladle. With VAD, under vacuum. With ASEA/SKF, under atmospheric pressure, but sealed off against ambient air. Degassing of the heat (combined with stirring) Desulphurisation by means of synthetic slag under favourable conditions: Hot slag under vacuum and/or hermetically sealed, and convection by stirring with inert gas and/or stirrer (ASEA/SKF). Duration of treatment may be considerably extended if necessary.	- Reduction of the hydrogen content (to less than 2 ppm and less than 3 ppm with alloy steels) - Considerable increase of the degree of cleanness due to prolonged treatment under optimised conditions - Alloying / heating: Even great amounts may be added with high yield and reproducibility. Heating capacity: less than or equal to 3° C/min - Desulphurisation: S less than 0.005 % adjustable by means of reducing slag - Final analysis and temperature: exact conditioning ensured - Relieving of the primary melting unit - refining time omitted - tapping temperature need not be increased - Disadvantage: - increased ladle wear and/or refractory cost of the ladle
VOD 	1963/65	Refining of steels with a high Cr (Ni)-content under vacuum in the ladle in order to utilise the low Cr melting loss in the vacuum. Stirring with inert gas from the ladle bottom.	- Protection of Cr, especially with low C-contents - Exact analysis and temperature adjustment, high degree of reproducibility - Relieving of the electric arc furnace capacity increase - Efficient desulphurisation possible - Higher degree of cleanness - Disadvantage: increased wear of ladle refractory

Table 4

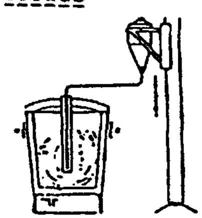
Process	Time of introduction	Brief characteristics	Effects of the process (primary and secondary)
Converter process AOD CLU VOD-K	1970/75	Refining especially of high-chromium-alloyed steel in the vessel with large reaction volume → considerably increased refining speed (~8 x VOD). High Cr-yield due to the use of inert gas at the end of treatment (= vacuum) and due to the vacuum (with VOD-K).	- Protection of Cr - Exact analysis and temperature adjustment - Excellent desulphurisation and/or optimum degree of cleanliness - Substantial relieving of the primary melting unit and considerable increase of the steel plant output - Cheaper charging materials (FeCr carb. etc.), can be carged due to the high refining speed
Injection of solids  + measures to minimise the furnace slag/ converter slag (taphole stopper device, automatic slag detection)	1970/75	Deep powder injection so that - Ca becomes effective with Ca alloys (vapour pressure) - a rapid reaction or a high yield respectively are achieved with desulphurisers on the basis of slag and with carburisers or other alloying elements due to intensive phase contact.	- Modification of inclusions by Ca → considerable modification of the mechanical properties and/or improvement of castability - Rapid desulphurisation outside the primary melting unit - Increase of the degree of cleanness - Exact carburisation or charging of other (special) alloys - Disadvantage: temperature loss (30 - 40° C)

Table _5

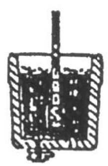
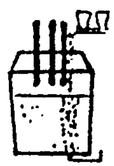
Process	Time of intro-duction	Brief characteristics	Effects of the process (primary and secondary)
Solid and filler wire injection or strip feeding 	1975/80	Rapid and controlled charging especially of oxygen-affine elements into the ladle, combined with sufficient stirring of the heat	- Modification of inclusions (under certain boundary conditions like [O]-content, etc.) - Deoxidation - Fine alloying (with special alloying elements) with high, reproducible yield - low temperature loss
Immersion of pressed bodies 	1982		

Table 6

Process	Time of introduction	Brief characteristics	Effects of the process (primary and secondary)
Ladle furnace 	1979/80	Electric heating of the liquid steel outside the primary melting unit, stirring of the heat ensuring a rapid heat exchange within the heat and rapid dissolution of alloys. Due to the cover design and/or the sensitive control of the exhaust ⟶ access of a small amount of O_2 only.	- Heating up of the liquid steel at max. 5° C/min ⟶ tapping possible at decreased tapping temperature (higher scrap rate possible in the converter; 40° C = 20 kg of scrap/ton!; higher productivity of the electric arc furnace) ⟶ charging of great amounts of alloys (up to approx. 40 kg/ton) - Exact fine alloying - Desulphurisation by intensive phase contact with the basic heating slag - Increase of the degree of cleanness - Buffer function → elimination of irregularities in the supply of heats from melting units → minimisation of return heats from the continuous caster

Specific Examples

From the multitude of examples, two typical cases are depicted here covering new processes and products at Kobe (JISI 1986) (2/) and primary melting and secondary refining processes for the production of heavy steel section for Light Water Reactor Pressure Vessels in Japan. (3/)

New Processes and Products at Kobe Steel

New Steelmaking Process

Kobe Steel has established a new steelmaking system that broadens its range of high-quality steel materials and reduces production costs.

The new system, which includes hot-metal pretreatment, BOF top and bottom blowing and ladle refining with heating, has greatly advanced the production of clean steels and lowers the cost of refining by the optimum sharing of refining functions. The steelmaking processes at the company's Kobe Works and Kakogawa Works respectively are shown in Fig. 1

Hot-metal pretreatment technique

This is a technique for desiliconization, dephosphorization and desulfurization of hot metal. At Kobe Works, desiliconization is carried out at the blast-furnace casting floor, dephosphorization and desulfurization in a hot-metal pretreatment furnace (H furnace) developed by Kobe Steel. At Kakogawa Works, desiliconization, dephosphorization and desulfurization are all carried out in a torpedo car.

Table 7 shows the main specifications of the H furnace. Figure 2 indicates the changes in hot

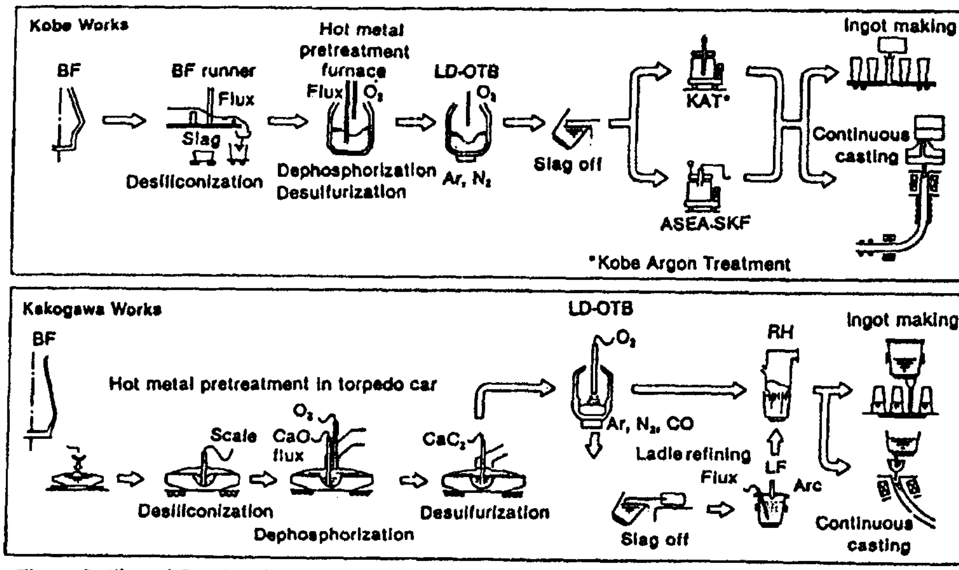
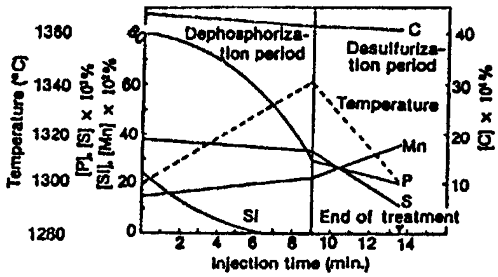


Fig. 1 Outline of Steelmaking Process at Kobe and Kakogawa Works

Table 7. H Furnace Main Specifications

Equipment			Specification
Furnace	Capacity	(t/heat)	80
	Height	(mm)	8,000
	Diameter	(mm)	5,300
	Inner volume	(m³)	54
	Lip diameter	(mm)	2,424
	Refractory		MgO-C
Injection	Carrier gas		N_2
	Rate	(kg/min)	Max. 400
	Immersion lance		High Al_2O_3 φ 300 mm

Fig. 2 Change in Hot Metal Composition During H Furnace Treatment (block quicklime 6.3kg/ton, manganese ore 6.5 kg/ton)



metal composition during H furnace treatment, which adjusts the hot metal's composition in a short time.

BOF top and bottom blowing technique (LD-OTB process)

The LD-OTB process developed by Kobe Steel, based on inert-gas bottom blowing, has the following features:

- ☐ Stable blowing by SA (single annular) tuyeres
- ☐ Bottom blown gas flow control for a wide range of low- to high-carbon steels
- ☐ Monitoring of refractory erosion around the tuyeres by FM (fine multiple sheathed) sensors
- ☐ Bottom blowing of CO gas separated from BOF gas—the world's first use of this approach

Table 8 Main Equipment Specifications for LD-OTB

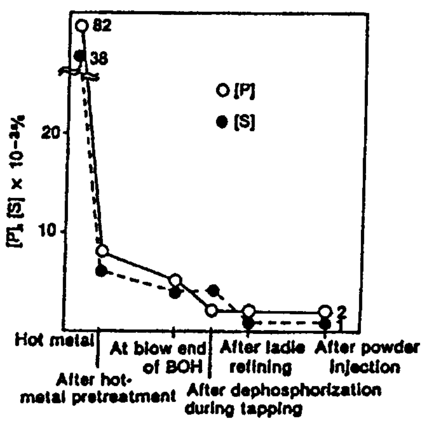
Item	Specification
Plant	No.1 steelmaking plant
Capacity of converter	240(t/heat) x 2/3
Kind of bottom blown gas	Ar, N_2, CO
Tuyere	SA Tuyere x 4
Measurement of refractory erosion	Erosion diagnosis technique by FM sensor
Controlling range of bottom blown gas	0.01 ~ 0.10 Nm³/min t.s

Table 8 shows the main equipment specifications for LD-OTB process.

Production of high-quality steel by the new refining process

By combining these techniques with ladle refining techniques, it has become possible to produce ultra-low phosphorus and sulfur steels, as well as high-quality steels such as HIC-resistant steels, valve spring steels and steel cord steels. Fig. 3 shows an example of ultra-low phosphorus and sulfur steel being produced at Kobe Works.

Fig. 3 Change of [P], [S] Contents



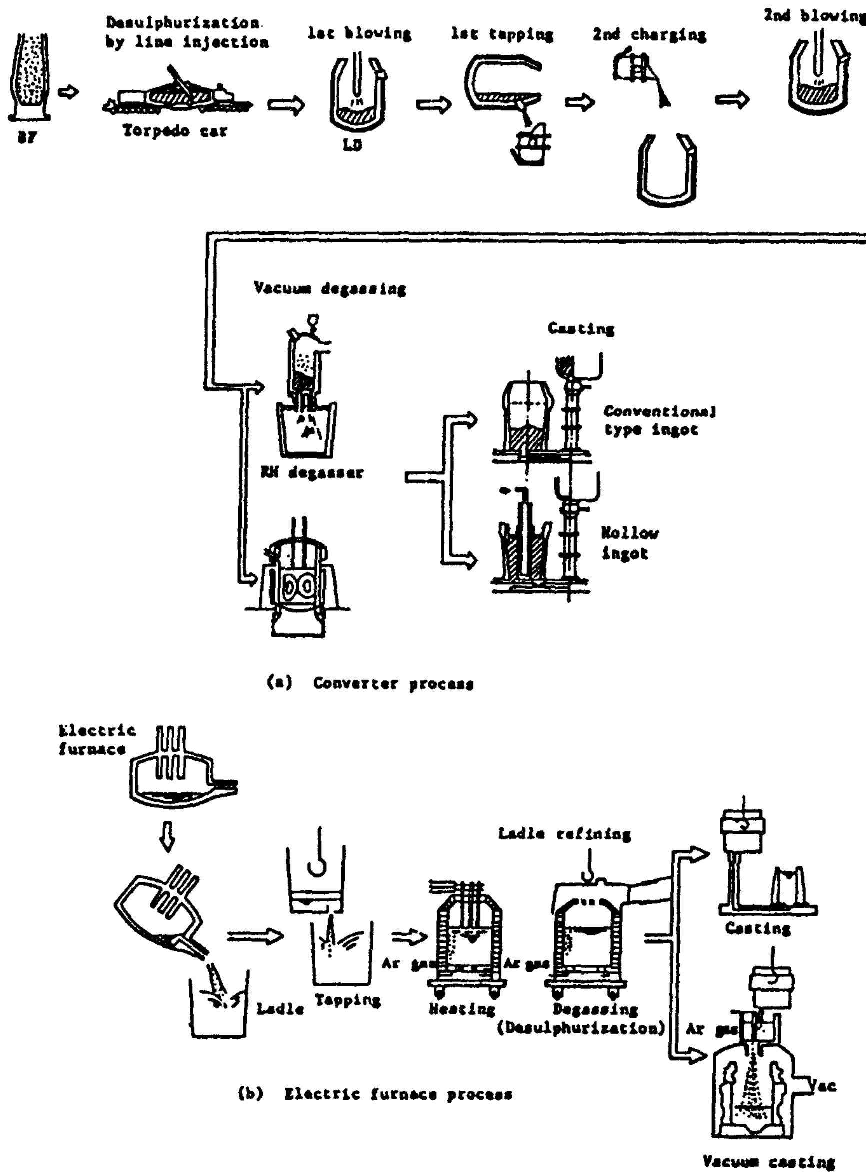


Fig. 4 Typical example of converter or electric furnace processes followed by second refining in production of heavy section steel for LWR pressure vessel

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1/ Compiled from UN/ECE sources/literature - Steel/SEM-13/R 20

2/ Journal of Iron & Steel Institute of Japan (1988)

3/ Tetsu-To-Hogane No. 14, Vol. 7, 1660 (October 1987)

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Current Status and Commercial Potential of Smelt Reduction Technology

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Abstract

In this short paper, references have been made to the current status of Smelt-Reduction technologies advocated many years back and their commercial applications to date. Some of these processes have not been reported upon beyond their earlier laboratory scale and pilot plant operations and possibly the latter are no longer active or leading to / sustaining any commercial scale implementation. However, submerged arc smelting in shallow open baths of rectangular furnaces with three electrodes, has made considerable headway on commercial scale to produce liquid iron suitable for ladle metallurgy to produce steel. Results of some very recent operations producing high quality low phosphorus liquid pig iron have been referred to using directly reduced / sponge iron fines as the feed in electric Submerged arc furnace.

The Rotary Hearth Furnace/FASTOMET process for sponge production using iron oxide fines and coal fines and the EOF (Energy Optimizing Furnace) processes have been touched upon as also the Corex process. It is concluded that much patience and caution are required in applying these hybrid technologies on industrial scale operations.

IN REVIEWING THE current status and commercial potentials of smelt-reduction technologies, one has perforce to identify and outline the main basis and reasons which led to their development in the first place and present thereafter how far such developments and newer processes have technologically been successful and commercially remunerative/acceptable. Proclaiming a new technological process or process route in itself in the background of a plethora of such processes mushrooming over the globe, can substantively mean or contribute very little in the long run. One has to look for and analyze the reasons/origin of the new processes/technologies before proceeding further.

One of the main reasons/causes which has led to a train of newer processes involving smelt reduction technologies, proven or still embryonic, is the "coke" for operating the iron blast furnace and the metallurgical grades of coking coals needed to produce blast furnace coke in the literally high/tall coke ovens and the high capital costs required to build them. Add to these capital costs, the costs of applying environmental pollution control measures to a capital intensive coke oven battery at a green field site or of a brown field installation, could be in the range of 300 - 400 US$ per annual ton capacity depending upon the extent of raw material's costs and the costs of auxiliary materials handling, by-product's recovery and environmental control mandatory provisions.

Such a new coke oven battery would need about a 100 US$ to operate it and about 70 - 85 US$ per annual ton for financial charges, and the coke would base to sell at 140 - 150 US$ per ton to reach the break-even point.

From the existing/operating coke ovens, in the early part of 1989, the F.O.B. market coke prices have ranged up to 125 US$ per ton and for spot market overseas coke prices have ranged up to 135 US$ per ton at the loading point excluding the freight and transport charges for the escalating CIF prices. With such a "coke" scenario, the race to develop technologies to do away with the metallurgical coke, was on, hurtling one process after another in rapid succession based on smelt-reduction technologies using non-coking coals, with each newer process proclaiming to be the winner. The resulting succession and procession of smelt-reduction processes/technologies have yet to fully establish their industrial acceptance for commercial scale operations. Other hybrid processes based on steel scrap with or without the use of electric power using coal, oxygen, oil and hydrocarbon gases are achieving significant industrial scale applications. Pulverized coal injection to the iron blast furnace has also gained considerable success and commercial acceptance. Meanwhile, concentrated efforts are being made world wide to develop Direct steel making including the USA where AISI has initiated co-operative efforts to develop direct steel making. (1/)

In the case of mini steel plants based on electric arc furnaces, with the applications of new technologies such as scrap preheating, water cooled panels, eccentric bottom tapping, oxyfuel burners, ladle refining and computerized process controls, etc., the electric arc furnace capacity could be increased substantially and power consumption reduced equally without increases in installed transformer capacity. Badische-Stahlwerke (BSW) recently estimated that electric arc furnace operations could achieve a production cost savings of up to 30 US$ per ton by following BSW practice/technology. (2/)

It is also fully possible that the applications of thin slab casting CSP - compact strip production by Scholoemann-Siemag and advancement in rolling operations will permit mini steel plants to diversity into flat products.

In the background of these success stories of mini steel plants, let us see how far the smelt-reduction technologies have developed to-date to obtain hot metal (liquid iron) directly from iron ores and non-coking coals as also other hybrid technologies to obtain liquid steel from hot metal and scrap charges in various proportions - EOF, KMS and KS processes etc.

The increasing applications of sub-merged arc electric furnace smelting operations in open slag baths in rectangular furnaces with six electrodes coupled with ladle metallurgy deserve full attention.

This then is the background and introduction to this paper which deals with complex and controversial subjects with the hope of not being misunderstood at the same time.

In doing so, no attempt will again be made to list all the smelt reduction processes that have been announced so far in having developed from laboratory to pilot plant scale and possibly attempted on industrial scale operations; these have been listed at many international conferences/seminars without in most cases providing full clues as to their industrial scale success and applications.

Current Status of Smelt-Reduction Technologies

It will neither be possible nor desirable to discuss each and every newly announced process; the lists are formidable and so is the task of doing so. Some of the newly announced processes are no longer heard of or reported upon in terms of their further progress to-date even by the sponsors of the processes themselves; process such as the ELRED, INRED fall into the latter categories without any industrial plant set up therefore.

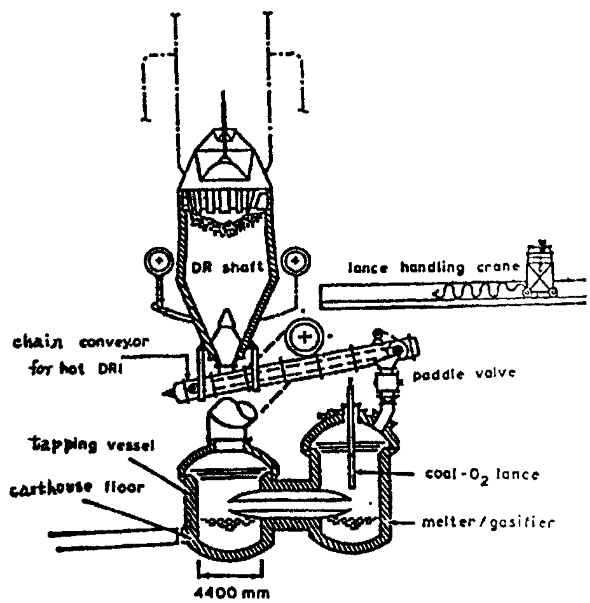
The analyses of such newly engineering technologies (3/, 4/) were furnished by the writer in the earlier symposia and conferences. Supplementary to these presentations, a most recent (5/) development relates to the British Steel and Hoogovens collaborating in a development in which the blast furnace is literally split. The hearth of the blast furnace becomes a two chamber melting pot, wherein partly reduced iron ore and coal are reacted with oxygen injected from a top lance. The molten metal flows over into a second chamber and is tapped intermittently using conventional blast furnace technology. Gases from the melting chambers are cleaned and cooled to a temperature suitable for injection into the top part of the hearth where direct reduction of the iron ore takes place. The cost comparison of the CBF (converted blast furnace) of the natural blast furnace is furnished in Table 1.

Table 1

Cost comparison - £s/ton of hot metal

Item	CBF	BF
Hot metal	45	48
Desulphurised hot metal	48.5	50
Liquid steel cost	57	60
Capital charges	29	37
Maintenance costs	13	18
Overall cost of liquid steel	99	115

Figure 1 shows Hoogovens no.3 blast furnace conversion to CBF



Hoogovens no. 3 blast furnace conversion to CBF
FIG-1

Smelt reduction processes of Kawasaki, Krupp Coin etc. have also not been reported in terms of their industrial scale applications/installations in recent years.

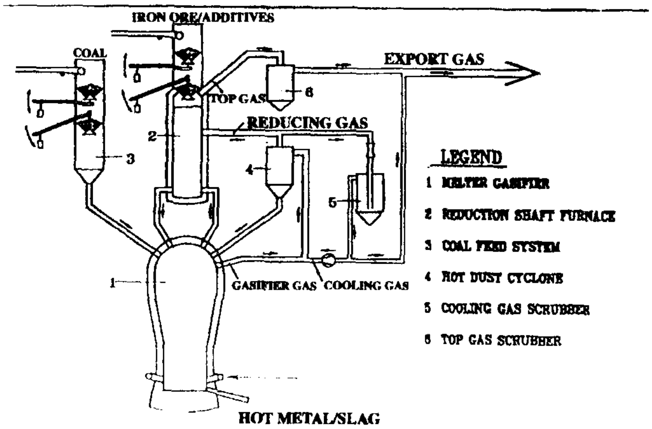
Concerning the Corex process, the industrial plant/project of Wierton in USA has been canceled a couple of years back whilst the industrial scale results at ISCOR's Pretoria works in South Africa have recently been summed up in the latest paper, (6/) presented during the AISE 1990 Annual Convention - October 90 vide the conclusions quoted herewith from this paper.

The COREX technology has proven its commercial maturity in an industrial sized plant.

For this 300,000 - tonne/year hot metal plant, a contract was signed in April 1985 between ISCOR, South Africa, and the consortium Deutsche Voest-Alpine/Voest Alpine.

After the initial operating campaign from August 1988 to February 1989, and the following period of debugging, the plant was restarted on November 10, 1989. Within four weeks, the plant was brought up to full capacity and based on excellent availability, considerably higher than 90%, very good metallurgical results have been achieved. Based on 100% noncoking coal mix, the hot metal had the usual blast furnace quality. With a 100% pellet feed, the production could be increased by 20 to 25% vs. 100% lump ore feed.

Consequently, on December 23, 1989, ISCOR officially took over the plant and integrated it into its production line of Pretoria works. Figure 2.



THE COREX® PROCESS
BASIC FLOW SHEET WITH EXPORT GAS
FIG. 2

The EOF - Energy Optimizing Furnace

The Energy Optimizing Furnace (EOF) has been developed at the Comphania Siderurgica PAINS located in Divinpolis, a town in the State of Mines Gerais in Brazil. The main features of the EOF are the following, as shown in the attached diagram:

1) The furnace shape is compact with a small surface area to reduce heat losses.

2) The submerged injection tuyeres and the after burning of CO to CO_2 above the bath with oxygen and air and oxy-fuel. burners results in a very high heat flux and release of 95% of the chemical energy in the bath and over the bath.

3) The scrap preheater is of a unique design, located above the reaction vessel so that the waste gases pass directly from the furnace through the scrap to the exhaust system.

4) The furnace is provided with a replaceable bottom which permits quick turnaround during the campaigns and results in very high furnace availability.

5) Water cooled side walls and roof which replace refractories and as a result reduce costs and increase furnace availability.

6) A very intense rate of bath oxidation reduces heat losses, increases energy efficiency and increases productivity.

7) Provision is made for the introduction of carbon and lime and other solid materials so that advantage can be taken of many variations in the raw materials.

These important design features, robust and practical construction have enabled PAINS to have 24 heats in 24 hours with liquid charges of hot metal to scrap in the ratio of 50-60%. The PAINS furnace set up in 1983 is of 28 tons capacity. An additional EOF furnace has been set up at PAINS in Brazil with a capacity of 30 tons in March 1988.

A 80 tons capacity EOF plant has been set up at Tata Steel, Jamshedpur in India, which will yield an annual liquid steel output of 600,000 tons. Another EOF plant of 60 tons capacity at Companhia Siderurgica Aliperti (CSA) went into operation mid 1988.

Additionally a 40 tons EOF plant for all steel scrap operation has been ordered end of 1988 by Ocean States Steel Corporation at Rhode Island in USA with a capacity of 250,000 tons/year of liquid steel. Figure 3 shows the EOF scheme.

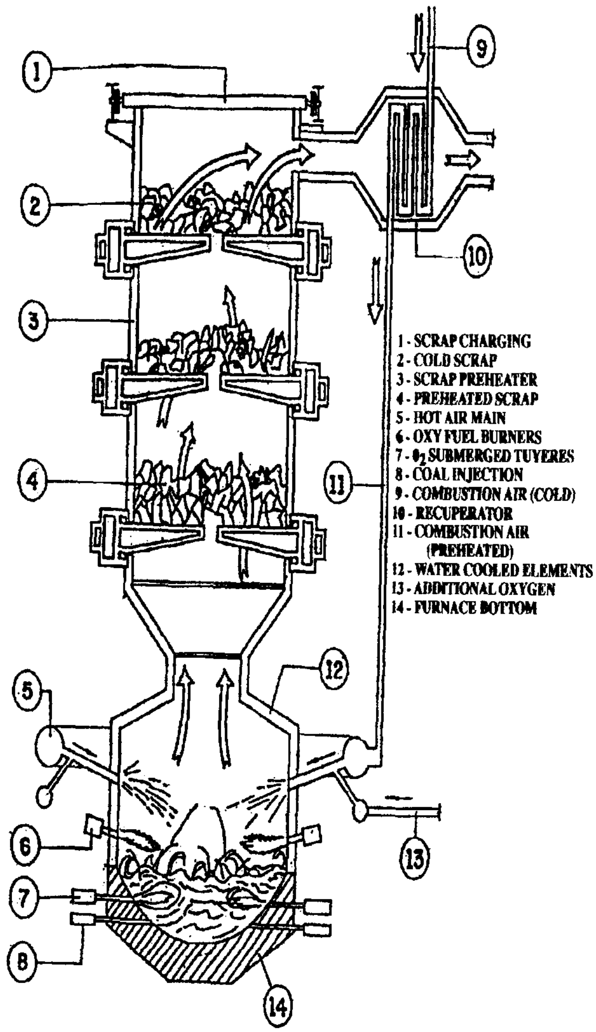


Figure 3 - EOF (Energy Optimizing Furnace) Scheme

Diado Steel Co.'s Process

Diado Steel Co. in Japan has recently developed a new non-electric steel scrap melting reactor/furnace process (7/) depicted in Figure 4. It is operated using a carbonaceous material and oxygen as the energy source.

The reactor has a preheating room above a melting furnace. The iron bearing materials are preheated by the exhaust gases from the melting furnace and then charged into the melting furnace.

A co-axial tuyere and a single tube tuyere are provided at the side wall in the bottom of the furnace. Oxygen gas is introduced through the co-axial tuyere at a blowing rate of 400 N/min. and nitrogen gas is introduced as a coolant through the outer slit at a blowing rate of 100 N/min. The single tube tuyere is used for carbon powder injection (particle size - 0.4 mm) carried by nitrogen at a blowing rate of 300N/min. Although the fine coal powder which contains volatile matter up to 30% can be used as a carbonaceous material, graphite is used in order to avoid the complex phenomenon caused by the combustion of carbon and hydrogen contained in the volatile matter. The melting furnace is equipped with another tuyere at the upper part of the furnace to introduce oxygen. This tuyere is made in a single tube structure with its tip in alumina. As such, the tuyere is free from oxidation and very stable against the high temperature of the furnace. About 50% of the CO gas generated in the iron bath is converted into CO_2 through the post combustion by the O_2 blown into the upper part of the furnace. Iron and steel scrap is first charged into an antechamber at the top of the melting furnace through a belt conveyor. The antechamber is separated from the preheating chamber by a door so that the scrap can be charged without disturbing the air tightness of the furnace system. Charging of the scrap can be completed very quickly. The preheating chamber is separated from the melting furnace by 2 doors. The lower door lined with refractory material shuts off the radiant heat from the inside of the furnace to protect the operating mechanism of the upper door from high temperature. Most interesting results have been obtained by Daido steel with 100% scrap charge using the liquid heel method. Figure 4 shows the schematic illustration of Daido reactor.

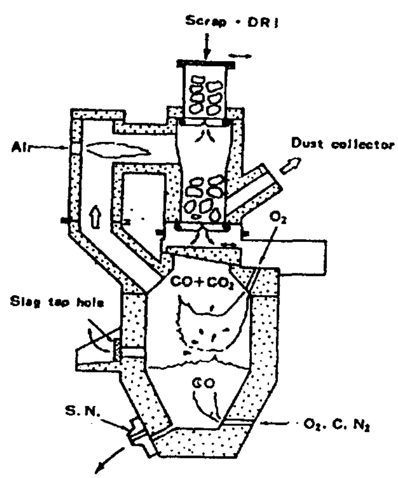


Fig. 4. Schematic illustration of a new reactor.

Open Slag Bath Smelting in Rectangular Submerged Arc Furnace

Whilst smelt-reduction processes have been figuring in the limelight without any tangible industrial scale success and commercial acceptance so far, there have been developments in smelting pre-reduced materials in open slag bath submerged arc furnace with rectangular hearths with 6 self-baking electrodes (8/).

Cold smelting in submerged arc smelting furnace started in 1925 in Norway, in 1937 in Finland and in the late 1950's with major industrial installations in Norway (Moirana) and Venezuela (Sidor). These plants entailed high power consumption about 3000 KWH per ton of iron smelted. Then came Skopje (Yugoslavia) plant 1966 and Highveld Steel-Witbank 1968 in South Africa using hot pre-reduced feed from rotary kilns to circular submerged arc smelting furnaces employing three electrodes. Relevant details of the operations of these two plants were furnished by the writer at the Third Inter-regional Symposium on the Iron and Steel Industry organized by UNIDO in Brazil in 1973 (9/). After the start of the Skopje plant in 1968, serious operational problems and hazards were encountered leading to explosions in the Elkem electric submerged arc smelting furnaces which thereby led to the closure of the six rotary kilns in 1971 for more than a decade. Early 1980's the operations were resumed and some highlights of the pre-1971 operations and post-1980's performance are furnished below.

During 1968-71, serious decrepitation and degradation of the dried lignite took place in the rotary kilns. The hot pre-reduced charge contained excessive lignite fines which led to explosions in the Elkem submerged arc smelting furnaces due to extremely poor permeability of the burden and pressure build up therein. For more than 10 years, the rotary kiln plant operations were moth-balled until early 1980's when the Skopje plant operations were resumed with reportedly better results which are outlined herewith from a recent paper (10/).

The iron ore used at Skopje is basically siderite -chamosite with some hematite - magnetitie limonitised ore from Tajmiste mines of the following analysis:

	%
Fe tot	- 41.46
Fe + 2	- 27.4
Fe + 3	- 14.06
SiO_2	- 13.65
CaO	- 3.25
MgO	- 0.95
Al_2O_3	- 5.5i
P	- 1.0
S	- 0.23
Moisture	- 2.0

Lignite used is in two granulations 15 - 30 mm and 30 - 60 mm and of the following chemical composition

	15-30 mm	30- 60 mm
Fixed C	37.18 %	38.10 %
Vol	47.86 %	48.95 %
Ash	14.98 %	12.84 %
S	1.55 %	1.37 %
H_2O	24.90 %	26.2 %

There are six rotary kilns, 95m long with inner and outer diameters of 4.15m and 4.55 m respectively with a speed of 0.55 rpm.

The ore, limestone and dolomite are added in exact proportions at the inlet of the kiln while the lignite is added through lignite scoop feeders arranged along the second half of the kiln. Depending upon the requirements, coke is added at the inlet of the kiln or through the lignite scoop feeders. Heat necessary for the reactions to take place in the kiln is provided by burning fuel oil through a central burner located at the outlet of the rotary kiln and by the combustion of volatile liberated from the lignite. The air needed for combustion of the volatile is injected through secondary fans placed on the kiln shell through 36 air blowing pipes built into the rotary kiln. The waste gases flow counter current to the charge. The heat of the flame and heat released by the combustion of the volatile and Co created in the reduction zone, enable the charge to reach a temperature of 1050^oC..

There are 5 submerged arc electric furnaces supplied by Elkem with transformer ratings of 34.5 MVA for 3 furnaces and 45 MVA for the other two. The inner diameter of the furnace is 15 m and Soderberg electrodes are of 1.9 m diameter.

The hot pre-reduced charge has the following analysis:

	%
Fe tot	40.53
Fe +2	33.97
Fe +3	1.8
Fe Met	4.77
SiO_2	13.26
CaO	12.24
MgO	2.96
Al_2O3	5.81
CO_2	2.56
Fixed C	5.59
S	0.41

The pig iron smelted from this hot pre-reduced charge from one furnace gives a daily production of 250 - 300 tons with power consumption of 1530 - 1550 KWH/t and electrode consumption of 10 Kg/t.

When using cold charge of iron ore and coke with no pre-reduction, daily output is 150 - 170 tons of pig iron with power consumption of 3200 - 3300 KWH/t and electrode consumption of 22 Kg/t. Thus with a hot pre-reduced charge, the pig iron production is increased by 40% and electrode consumption reduced by 50% compared to un-reduced cold charge.

Highveld (Witbank - South Africa) now has 7 submerged arc electric smelting furnaces (4 x 45 MVA, one 63 MVA and 2 x 33 MVA) with 13 rotary kilns which yield over one million tons of pig iron annually. Highveld has developed a process to smelt hot pre-reduced charge at levels of about 60% pre-reduction. The power consumption is around 1200 KWH/t and electrode consumption from 6-8 kgs/t or iron. The main objective of Highveld is to produce pig iron with 3.3 to 3.8% C with adequate metalloids for oxygen steel making and optimum recovery of vanadium from the hot metal in shaking oxygen ladles prior to steel making. The high titania content of the pre-reduced charge and flux required to reduce S and P result in 700 kg of slag per ton of iron. The titania rich slag is discarded.

QIT is operating open slag bath electric iron smelting furnaces in Sorel, Canada, and Richards Bay, South Africa for smelting cold feed of iron bearing titanium ores to produce high grade titanium (>80%) slag for paint pigment with molten iron as a by-product; the Richards Bay Plant is smelting beneficiated beach sands for the same products. These open slag bath smelting furnaces are equipped with 6 - in line semi - baked graphite electrodes of 600 mm diameter. These furnaces are cold fed with ore and carbon with precaution taken to avoid slag foaming. Chrome-magnesite suspended on arched roof lasts up to one year despite the severity of operating conditions, corrosive titanium slags, radiated heat and heavy volumes of high temperature hot gases.

Open Slag Bath Smelting with Hot Pre-Reduced Charge in Rectangular Submerged Arc Electric Furnaces with Six in-line Soderberg Electrodes

New Zealand Steel Co. had been operating a direct reduction rotary kiln to produce a 92% metallized product from ilmenite beach sands. The pre-reduced/metallized finely grain-sized (0.045mm to 0.212 mm) sand product was fed cold but continuously into conventional electric arc steel making furnace to produce liquid steel along with high volume of slag and equally high power consumption.

During 1985, New Zealand plant put up 4 rotary kilns for pre-reduction and addition of the hot pre-reduced metallized products to two, 69 MVA rectangular submerged arc smelting furnaces to yield 720,000 tons of pig iron annually. The new rotary kilns 65m long x 4.5m diameter were upgraded to increase the bed area which improved the transfer of heat from the gases to the charge. The pre-reduced product metallized 70-80% along with the char, was charged hot into the rectangular electric smelting furnaces to produce pig iron with power consumption ranging from 850-950 KwH/ton of iron at an input of 25-30 MW. The electrode consumption is very low at 2.5-3.5 Kg per ton of iron.

These rectangular smelters have six electrodes 1.32m diameter which are stronger and less prone to fracture. In the open slag bath smelting, the electrodes are immersed in the slag whose resistance determines the power consumption. The open bath furnace is operated at higher effective resistance than conventional circular submerged arc smelting furnace since the electrodes are not affected by the conductivity of the charge. The rectangular furnace can accept fine grain sized feeds without agglomeration. In an orthodox circular submerged arc furnace, the electrodes are subjected to severe physical strains when the burden slips during tapping whereas electrodes in the open bath furnaces are not subjected to these physical shocks with minimized thermal effects. Desulphurization is effected through fluxes charged into the rotary kiln and/or to the smelter furnace. A highly metalized>90% hot continuous feed into the open bath furnace could reduce power consumption to 500-600 KwH/ton of iron with a single furnace producing about 2500 tons of metal daily.

Even semi-steel containing 0.2-0.5% C could be produced which can be further refined in a ladle furnace with a small transformer to produce high quality steels.

A key advantage of the rectangular submerged arc furnace is that it does not have the drawbacks of a batch process involving thermal stresses, and low cost Soderberg electrodes can be used.

In India, in a recent trial, smelting of sponge iron fines has been undertaken in a circular submerged arc furnace to produce high quality low phosphorous pig iron. The sponge iron fines analyzed the following:

	- 6 + 3 mm	- 3 mm
	Percentage	
Fe tot	90.48	84.72
FeM	80	70.10
C	0.2	0.68
S	0.017	0.064
P	0.058	0.08
SiO_2	3.56	5.32
Al_2O_3	2.98	4.12
FeO	13.47	18.81
CaO	0.51	0.69

The pig iron smelted from these sponge fines gave phosphorous values as low as 0.02-0.03% with sulfur ranging from 0.005-0.02%, carbon up to 3.5%, Si up to 0.7% and manganese up to 0.09-0.06%.

The power consumption was of the order of 1100 KwH/t of iron smelted. The FeO content of the slag was 2-4% showing abnormally low iron losses with slag basicity of 1.8.

The hot metal producer was an ideal feed for the production of SGI-spheroidal graphite iron - ductile iron for high quality castings.

Elkem has built a plant at Tyssedal in Norway for the production of 100,000 tpy of "Semi-Steel" (partly refined pig iron) and 210,000 tpy of high titania slag. The pre-reduction kiln has been supplied by Allis-Chalmers and the cylindrical 3 Soderberg electrode submerged arc furnace is supplied by Elkem. Iron bearing titaniferous ores will be pre-reduced in the rotary kiln. The cold pre-reduced sponge is charged into the Soderberg submerged arc furnace to produce "Semi-Steel" partially refined pig iron and high grade titania slag. The semi-steel is then further refined in a ladle furnace to produce high quality steel.

Thus these submerged arc open slag bath smelting technology coupled with pre-reduction open up possibilities of producing semi-steel and then finished steel to be much more attractive and pragmatic than the current smelt-reduction processes, at the present stage of their development, can justifiably claim.

Processes based on the above technological pattern such as the "Combismelt" developed by Lurgi jointly with Demag fall into the category of potentially viable industrial projects.

The FASTOMET Iron Making Process

The FASTOMET (*11*) iron making process consists of mixing and pelletizing iron ore and coal fines, drying the pellets on a grate, pre-reducing the dried pellets on a rotary hearth and then charging the hot-pellets in a submerged arc furnace (SAF) operating with an open slag bath. Hot metal is tapped into ladles in batches, at intervals dependent upon the requirements for down stream steel making. The SAF can also serve as a hot metal reservoir if so required since it can hold up 4-5 hours of production. Carbon content of the hot metal can be controlled from 0.1 to 3.5%. Desulphurization is very effective in the SAF as also in the ladle using lance injection of based reagents.

The hot reduced pellets from the RHF are continuously melted in the SAF whose operations are independent of the RHF. By charging the quantity of carbon and lime in the charge, hot metal chemistry can be adjusted within the following limits:

Carbon	0.1 - 3.5%
S	0.05-0.15%
Si	0.1-0.6%
P	0.01-0.05%
Temperature	1400-1600°C

The hot metal can be refined if it has high C content in the BOF/LD oxygen steel making. If the hot metal is of low carbon content, it can be refined into high quality steel through ladle metallurgy/refining. If normal cast/merchant iron is required, it can be granulated or cast in the pig iron machine.

Fastomet process can utilize effectively mill scale, undersized sinter fines, coke breeze, flue dusts etc., in producing supplemental hot metal and steel. The key, however, is the pre-reduction followed by SAF technology operating with open slag bath as advocated earlier in this paper.

It will not be out of place to mention that direct reduction processes based on gaseous and coal reductants have in recent years made significant industrial progress particularly in developing countries. After the full success of UNIDO sponsored demonstration plant for the production of sponge iron using non-coking coals at Paloncha in India with an initial capacity of 30,000 tons/year raised to 60,000 tons/year through a second kiln, there have been 6-7 new Indian projects in various stages of implementation whilst two coal based industrial sponge plants have been completed and started operations in India. These new plants have been based on SL/RN and Krupp CODIR processes in India and the gas based new Indian sponge plants of ESSAR and Grassim are based on Midrex and HYL III respectively. Identical progress is being made in Venezuela about the expanding role of Midrex whilst HYL III has consolidated and expanding its capacity in Mexico (Sicartsa plant). And yet in the developed/advanced countries, the sponge plants are closed or moth-balled. The lists of DR/sponge plants released periodically by Midrex and other agencies depict the rosy and the dismal status of the DR/sponge plants in the developing and developed countries respectively. It is stressed that much patience is called for in advocating new technologies and processes and pressing them through to industrial adolescence and commercial acceptance. The revolutionary technologies and developments in electric arc steel making practices, equipment, plant operations and results achieved in recent years for Mini Steel Plants worldwide, are tributes to such dogged patience and exercises. The plants and processes that have fallen by the way side such as at Inchon in South Korea, Purofer in Brazil, Armco in USA etc., have been the casualties in the global progress of direct-reduction/sponge production technologies and industrial plants now operating successfully.

A Word of Caution

In the case of some of the emerging relatively newer technologies that have still to cut their industrial teeth, attempts are made to empirically extrapolate their production costs on industrial scale even when there is no industrial plant yet installed to prove or disprove their industrial scale techno-economic data and implied performance. In the maze of vastly conflicting data and in the wake of current economic depression in some industrially well developed parts of the world, one is left to his own pragmatic analyses to suit particular markets and raw materials and derive his own conclusions. And today of course, the customer/client is not supposed to be always right.

Furthermore, the cost data for a specific process calculated for a particular country/region do not lend themselves to universal/global acceptance. There are some excellent papers/reports recently published providing the economic data and production costs to cover most of the newer technologies/processes, proved technologies and well established processes under trials on pilot plant scale; in the case of the latter, commercial cost data have been extrapolated albeit without any commercial plant operating anywhere. The point(s) one would seek to emphasize is that economic study of newer processes/technologies today presents a fast and vastly changing spectrum and can by no means be accepted universally for all countries, for all conditions/environments and for all the time to come.

During the last few years several international conferences/symposia have been held in the developing and developed countries on the above subjects. Some processes that had until recently withstood the onslaught of the critics, have finally dropped out whilst others have proved their mettle/ground and are finding increasing applications/acceptance.

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Some Recent Developments in Steels for Power Engineering Applications

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Abstract

The requirement for increased efficiency and lower emission levels in steam power plant has important implications for choice of power generating systems and for materials used in critical applications. In response to these imperatives collaborative research work has been carried out in Europe to evaluate steels for rotor and other applications with increased temperature capability and with improved toughness. Some of the results from these programmes are presented in this paper in the context of the requirements of the industry. It will be shown that considerable potential for development remains for ferritic steels and that modifications to composition and heat treatment can provide materials with attractive properties for advanced applications.

CONCERNS ABOUT THE EFFECTS of environmental pollution arising from the combustion of fossil fuels, the tendency for fuel costs to rise, and public opposition in many countries to further nuclear power plant construction are factors which have had an important influence on plans for power plant developments. In the UK the restructuring of the utilities has been an additional factor influencing decisions on future generation systems. As a result there have been significant changes in emphasis with regard to the types of plant which will be constructed in the immediate future. In particular there has been a move away from large plants supplying base load to smaller, more flexible systems, based on combined cycle operation. The emphasis will be on high efficiencies and on low levels of environmental pollution so that there will be a demand for novel techniques of coal conversion with high operating temperatures to maximise the thermodynamic benefit for increased efficiency[1].

In anticipation of these changing needs in the industry work has been carried out in Europe in two collaborative research programmes, COST 501 and 505, to develop and characterise improved materials for steam turbine application. Some of these developments are briefly reviewed in this paper with particular emphasis on materials for steam turbine rotor applications.

Rotor Materials for Conventional Steam Temperatures

Material Development. The 1CrMoV steels which are widely used in Europe in this application have good creep strength at the operating temperature ie up to 565 °C but service conditions have to take account of the rather limited toughness of this material. Thus rapid start-up and shut-down would not be appropriate for units working with rotors of this composition.

Within this context a new steel was developed by Saarstahl AG, Germany with the aim of maintaining the high temperature creep strength of the existing 1CrMoV steel but with better toughness and resistance to temper embrittlement[2]. Following satisfactory results from laboratory-scale melts of a 2CrMoNiWV composition, two large rotor forgings, A = 1390 mm dia, B = 1000 mm dia, were produced using ESR and VCD melting practices respectively. Both forgings were oil quenched and tempered and the mechanical properties fully characterised in a programme of collaborative work in the COST505 Project[3]. The smaller forging was completely sectioned for testpieces as was an extension piece from the second forging. The main part of this larger forging was subsequently installed in a turbine by Siemens AG.

Mechanical Properties. The characterisation of the mechanical behaviour involved an extensive programme of testing to determine tensile, creep, fatigue and toughness properties[3] and only selected information concerned with the most critical parameters will be described here.

Fig 1 shows the fracture toughness measured by J_{1C} and K_{1C} as a function of temperature for both rotors with similar data for 1CrMoV for comparison. The improved performance of the newer alloy is evident and further testing on subsequent rotors has confirmed this toughness advantage. After exposure at temperatures between 425 and 480 °C for times up to 40,000 h the toughness as determined by the fracture appearance transition temperature (FATT) deteriorated somewhat. However the values of FATT were still superior to that of 1CrMoV core material in the unexposed condition. Exposure at temperatures between 480 °C and 550 °C had little deleterious effect on toughness.

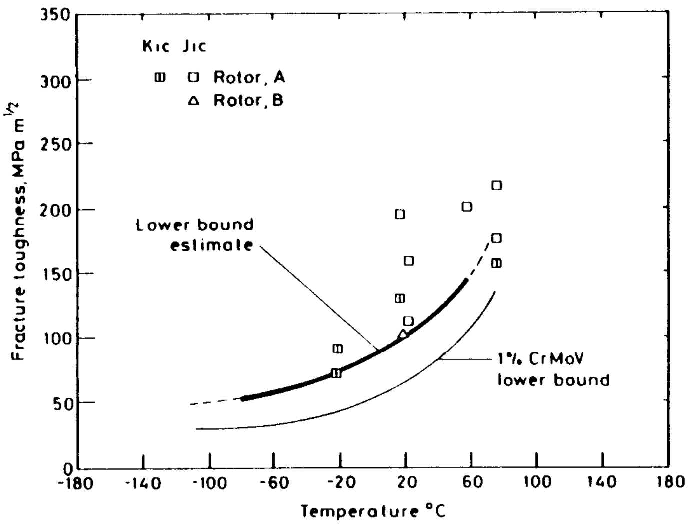

Fig 1 Fracture toughness as a function of temperature for 2CrMoNiVW steel.

The creep rupture properties at 550 °C are given as a function of the Larson-Miller parameter in Fig 2 and it is evident that the results for the present material lie within the scatter band for 1CrMoV manufactured and processed according to modern practice. The rupture ductility showed a substantial improvement with a minimum of ~ 15% compared with ~ 5% for the lower chromium alloy in similar test conditions[2]

Design Aspects. The main advantage of the 2CrMoNiWV steel lies in the significantly improved toughness values obtained at the centre of large forgings. In the case of an intermediate pressure (IP) rotor in typical start-up conditions this improved toughness represents a critical defect size 2.5 times larger than that for the 1CrMoV steel. For a combination high pressure/low pressure (HP/LP) monoblock rotor of the type used in combined cycle plant the superior toughness of the 2CrMoNiWV steel represents an advantage of a factor of 4 in critical defect size[2]. This advantage could be exploited in greater operational flexibility, ie shorter times for start-up and shut-down, for temperatures up to about 550 °C. Alternatively HP/LP rotors could be produced with larger diameters while maintaining acceptable toughness properties.

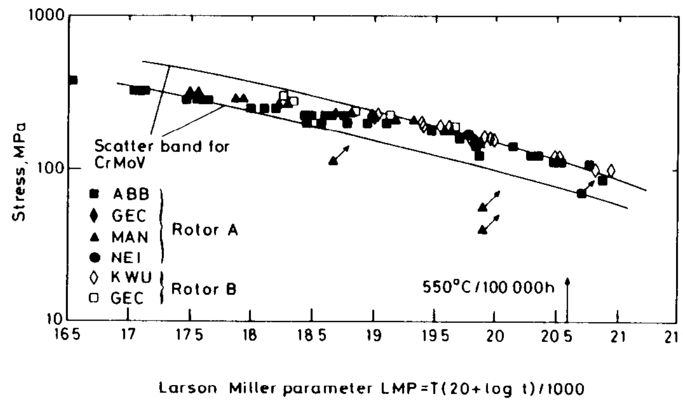

Fig 2 Stress rupture properties for 2CrMoNiVW with scatterband for recent 1CrMoV data for comparison.

Rotor Steels for Advanced Steam Conditions

Material Development. In order to operate with steam temperatures of 600 °C it will be necessary to use steels with higher chromium contents of ~ 12% to give increased strength and better oxidation resistance. Steels of this type have been used for some time in blading and rotor applications in steam turbines. However a tendency in some cases for structural instability after long exposure times (~ 50,000 h) which can result in a significant drop in stress-rupture properties has limited the service temperature to ~ 550 °C[4,5].

Table 1: Advanced 12%Cr Steels: Project Goals

- 100,00 h creep rupture strength at 600 °C of 100 MPa
- creep ductility of > 10% with no notch sensitivity
- through-hardening to at least 1200 mm dia
- minimum yield strength of 600 and 700 MPa

All other properties as for conventional 12 Cr MoV rotor steels

Table 2: Composition of the 12% Cr Steels in Weight Percent

Steels	C	Mn	P	S	Al	Cr	Mo	Ni	V	W	Nb	N
D	0.10-0.16	~0.5	<0.01	<0.005	<0.01	10-12	<0.5	0.5-1.0	~0.2	~2.0	<0.06	<0.07
E	0.10-0.18	~0.5	<0.01	<0.005	<0.01	10-12	~1	0.1-1.0	~0.2	~1.0	<0.06	<0.07
F	0.10-0.18	~0.45	<0.01	<0.005	<0.01	9.5-12	1-2	0.5-1.0	~0.2		<0.06	<0.07

Recent work in Japan in particular has focused attention on the potential of improved types of 12% chromium steels with additions of W and Mo[6]. In view of the likely demand for higher steam temperatures for increased efficiency, work was initiated in COST 501 to examine the performance of some modified 12% Cr steels for potential application with 600 °C steam[7]. The target requirements for the steel are given in Table 1.

As a result of work conducted in Japan and elsewhere it was evident that successful development of an advanced 12% Cr steel would involve:

- optimisation of composition, particularly with regard to C, N, Cr, Mo, Nb and W;
- long-term testing to confirm the structural stability of the material.

Heat treatment conditions were identified as a key issue in the context of long-term stability since there was evidence to suggest that low tempering temperatures to give good tensile strength could result in microstructural instability and poor stress-rupture performance[8].

The main thrust of the work carried out in the COST 501 Project has been on the effect of Mo and W, individually or in combination on the high temperature performance of 12% Cr steels.

Three types of composition were examined viz:

D ~ 2% W: < 0.5% Mo

E ~ 1% W: ~ 1% Mo

F ~ 1.5% Mo with optimised level of C, and Nb

and the details of the chemical analysis are given in Table 2.

The steels were produced as small-scale melts, and variations in composition were included to enable the effects of segregation to be assessed.

Table 3: Heat Treatment Schedule, 12% Cr Steels

1) Austenitising at 1020 °C - 1120 °C, 2-4 h.
   Cool at 120 °C/h to 500 °C
   50 °C/h to ambient.

2) Temper at 570 °C for 8-16 h
   Air cool or cool at ~ 10 ° C/h.

3) Final Temper at 685 °C - 730 °C for 16-24 h
   Cool at ~10 °C/h to 300 °C
   Air cool from 300 °C to ambient.

Heat treatment. The full heat-treatment schedule is given in Table 3. Austenitising temperatures between 1020 °C and 1120 °C were used followed by cooling at 120 °C per hour to simulate the cooling rate at the centre of large (1200 mm dia) forgings. Tempering temperatures between 685 and 730 °C gave yield strengths between 580 and 780 MPa. Ageing treatments at 480, 600 and 650 °C for up to 10,000 h prior to mechanical testing were used to assess resistance to temper embrittlement and overaging for 200 h at 700 °C, which was estimated on the basis of a Larson-Miller parameter of 25 to be equivalent to 270,000 h at 600 °C, was used to evaluate the microstructural stability of the materials.

All the steels were fully hardened with 100% martensitic structures and grain sizes varied from ASTM 3-7 for low and ASTM 0-2 for high austenitising temperatures.

Mechanical Performance. After the standard heat treatment of 1070 °C + 570 °C + 720 °C (see Table 3) all steels with the exception of steel F exceeded the 600 MPa target requirement for yield strength, Table 4. Overageing at 700 °C resulted in a slight decrease in yield strength (~ 10%) and in long term ageing between 480 ° and 600 °C all steels showed some deterioration in yield strength to a maximum of ~ 10% after 10,000 h at 600 °C. The effect of these ageing treatments on toughness was not significant and the value of

FATT for the Mo variant (steel F) remained at ~ 0 °C even after 10,000 h at 650 °C. Comparison with a conventional 12%CrMoV steel showed that the toughness and resistance to temper embrittlement of the trial heats was substantially better.

Where embrittlement did occur this appeared to be associated with the formation of Laves phase which was most rapid at 600 °C and was accelerated at high levels of tungsten.

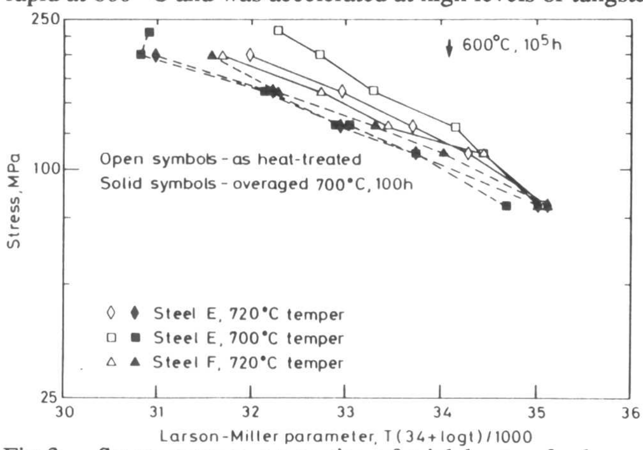

Fig 3 Stress rupture properties of trial heats of advanced 12%Cr steels at 600°C.

Table 4: Proof Stress Data for the 12% Cr Steels

Steel		Proof Stress, MPa		
		20 °C	600 °C	650 °C
D, tungsten,	AR OA	630 583	292 286	255 208
E, tungsten, molybdenum	AR OA	626 565	328 280	
F, molybdenum,	AR OR	579 533	286 282	

AR = 1070 °C, 570 °C, 16 h 720 °C
OA = AR + 200 h, 700 °C

The stress-rupture behaviour of steels E and F in the normally heat-treated and in the overaged condition is shown in Fig 3, and for steel E data for both the 600 MPa and 700 MPa strength levels are included. The results suggest that, even in the overaged condition, the steels will meet the target stress-rupture properties. This is confirmed by the results of iso-stress tests shown in Fig 4 for the steels in the same conditions of heat treatment.

Currently stress-rupture data are available for times up to about 20,000h and longer term testing is in progress. However the results obtained from these laboratory-scale melts were considered sufficiently promising to justify the manufacture of large-scale forgings[9]. Consequently forgings of about 42 Mg (40 Ton) have been produced with compositions similar to those of steels E and F and the evaluation of the properties of these forgings will be carried out in a further phase of the programme.

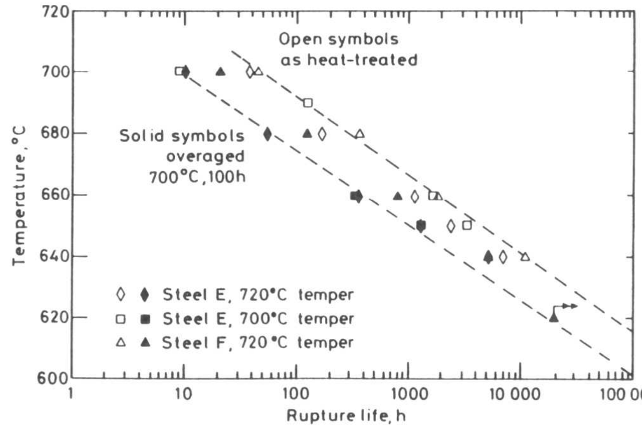

Fig 4 Isotstress data for trial heats of advanced 12%Cr steels at 100 MPa.

Steels for Boiler Applications

Materials Development. The critical component in advanced boiler plant is the steam header which collects the steam from the individual superheater tubes. In particular the welded joint between the stub pipes and the main header is subjected to a high thermal loading in addition to any mechanical loads from the pipework. The traditional manufacturing route for steam headers involves the welding of stub-pipes and nipples to thick-walled pipe and the subsequent on-site connection of the superheater tubes and steam lines. In order to reduce manufacturing costs and improve component reliability an alternative approach involving processing of steel powder by hot isostatic pressing (HIP) has been developed and component evaluation has been carried out within the COST501 Project[7].

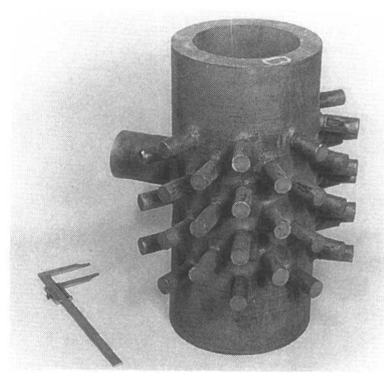

Fig 5 Prototype header manufactured in PM 12%Cr steel.

A prototype header manufactured in a conventional 12%Cr steel powder is shown in Fig 5. When the manufacturing route had been established a demonstrator header was produced in a powder version of the advanced alloy T91 and this material which is currently being evaluated would be used in power-plant applications.

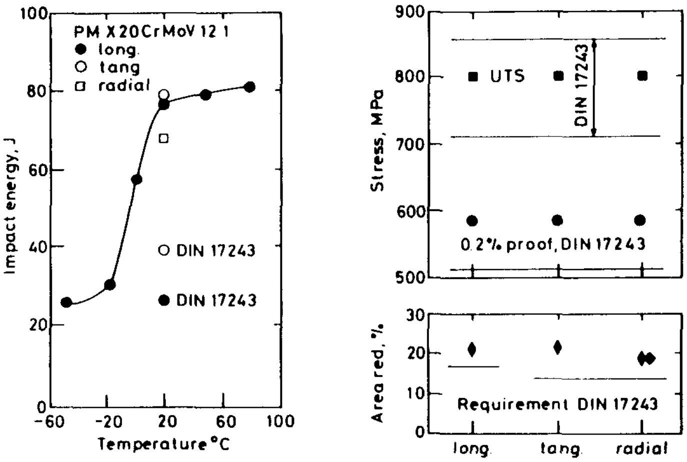

Fig 6 Tensile and toughness data for PM12%Cr steel.

Mechanical Properties. The powder processed (PM) material is characterised by a fine, uniform grain structure with no evidence of segregation. The tensile and toughness properties are highly isotropic and, as Fig 6 shows, are significantly better than the values given in the appropriate DIN standard for tube material.

Stress-rupture properties of various batches of PM-produced material including material from the prototype headers are shown in Fig 7 and it is evident that, despite the extremely fine grain size, the results are generally superior to those for the conventional tube material. Results from low cycle fatigue testing showed that data for PM and tube material formed a single scatterband. Thus in this respect also the PM materials appear at least as good as the conventional tube steel. The next phase of development will involve installation of a unit in a power-plant boiler.

Conclusions

1. The improved toughness of a new low-alloy rotor steel will allow greater flexibility in power-plant operation.
2. 12% Cr steels with optimised levels of Mo and W have attractive properties at 600 °C and are candidate materials for rotors operating with high temperature steam.
3. A powder processing route developed for steam headers offers advantages in reduced manufacturing costs and greater component reliability.

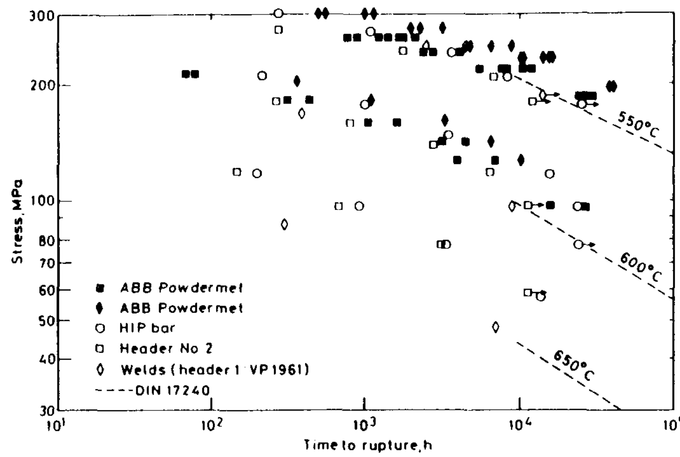

Fig 7 Stress-rupture data for 9-12Cr steels manufactured by powder processing with conventional tube data for comparison.

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Emerging Steel Technologies and Future of the Steel Industry

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Abstract

The continuing refinements in iron and steel technologies and the emergence of new technological concepts are attuned to energy optimisation, higher productivity, improved quality, cost-effective production and zero pollution.

The 1990s and early part of the 21st century will witness further refinements and technological advances. The bulk of steel production will continue to come from the BF-BOF route. In cokemaking, the trend is towards building energy-efficient, environment-friendly jumbo coke ovens. In ironmaking, the BF is expected to maintain its predominance. The continuing innovations and improvements in BF practice, as well as use of artificial intelligence have given a new lease of life to it, despite the challenges from emerging processes. However, the technological thrust will be on the development of ironmaking processes such as smelt-reduction without using coke.

Concurrently, there has been rapid progress in the development of alternative materials, light metals and their alloys as substitutes to steel in many engineering components. However, the development of newer, improved quality steels with special properties will enable steel to retain its predominant position. The steel industry will have to reorient itself to more exacting consumer demands and stringent quality requirements, while remaining cost-effective.

THE TWO OIL SHOCKS OF THE 1970s and the recession following in their wake forced the major steel producers to pursue extensive rationalisation measures such as closing down older non-profitable units, improving productivity and adopting an aggressive marketing policy. These efforts to rationalise operations and improve profitability along with substantial investment in R & D, are radically changing the structure and technological base of the steel industry. The 1980s thus witnessed the beginning of a massive restructuring of the world steel industry which has resulted in a marked recovery of the competitive strength of the major producers. The need for continuing technological innovation and modernisation was felt more than ever before.

Restructuring and modernisation. The restructuring of the steel industry has generally been in the form of:

i) Modernisation of existing facilities to maintain competitiveness
ii) Response to growing market demand for higher quality steel to meet customers' specific requirements
iii) Energy optimisation
iv) Improving environment all round and recycling of waste products and
v) Developing human resources and skilled workforce to handle effectively the technological changes in the modernised or newly built steel plants.

The steel industry is today facing greater competition from alternative materials. It has, therefore, become necessary for the steel industry to evaluate the potential of emerging technologies which can be exploited with advantage in the coming decades and to plan a workable strategy for its survival and progress.

It is in this context that the emerging steel technologies and the future product-mix of the steel industry will be discussed in this paper.

Technology Trends

The technological advances and modernisation witnessed in the steel industry during the last two decades have been more in the nature of fine tuning of the existing processes rather than any radical technological transformation. This trend is likely to continue.

The 'Coke oven-Blast furnace-BOF steelmaking' route will continue to provide the lion's share of crude steel for a long time, as further improvements and refinements in these major production technologies will continue. At present, about 57% of the total world steel production comes from the BF-BOF route, about 27% from the Electric Arc Furnace (EAF) route and the balance through the open hearth processes. In the next four or five decades, it is expected that the BF-BOF steelmaking will account for about 50% to 55% of the total steel production, with EAF steelmaking improving its current position to around 30%. The share of the newer smelt-reduction processes such as Corex, HIsmelt etc which will produce steel through the BOF route may amount to about 15%, depending on the local conditions.

Ironmaking

Alternative Ironmaking Processes. A wide variety of smelt-reduction processes for ironmaking are under various stages of development. A common feature of these emerging processes is the direct use of non-coking coal and oxide feed for the production of hot metal. The oxide feedstock varies in character; some are using fines, others need agglomeration or lump-size feed. All these ironmaking processes are, however, aimed at optimizing the use of waste heat to reduce the overall energy cost, and at reducing environmental pollution to much lower limits than those obtaining in the conventional BF route. Among these, pre-reduction electric smelting and Corex processes are at a very advanced stage of development.

Producing steel directly from iron ore and coal has been attracting attention in the past several decades. Large-scale efforts in this direction have been made in the recent past in Japan, USA and UK. Although these R & D efforts are ultimately aimed at and are billed as direct steelmaking, all these processes at the present stage have one objective in common, namely production of iron through smelt-reduction processes which can be converted into steel subsequently.

AISI Direct Steelmaking Project. AISI has taken a lead in the USA in direct steelmaking investigations. The widely known AISI direct steelmaking project was announced in June 1990, when a pilot plant was set up. The basic objectives of this project are:

i) Elimination of coke ovens, blast furnace, agglomeration plants
ii) Simplification of facilities
iii) Operational flexibility
iv) Scrap melting flexibility
v) Specific lower cost and
vi) Zero/minimum pollution

The project is being heavily subsidised by the US Department of Energy.

The pilot plant consists of a pear-shaped vessel holding liquid iron. Iron ore pellets, coal and limestone are continuously introduced into the vessel, while oxygen is also blown in through a lance to burn the coal which produces the requisite heat and chemical reaction for reducing the ore. The aim is to produce liquid iron containing 3.5% carbon which can then be refined by oxygen to produce steel. The present stage of development indicates that it may take another decade or so before it is commercially established.

Other smelt-reduction processes. Smelt-reduction processes (SRP) are mainly composed of a pre-reduction system, the smelt-reduction furnace and the process gas treatment and handling system. Since 1988, eight of the major steel companies in Japan along with the Japanese Coal Mining Research Centre have embarked upon Direct Iron Ore Smelting R & D activities. SRP processes which are based on fluidised bed pre-reduction of iron ore fines combined with in-bath smelting, may confront problems of scaling-up especially in the case of fluidised bed pre-reduction.

Nippon Steel achieved a production rate of 41 tons of hot metal per hour using a modified 170-ton BOF furnace as an experimental in-bath smelt-reduction furnace. Many problems in the smelt-reduction were noticed during the experiment, which are now being solved. One of the major operational changes envisaged was that the reduction reaction should occur in the presence of a large quantity of foamy slags.

The HIsmelt process, after six years of operation in a small-scale pilot plant, is now in the process of establishing parameters for design, construction and operation of a 100,000-ton/year plant to establish its commercial feasibility. If the current efforts for large-scale operation succeed, further R & D activities are planned to investigate the feasibility of scaling up the HIsmelt process to install a commercial plant with an annual capacity of 500,000 tons of hot metal.

The Corex process, which is operating at ISCOR, South Africa, is on the way to establishing itself commercially, at least with the type of raw materials available at that plant.

Direct reduction processes. In the case of direct reduction for the production of sponge iron or HIB, several processes - both gas-based or coal-based - are now well-established. A number of plants are in operation in various parts of the world. The primary objective of developing the direct reduction (DR) was to replace melting scrap. Sponge iron and HIB are suitable substitutes for scrap in electric arc steelmaking, especially in situations where scrap is not available or its price very high. Easy availability of suitable grades of iron ore and reductants like non-coking coal or natural gas provided the impetus for the development of DR processes. Gas-based DR accounts for over 90 per cent of the world's DRI production, and its advantages will lead to its further growth. The most successful gas-based processes are Midrex and HyL and the coal-based processes are SL-RN, DAV, ACCAR, CODIR etc. For the past several years, DRI production has been rising at the rate of around one million tons per year. In 1989, the production was about 18 million tons, and this is expected to grow further depending on the location and scrap shortage, especially in the third world countries.

Blast Furnace. Further improvements in the blast furnace operation will ensure that it continues to be the chief source of iron for steelmaking well into the 21st century. Large modern blast furnaces of today have already achieved campaign lives of 12 to 14 years and a productivity of about 2.2 t/m^3 per day. By 2000 A.D., these figures are expected to improve further to over 15 years and 3.0 t/m^3 per day respectively. Efforts are also now being made to develop a blast furnace for 100% oxygen blast operation along with coal injection. This may drastically reduce the investment cost and further lower the coke rate, while at the same time offering a workable solution for more economic hot metal production and possibly on a smaller scale also, if required.

Powder coal injection and coke rate. Powder coal injection (PCI) into the blast furnaces for the replacement of coke and other fuels is attracting global interest to reduce the current dependence on coke ovens and the inherent environmental problems. Efforts are under way to bring down the coke rate in the blast furnaces to around 360 kg or so. PCI rate is also expected to over-shoot its present 150 kg/ton level.

Development work in oxygen blast furnace operation indicates that PCI may eventually be raised to a level of 250-360 kg/ton. It should be noted, however, that blast furnace operation with oxygen is yet to be developed fully and commercially established. Further reduction in the coke rate from the existing levels is also likely to be achieved by increased use of self-fluxed high iron agglomerates in the burden.

Cokemaking

Cokemaking technology perhaps will undergo the greatest change in the coming decade and this will spill over into the 21st century. The emphasis will be on increasing the battery life, advanced oven heating controls, improved charge quality and compliance with environmental control regulations. A large number of coke ovens in Japan, USA and Europe which are due for rebuilding by the end of the century and during the first decade of the next century, will have to be rebuilt even to maintain the existing level of the crude steel production in these countries.

Improved coke quality, energy efficiency and zero-pollution. The new coke ovens are aiming at improved coke quality with higher yield, minimising specific energy consumption and reducing environmental pollution to almost zero level. For instance, National Steel in USA has announced its programme to build a new coke battery of conventional type with 900,000 tons/year capacity which is scheduled for start-up in the last quarter of 1992. Similar moves are expected from the Japanese steel producers whose rebuilding programme for coke ovens is expected to commence in about the next 4-6 years and will continue well into the first decade of the next century.

Jumbo cokemaking reactors. In Europe, cokemaking technologies are poised to take a significant leap into a new advanced system called "Jumbo cokemaking reactor" with capacities around 2 million tons/year or more from a single battery of reactors. According to current plans, these will become available in the second half of the 1990s. The two experimental ovens now being developed by Deutsche Montan Technologie, Essen, Germany in collaboration with Ruhrkolhe AG are scheduled for commissioning in 1992-93. This new cokemaking technology which is claimed to be 'environment friendly' is expected to be in operation in the coming two decades or so. The process is reported to be amenable to the use of coals of inferior grade than those used at present and will produce better coke with much higher coke yield and lower energy consumption. It is also claimed that these 'jumbo reactors' will lead to an overall effective cost reduction of about 20%, compared to the operating cost of the conventional coke ovens now in use. The productivity will be about 150 tons of coke per reactor. It is expected that the thermal efficiency of the cokemaking system will be raised to as much as 70% from the current level of 38% in the case of conventional coke ovens.

Steelmaking

BOF and EAF steelmaking. The BOF and EAF steelmaking routes will continue to enjoy their predominant status over other routes of steelmaking in the foreseeable future. BOF steelmaking has changed considerably since its inception in the mid-1950s. Since the 1980s, combined blowing (inert gas bottom stirring) in BOF plants has become a standard practice the world over. With refractories of superior quality used for lining as well as hot metal of better quality, campaign life of 3,000 heats has been achieved compared to 100 to 400 heats in the early years of BOF operation. The campaign life could be extended even further, adapting the practice of intermediate repairs and patchwork, developed in the last decade. Computer control of BOF blowing which started in mid-1960s with a static model has now mostly changed over to the dynamic control system with the successful implementation of the sub-lance technique of fine tuning the operation.

In EAF steelmaking, developments like inert gas bottom purging during melting and refining, eccentric bottom tapping, foamy slag practice, long arc operation etc are now being increasingly employed in many EAFs to reduce the specific operating costs and improve productivity.

DC arc furnaces are gaining ground, because of their stable power system characteristics and very low noise levels during operation. The consumption of electrodes and electrical energy are the two main cost elements in arc furnace operation and on both these counts, DC furnaces score over AC furnaces. It is reported that the specific power consumption is about 7% lower and electrode consumption 60% lower in DC furnaces compared to AC furnaces. In areas like lining wear, molten steel stirring etc, however, considerable experience with DC furnace operation will be necessary before fully automated operation can be adopted. Yet, the DC furnace, because of its simplified operational set-up holds promise of far easier automated operation, requiring only one operator. The development of technology for this one-man electric furnace operation with the help of artificial intelligence, robots and sensors will facilitate the transformation of arc furnace steelmaking from a dirty, dangerous and hard-worked industry it is today to a high-technology industry with a much smaller workforce.

These steelmaking process routes will continue to be upgraded in close conjunction with secondary steelmaking processes including the recently established and emerging tundish metallurgy processes to improve productivity and quality at lower specific costs. Sensor equipment for monitoring steelmaking processes at various stages will attract more attention for developing intelligent steelmaking process routes aided by computers and the already developed expert systems.

Near-net-shape casting (NNSC). Of special interest to the steel industry is the emergence of near-net-shape casting (NNSC) with its high capital productivity and lower operational cost for specialised products. R & D activity in this field is extremely high. In Europe alone, some thirty R & D projects are devoted to investigations on the development of direct casting of thin slab (up to 80 mm) and hot strip (0.5 to 8 mm). The driving force for these R & D activities is the potential for large-scale savings in energy and cost.

Most of the NNSC projects are still in the R & D stage, with the exception of a few thin slab casting processes which have reached the stage of commercial exploitation, these processes are based on the conventional CC process with oscillating moulds. The success story of SMS thin slab casting at the Nucor Steel in Crawfordsville, Indiana has demonstrated that thin slab casting technology (TSCT) can produce hot rolled strip of carbon steels and cold rolled sheets for roofing, siding as well as for some automotive parts.

The in-line strip production plant at Arvedi, Italy, is another example of the adoption of thin slab casting technology. This plant based on Mannesmann-Demag know-how is expected to go on stream by end-1991.

The production of strip directly from liquid steel in the not too distant future is now considered quite feasible. This will perhaps eliminate virtually the need for any hot rolling before cold strip is produced. It is expected to result in significant savings in energy, once the process becomes commercially established. However, there will be greater pressure on steelmelt shops to produce much better quality of steel which will be attuned to the more exacting process needs and consumer requirements in terms of performance reliability, durability etc.

Recycling steel. Unlike some of the competing materials, steel is a 100% recyclable material and can be easily recovered from mixed waste material by magnetic means. Steel scrap recycling has given impetus to the rise of a now well developed industry. The importance of the industry can be best appreciated considering that some 38% of world steel was made from scrap in 1989, the corresponding USA figure being about 50% of steelmaking furnace charge. Apart from increased inhouse recycling and use of steel plant process wastes, independent steel waste recovery and recycling industries are likely to grow further. Better methods of salvaging steel from surface coatings and claddings etc will attract greater attention in the coming decade. Several of the pretreatment processes now being tried on pilot scale for recovering and purifying steel scrap from disposable wastes may well grow into separate industries by themselves.

Computerisation And Use Of Expert Systems

With increased computer use, process automation and adoption of expert systems, and knowledge-based approach, many operating rolling mills today are processing directly charged slabs or blooms from the caster with or without homogenising heat soaking. Schedule-free computerised rolling systems for flat products have been developed and are being used by several steel plants the world over. Several expert systems are being used extensively for reducing energy consumption and maintenance downtime as well as for improving product quality. In the decades ahead, many more operations will be fully computerised - complete with diagnostic, fault-finding and quality control programmes.

An expert system at NKK's Keihin Works schedules the five continuous casters as well as three converters and six secondary refining operations for 'just in time' (JIT) deliveries to the mills. Expert systems are also used in the Japanese industry quite extensively for the primary operations, such as ironmaking, steelmaking and rolling as well as for energy and utilities management, quality control, research and planning. Targetted activities of expert systems include interpretation, prediction, diagnosis, design, planning, monitoring, debugging, repair, instruction and overall control of the process.

Finishing operations are already relying heavily on computer controls, mostly in batch processes. In the 1990s, greater attention will be given to linking the batch processes (for example cleaning, pickling, cold rolling, heat treating, finishing etc) into one continuous integrated operation which will be controlled by intelligent processing, utilising advanced sensors and computer programmes as mentioned above.

An allied area of AI and Expert Systems methodology is the development of intelligent robot system for steel industry. Nippon Steel Corporation has developed the intelligent robot system for the automatic operation of the continuous caster which recognizes the changing conditions during casting, judges optimum tasks and takes optimum action. Such intelligent robot systems are also being developed for several other areas of the industry.

Application of Neural Network Technology to the iron and steelmaking industry, though in its infancy, is expected to give startling results in the future.

Intelligent Processing and Expert Systems. Today, a large number of expert systems are available for application in the steel industry. The Japanese steel industry initiated intelligent processing systems in the mid-1980s and today, it is in a fortunate position to adopt 'artificial intelligence' for several operations in its steel plants.

On a larger scale, AISI is preparing a proposal for joint industry-government research projects to develop an intelligent processing system that will allow the industry to control the steelmaking process based on the ability of an intelligent computer to immediately sense the changes in the chemistry of the hot metal and steel, beginning from the blast furnace down to the finishing lines. Armed with the sensor information, the system then immediately adjusts the process or reschedules the operations. Sensors that report real-time conditions will be playing a much greater role in the intelligent processing of steel. Special efforts are being made to develop specific types of sensors for use in various expert systems including intelligent sensors.

Competing Materials

Concurrently, there has been rapid progress in the development of alternative materials, light metals and their alloys which are expected to substitute steel in many engineering components, especially in the transportation, aerospace and defence sectors.

The largest single example of competition to steel by alternative materials is noticed in the automobile industry. Since 1977, the steel content of an average 4-wheeler family vehicle has dropped by over 200 kg. The steel content which was earlier on an average around 60% of the vehicle weight is now around 54% and is likely to come down further by the turn of the century. Economic and environmental concerns as well as the need for fuel-efficient cars indicate that at least in the automobile industry, competing light metals, plastics and composite materials may replace steel substantially in the passenger vehicles.

In line with this trend, applications of aluminium, magnesium and zinc alloys in automobiles will pick up in the coming decades. The development of cast aluminium engine blocks with metallurgically bonded in-place cylinder liners, cast-spun wheels, aluminium space frames and new Al-Mn alloys with higher levels of titanium for a new generation of heat exchangers hold out promise of enhanced performance. Aluminium-matrix composites may also find greater use in some auto components.

Recycling of polymers and plastics, however, poses a serious environmental problem and unless cost-effective solutions are found for this nagging problem of handling and disposal of waste plastic products, the proven methods of recycling of steel scrap will have an edge over the lighter weight substitutes of polymers and plastics. The mounting pressure on the steel industry to produce steels in thinner gauges with higher performance levels at competitive prices will in turn spur the industry to adopt innovative technologies.

Product-mix Of The Steel Industry

The future product-mix of the steel industry will have to be necessarily more oriented towards the production of special grades of steel with enhanced properties and performance to meet specific service conditions. These steels will have to be often tailor-made to meet the exacting customer specifications and offered in as finished a state as possible for direct end-use. Thus, quality, price and customer satisfaction will be the guiding factors of the steel industry's product-mix.

It is to these major tasks that the industry will have to increasingly address itself to retain its market supremacy and to successfully resist the inroads by competing materials.

Product Quality. The quality requirements for steel in general have become more stringent than ever before. The acceptable limits of impurities in many steel grades are being monitored at PPM levels and at times even lower. For instance, acceptable sulphur level in the line-pipe steel is around 0.005%, and phosphorus lower than 0.002%. It is visualised that by 2000 AD, the sulphur level specified may be as low as 0.0015%. The specified limits on other residuals and gases will also become much stricter in the coming decade.

The level of non-metallic inclusions in steel will have to be reduced substantially to improve its weld integrity and toughness in many a specification for structural steels. The tin plate container (can) market is insisting on very low levels of non-metallic inclusions to ensure against failures in the can walls and flanges, resulting especially from their presence in critically strained areas. The detection of these non-metallic inclusions of extremely low incidence is so difficult that much care and control is needed to produce steel of acceptable quality for the tin markets. To remain competitive, the steelmakers will need to provide in the future thinner gauge material of excellent quality which can be used for manufacturing larger cans with thinner wall at faster rates, without interruption to the production line. All these will require much better surface texture of the tin plate and greater consistency with regard to dimensional tolerances and tin coating weights etc. In the flat products area, the demand for coated sheets has been increasing over the past few years. The growth in this sector unlike others, has been initiated by the automotive industry and quite a few auto producers have also participated in the investment in these plants. Special steels have been developed to improve the yield strength during the paint baking operation. These steels, popularly known as Bake-Hardening Steels (BHS), are being increasingly used for the auto body panels for their higher strength and improved dent resistance. These steels have also contributed in reducing the thickness of the sheets for the auto body. The new coating lines are using basically a number of specialty Zn-alloys for preventing various types of corrosion.

Demand for coated sheets with metallic and organic coats based on polymers, resins, vinyls and others has been increasing over the past few years. Newer applications of coated steels are also increasing. The demand for coated steels in the western world alone is expected to grow beyond 25 million tons by 1995.

A variety of high-strength formable steel sheets with transformation-induced plasticity (TRIP) characteristics, which will facilitate the use of thinner material for the auto bodies, have been developed for mass consumption. It is claimed that these TRIP steels have been able to compete successfully with Al-alloys, plastics and composites in the weight reduction areas. Vibration damping steel sheets for automotive applications, wherein steel sheets are being produced by rolling together a thick layer of visco-elastic polymer sandwiched between two outer steel sheets, have also been developed for better performance reliability of the auto body. Apart from the automotive applications, these vibration damping steels are expected to find a number of useful consumer applications in the near future.

Human Resource Development

To be effective, the emerging steel technologies will need continuous monitoring of process activities including the input materials. One of the basic objectives of these innovative technologies will be greater use of automation and computer-based expert systems as well as knowledge-based systems approach to the control of operations. The workforce of yesterday cannot fit into the culture of the futuristic or modernised steel plants. Many of the routine activities in a steel plant have been taken over by simple robots, reducing the number of shop floor and other operatives. The successive layers of management have also come under close scrutiny, as much of the decision-making can now be taken over by the expert systems or automation and intelligent processing as required.

The steel industry today is aiming at a productivity level of about 1.0 to 1.5 man-hours per ton of finished steel. One can visualise that the future steel plants will be operated with fewer personnel due to extensive automation and computerisation. The quality and calibre of personnel required to operate and manage these sophisticated systems will have to be of a higher order than that obtaining at present. This would imply that special efforts will be needed to develop and train a new breed of qualified personnel for plant operations and management. In this context, it may be interesting to note that the National Science Foundation, USA has sounded a note of caution that there may be a shortfall of 700,000 scientists and engineers by the 21st century in the USA alone, if the current enrolment patterns are not reversed. The steel industry the world over is alive to this problem and is aware that it will require a world class workforce to produce world class steel products in the decades ahead.

CONCLUDING REMARKS

Restructuring and modernisation are the two continuing phenomena in the steel industry, particularly to meet the increasing demand for quality steel to satisfy the ever-growing consumer needs and also to remain competitive in the face of rapid growth of alternative materials. A number of emerging technologies nearing full commercial exploitation are now available for adoption in the steel industry. These technologies will be absorbed at a slower rate for various reasons. A major one would be that the existing global steel industry cannot wish away the huge investment already made and more so, as fine tuning of the existing technology can revive many of the integrated steel units to confront the challenges in its way with confidence. However, all these will require an acceleration of the existing R & D activities. These would include cooperative research with universities and increased customer interface as part of the steel industry's strategy for survival and progress. The ongoing and the anticipated changes in the steel industry will demand more developed and specialised skills from the operatives and managers of the industry. A continuous upgrading of the human resources through training at all levels will, therefore, be of vital importance to sustain the steel industry.

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Production of Low Residual Steels from Indian Raw Materials

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Abstract

Virtually all steels in today's market, particularly those used for flat products, contain very low levels of sulphur, phosphorus as well as oxygen and nitrogen. Even if specifications do not require these residual elements to be restricted to such low levels, it is for the benefit of the steel maker as well as the user, that these are adhered to.

Tata Steel is entering the flat product market by installing a 1 mtpa Hot Strip Mill, to make strips of 1.6 to 12 mm thickness. Two 130 t LD converters equipped with bottom stirring facilities will be installed in a new LD Shop along with a ladle furnace, a vacuum degassing unit and two slab casters. 70% of these continuously cast slabs will be hot charged in the Hot Strip Mill, the product from which will ultimately be cold rolled (initially by others).

Only by very stringent control at all stages would it be possible to cater to the flat product market requirements since Indian hot metal chemistry is not very favourable, particularly in terms of phosphorus, titanium, silicon, etc. These aspects are being attended to in Tata Steel in its endeavour to cater to the demand of high quality flat products in the domestic as well as the global market. This is the sea change facing Tata Steel as the 1990s flow into the 21st century.

SUBSTANTIAL EFFORTS have already been made and are still going on in the global iron and steel industry to improve the quality of steels used for long and flat products. The main task ahead of steelmakers is to produce these grades of steels with low amounts of residuals without extremely high capital investments, i.e. at reasonable costs. Only in this way would it be possible to cater to the requirements of the users and yet make the whole exercise profitable. The key to success in this endeavour is to know what the actual requirements of the users are and then produce steels which satisfy them in the most efficient manner. As far as the steelmaker is concerned, these efforts can be classified into :

* Consistency in the purity of steels by narrowing down the limits of sulphur, phosphorus, as well as gases such as hydrogen, oxygen and nitrogen.

* Cleaner steels by dramatically reducing, if not eliminating, non-metallic inclusions.

* Introducing homogeneity in all parts of any given steel product.

* Casting as close as possible to the final product shape and close dimensional tolerance in the finished material.

The conditions prevailing in Indian steel plants are in no way different from elsewhere. Today, Tata Steel is preparing for the period beyond the immediate future and for a sea-change in India's industrial scene. Projected growth in conventional, mostly commercial grade products, is 6-8% per annum but more importantly, the Indian steel industry will be expected to meet higher product and quality specifications, provide better service levels and more new products to a growing set of customers.

Steel Property Requirements and the Position at Tata Steel

Commercial steels always contain certain amounts of sulphur, phosphorus, oxygen, nitrogen, hydrogen and sometimes even some tramp elements arising out of the metallurgical process used to manufacture steel. It is worth mentioning that even if specifications do not require these residual elements to be restricted to very low levels, it is for the dual benefit of steel makers as well as users that it has become mandatory to go in for low residual steels, the culmination of which, of course, is the advent of interstitial-free steels. Moreover, from the point of view of efficient and economical operation of continuous slab casters as well as hot strip mills "defect free slabs" are a paramount requirement. Since hot charging is by far the most economical means of processing slabs in a hot strip mill, more and more plants are opting for such a facility (1,2,3). This again makes top-class steel quality absolutely essential so as to eliminate conditioning of slabs, as an intermediate step, between slab production and slab rolling.

The production of clean steels therefore includes practices adopted during steel production such as bottom agitation, use of a sub-lance, slag-free tapping, secondary metallurgy, etc., as well as measures taken at the continuous caster like the use of a large and deep tundish, stream protection, automatic detection of slag flow and an appropriate caster design. It was with this in view that Tata Steel installed a combined blown LD Shop with two, 130 t converters, a large VAD unit, a six strand billet caster and a state-of-the-art 300,000 tpa single strand Bar and Rod Mill as it entered the area of high quality long products in 1982-83. As a result, Tata Steel is today in the market for some very sophisticated steels - Table-I describes some of the current trends in the demand for value added steels in the long product segment, many of which can be catered to by Tata Steel. To achieve this goal using Indian raw materials is a daunting task, to appreciate the magnitude of which it is necessary to assess at first the influence of various elements on the properties of steel.

Influence of Steel Composition

Under Indian conditions, the realistic target for residual elements in flat products is sulphur 0.015%, phosphorus 0.015%, nitrogen 40 ppm, oxygen 20 ppm and hydrogen 2 ppm, maximum (in all cases). Steel properties which are to be guaranteed depend, to a large extent, on the chemical

Table-I. Current trends in the demand of value added steels in the long product segment

Steel Categories	User Industry	Form	General requirements
Forging quality steels	Automobile, engineering	Bars, Billets, Blooms	High intrinsic quality, close dimensional tolerance, good surface
Long forged products	Automobile, engineering	Bars, Shafts	High intrinsic quality, close dimensional tolerance, good surface
Wire rods and structurals	Construction, fabrication, fastener	Coils, Rods, Angles, Sections	Controlled mechanical properties within a narrow range, good weldability, excellent surface, close dimensional tolerance
Special bars	Bearing	Bars	Close control of chemistry, narrower than specified hardenability band, restricted residual tramp elements, low segregation, tight gas content and cleanliness, closer dimensional tolerance, free from harmful defects and internal soundness

composition, and yet over-emphasis on very low residuals can add considerably to cost of production. There is thus a 'trade-off' and at Tata Steel, efforts have been made not to plan for removing the harmful elements to the maximum possible extent but to the extent necessary for efficient manufacture and processing. An attempt will now be made to quantify the extent of the harmful effects of some of these elements.

Effect of Sulphur. The predominant influence of this element on the properties of steel, particularly ductility, is well known. The effect of sulphur on the shelf energy of hot rolled strips in different directions of the rolling plane is shown in Figure 1. Inclusion engineering, especially calcium metallurgy, has been introduced by steelmakers not only for decreasing the sulphur content but also to improve the overall cleanliness and to modify

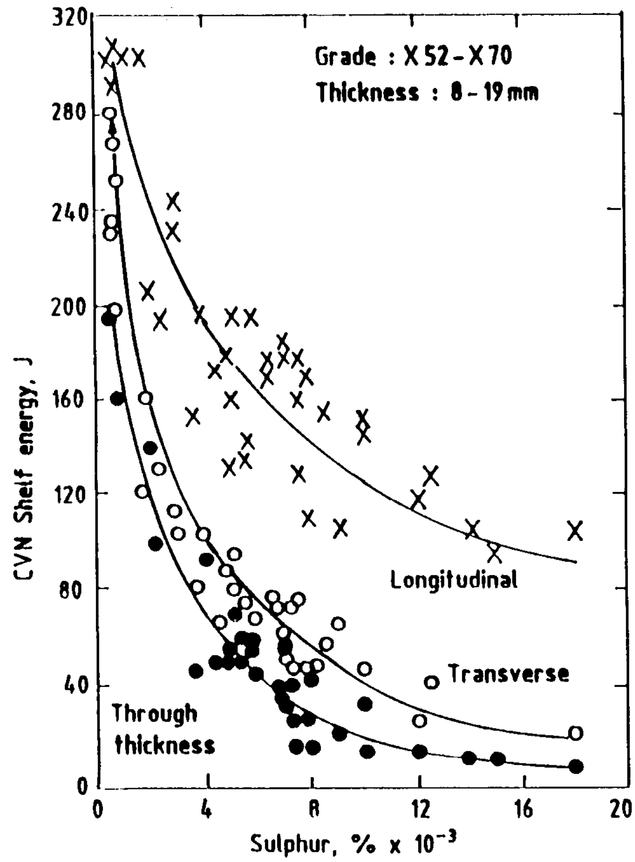

Fig.1 - Effect of sulphur content on shelf energy of hot wide strip in different directions of rolling plane

the remaining sulphide inclusions to a globular shape. The deleterious effects of sulphur have been studied extensively (4,5) from the point of view of smooth slab caster operation with an aim to produce defect free slabs amenable for hot/direct charging.

At Tata Steel, blast furnace hot metal with 0.050-0.060% sulphur will be pretreated using calcium carbide and/or other suitable reagents to lower the sulphur level to below 0.020% before the metal is charged in the LD converters where hot metal will constitute 85-90% of the charge. It should then be possible to tap steels containing a maximum of 0.015% sulphur by choosing an optimum slag chemistry.

Effect of Phosphorus. The detrimental effect of phosphorus is also well established (6) and its control requires a "systems approach" (7) since most aspects of steelmaking have an impact on the level of phosphorus in the product. As far as flat products are concerned, the world-wide trend is to classify them into three categories based on phosphorus : (a) very low phosphorus, (b) moderately low phosphorus and (c) high phosphorus (rephosphorised). Among these, the first two are more important for Tata Steel.

(a) Very low phosphorus steels.: Steels which are susceptible to embrittlement need very low phosphorus levels, the maximum permissible level being 0.020%. It has been reported (8) that in future, line pipe applications (particularly heavy wall pipes) will demand less than 0.020% phosphorus and for the transmission of corrosive gases, less than 0.020% phosphorus will be mandatory and less than 0.010% phosphorus desirable. Besides, less than 0.010% phosphorus will be indispensable for low temperature service and hence, such low levels of phosphorus represent a potential alternative solution to the embrittlement problem.

(b) Moderately low phosphorus steels. include products for which about 0.020% to 0.030% phosphorus is tolerable and this covers most low strength grades and high strength steels which are not subjected to hostile environments.

In India, the position of the "phosphorus front" vis-a-vis iron and steel operations elsewhere in the world, is the most unfavourable. This is essentially because of high phosphorus contents in many Indian iron ores (0.080-0.120%). At Tata Steel, hot metal contains around 0.25% phosphorus and bringing this down to 0.015%, as decided by the product mix as well as from the point of view of smooth slab caster and hot charging operation, is quite a challenging task. The magnitude of the problem is schematically illustrated in Figure 2. Efforts were made to calculate the lime consumption and slag volume for typical silicon levels in hot metal of 0.8% to 0.5% and it was found that with a reduction of silicon levels in hot metal, the LD slag rate decreases but the percentge of P_2O_5 in the slag for the same phosphorus input, increases sharply. This is shown in Table-II. As a result, the partition co-efficients becomes abnormally high at low hot metal silicon levels and can reach values not normally achieved by steel producers. It has also been calculated that if the partition co-efficients in Tata Steel's practice are restricted to 150-160 (normally obtained by steel producers elsewhere), the P_2O_5 in the slag would have to reach 3.5-4.0% as against 2% in Tata Steel's present day practice.

Table-II. Calculated slag volume in LD converters at different hot metal silicon levels

Inputs : Hot metal : Mn, % 0.15
P, % 0.28

Output : Slag : Fe total, % : 20
Steel : Turn down phos., % : 0.010

Hot metal silicon, %	LD slag basicity, CaO/SiO_2	Lime consumption, kg/t	Converter slag volume, kg/t
0.8	3.0	60.0	140.0
	4.5	100.0	186.0
	5.0	115.0	202.0
0.7	3.0	50.0	137.0
	4.5	87.0	170.0
	5.0	100.0	183.0
0.5	3.0	28.0	96.0
	4.5	61.0	134.0
	5.0	71.0	145.0

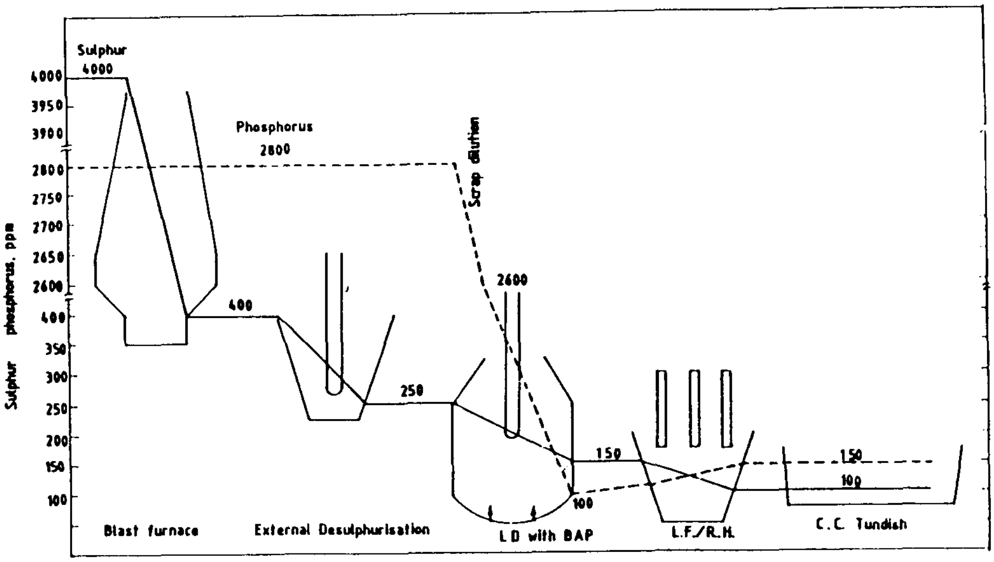

Fig. 2 - Sulphur and phosphorus levels in iron and steel in Tata Steel

Effect of Oxygen. Because of its low solubility in steel and owing to its high affinity for many of the alloying elements, oxygen tends to form various types of non-metallic inclusions. Very high demands on oxide cleanliness are put on HIC resistant steels, non-oriented silicon steels and bearing steels as shown in Figure 3 (10). Because of the above demands from customers, a whole series of secondary metallurgy processes, for instance the well known RH vacuum degasser or its variants, have already established themselves. Efforts have also been made to decrease the oxygen content of steel at the end of blowing in combined blown converters and to provide efficient shrouding and other measures during continuous casting.

At Tata Steel, silicon in hot metal is at present around 1.0-1.2% and to produce low phosphorus

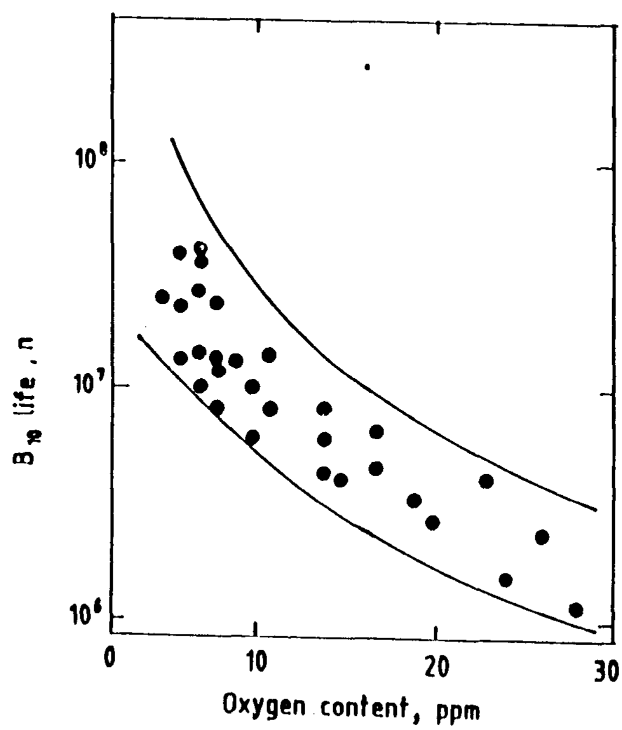

Fig.3 - Relationship between oxygen content and rolling contact fatigue life

steels with reasonable oxygen contents, it is essential to bring down the silicon content. Based on actual plant trials conducted at Tata Steel, it is estimated that the silicon content in hot metal can be lowered from around 0.8-1.2% (0.8-0.9% is the expected silicon content in hot metal from Tata Steel's new blast furnace) to about 0.5-0.6% by adding about 40 kg/thm of a reagent consisting of 90% mill scale or sinter fines and 10% limestone in the blast furnace runner.

Reblows during LD steelmaking also have a very significant effect on the final dissolved oxygen content and reblows can be brought down using low silicon hot metal. Detailed studies were conducted at Tata Steel to establish a quantitative relationship between reblow time and increase in the dissolved oxygen content. It was found that for every one second of reblow, the average increase of oxygen was 9.5 to 10 ppm. In the present practice, the turndown dissolved oxygen content is around 800 ppm (at 0.03% carbon) with the recently introduced bath agitation facility as against 1300 ppm (at 0.03% carbon) obtained earlier with straight LD operation. Hence, substantial reduction of oxygen in steel has been made possible by the BAP technique, using which, Tata Steel is now producing controlled oxygen steels.

Effect of Titanium/Nitrogen. Recently, very low nitrogen levels have become extremely important for ultra low carbon cold rolled steels, particularly with respect to their formability during continuous annealing.

At Tata Steel, the nitrogen content in hot metal is in the range of 60-70 ppm and this low value of nitrogen is basically because of a higher armount of titanium (0.09-0.12%) always present in hot metal. After LD tap, the steel contains about 18-22 ppm titanium and about 25-40 ppm nitrogen. Although for most of the steel grades titanium is not detrimental, production of a few special grades, like ball bearing wire rods (specified titanium content 30 ppm max.), is difficult.

Effect of Hydrogen. Relatively low levels of hydrogen (3-5 ppm) in steels are sufficient to cause internal micro cracks. By slow cooling and long annealing treatments, hydrogen can be removed by diffusion but this is not always economical. Figure 4 illustrates the critical hydrogen limit (11) in liquid steels for flake formation without slow cooling, as a function of plate thickness.

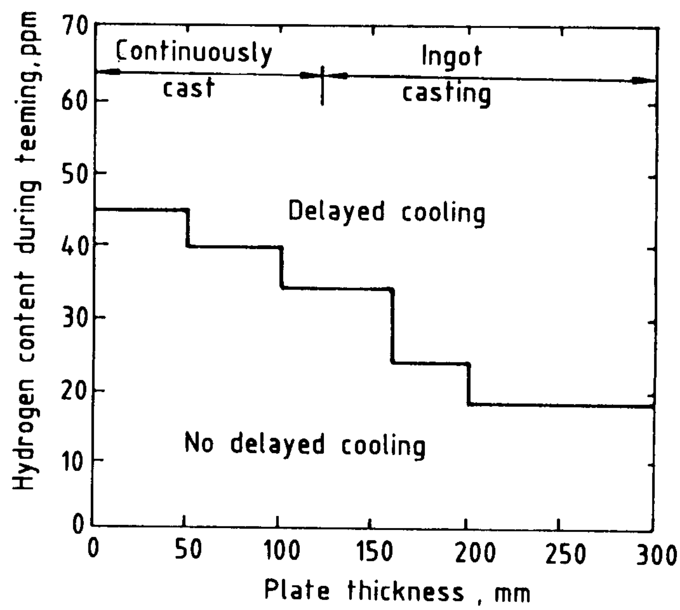

Fig.4 - Critical hydrogen contents as a function of heavy plate thickness

The potential source of hydrogen in steels is lime which is added during different statges of steelmaking. At Tata Steel, hydrogen measurements have indicated that reduction in 200 kg lime during VAD treatment reduces the hydrogen content by about 1.5 ppm for a typical forging quality grade. The average hydrogen content of steels tapped from the LD converters at Tata Steel is 9.4 ppm which decreases to around 2-3 ppm following normal VAD treatment (in special cases, this can be brought down further).

Low Phosphorus Steel Production at Tata Steel

The average hot metal composition at Tata Steel is C - 3.8/4.2%, Mn - 0.30/0.60%, Si - 1.20/1.40%, S - 0.040/0.060% and P - 0.25/0.28%. Since most of the difficulties are foreseen with phosphorus content in steel, basically owing to adverse chemistry of the hot metal, detailed studies in the area of phosphorus reversion, pick-up from slag, pick-up from ferro-alloys, etc. have been carried out. This has shown that the phosphorus content of steel increases by about 0.010% from the final turn down analysis to the ladle sample. This increase is a result of phosphorus pick-up from ferro-alloys and slag carry over; some typical test results are shown in Table-III. Depending on the quantity and quality of ferro-alloys added, the pick-up of phosphorus varies from 0.002-0.008% whereas phosphorus increase as a result of slag carry over varies from 0.0015% to 0.010%. Slag arresting facilities are, therefore, absolutely essential and are being provided in the new as well as the existing LD Shop. Use of special low phosphorus ferro-alloys, which are more expensive, has also commenced in certain grades and will become more wide-spread in the years ahead.

The recent use of BAP (inert gas agitation) has significantly improved steelmaking at the LD Shop. The notable advantages obtained from BAP are illustrated in Table-IV. Reduced flux and oxygen consumption, lower oxygen content in steel, increased yield, higher lining life and higher gas recovery have decreased costs and improved steel quality. Efforts are also being made to decrease the phosphorus content in steel by using a 4-5 hole lance instead of the 3 hole lance now in use. Work has

Table-III. Typical phosphorus pick-up from ferro-alloys and slag carry ovr at Tata Steel

Grade	P, at final turn down, %	P ladle sample, %	P pick-up, %	P pick-up from ferro-alloys, %	P pick-up from slag carry over, %
BG4	0.023	0.034	0.011	0.00346	0.00754
EN4 3D	0.025	0.029	0.004	0.00239	0.00161
ST-27	0.021	0.031	0.010	0.00199	0.00801
N-80	0.020	0.029	0.009	0.00686	0.00214
TISFORGE C20	0.023	0.028	0.005	0.00262	0.00238

Table-IV. Improvements in LD operations at Tata Steel arising out of adopting BAP

Parameters	Straight LD	BAP
Yield, %	85.0-85.5	86.0-87.0
Lime consumption, kg/t of liquid steel	95.0-100.0	80.0-85.0
Vessel life, No. of heats	350-360	405-410
Manganese in turn down steel, %	0.15-0.17	0.20-0.22
Aluminium consumption, kg/t of liquid steel (Rimming heats)	0.19	0.08-0.10
Slag P_2O_5, %	2.0-2.5	2.8-3.0
Oxygen at turn down (C 0.03%), ppm	1250-1300	750-800

already been started in the area of optimisation of lance design with particular reference to combined blowing and production of low phosphorus steel. The results obtained from model studies have indicated that the total contact area between the oxygen jets and the bath surface with a 4 hole lance would be about 30% more than with the present 3 hole lance at corresponding lance heights while the penetration depth would decrease by 10-15% in each of the craters formed by the impinging jet. This increase in contact area and reduced impact velocities should help in reducing slopping, aid lime dissolution and promote earlier fluid slag formation - all of which will help counter the phosphorus problem.

It is foreseen that it would be possible to tap steel from the LD vessels with 0.010-0.012% phosphorus at turn down by exercising all these controls.

Forthcoming Scenario at Tata Steel

The modernisation programme currently underway (Phase III), launches Tata Steel into its boldest step since its inception (12). Entering into the manufacture of modern, wide flat products for the first time, the Company is building a new 1700 mm wide Hot Strip Mill. The unit will have an initial capacity of 1 mtpa in coils of upto 28 t with thickness down to 1.6 mm. The mill will have a roughing stand, coil box and five finishing stands with roll bending, and a high degree of automated process control.

From Table-V it can be seen that the product mix for Tata Steel's Hot Strip Mill is diverse in nature. It has been accepted that handling of such a wide range of products will definitely be a difficult task. Grades like extra deep drawing quality, TMBP, micro-alloyed plates with guaranteed toughness, high/medium carbon strips, etc., will require judicious steelmaking and slab caster operation to achieve high quality such that subsequent rolling at the Hot Strip Mill is trouble free. Extensive post converter treatment of LD steel will be necessary. It is well known that post converter treatment in general consists of suitable combinations of the following :

* Argon rinsing
* Ladle furnace
* Vacuum degassing

Argon Rinsing Station. These facilities are the least expensive among all others and are primarily used for temperature and composition homogenisation, inclusion flotation, trimming additions, etc. The notable disadvantage is with phosphorus reversal, nitrogen

Table-V. Product mix for the hot strip mill (HSM) in Modernisation Phase III of Tata Steel

Grade	Quantity, tpa
Corten plates	24,000
Light plates	118,000
High tensile plates	24,000
Long and cross members	59,000
Deep drawing quality	127,000
EDD	
DD	
Hot rolled strips for cold rolling	107,000
D	
DD	
EDD	
Tin Mill black plate	270,000
Hot rolled strips for commercial tubes	100,000
Medium and high carbon strips	54,000
Strips for precision tubes	97,000
LPG	82,000
API	43,000

pick-up, reoxidation, lack of high degree of cleanliness, etc.

In order to optimise the rinsing operation at Tata Steel, detailed model studies were carried out in a slice-two-dimensional (2D) model having a rectangular cross-section and in a three dimensional (3D) model of circular cross-section. This was done in order to optimise the process parameters for rinsing in 130 t steel ladles at the existing argon rinsing station from where ladles are transferred to the six-strand continuous billet caster. From the above studies, it was concluded that a nozzle diameter of 6-8 mm is ideal for the 130 t ladle, maintaining a gas flow rate of around 350 lpm at a lance immersion depth of around 80%. This results in the most effective purging, giving a mixing time of around 4 minutes and removing dissolved oxygen to the extent of 20 ppm.

Ladle Furnace. A ladle furnace (LF) has now-a-days become an essential component of any fast running LD-CC complex. There are several advantages associated with a LF namely, maximising sequence casting, alloying and trimming via bulk additions along with wire feeding and/or injection, inclusion removal and modification, desulphurisation, temperature adjustment and chemistry homogenisation. However, the main disadvantages are associated with carbon and nitrogen pick-up. In Tata Steel, one of the necessary preconditions for ensuring low levels of phosphorus is to tap the LD heat at as low a temperature as possible. Considering all the above aspects, a ladle furnace is being provided in the new LD Shop to maintain the necessary productivity of the LD-Slab Caster-HSM complex, along with successful production of all the steels envisaged in the product mix.

Vacuum Degasser. From Table 5, it would be seen that Tata Steel's product mix contains steels for cold rolled strips and aluminium killed steels such as TMBP, EDD, etc. which are very prone to surface defects such as slivers, seams and black lines where clusters of alumina inclusions are primarily present. It was felt that a recirculating vacuum degasser of the RH type, will be a must to produce these steels in the most economic way. Since the cleanliness of the product would improve significantly as a result of degassing, ultimately, it would cut down rejections. Figure 5 illustrates the variation of dissolved oxygen in steel during a typical RH treatment. So called "light treatment" is also practiced, which is illustrted in Figure 6, where the tapping carbon content increases as no deoxidants are added to the ladle during tap.

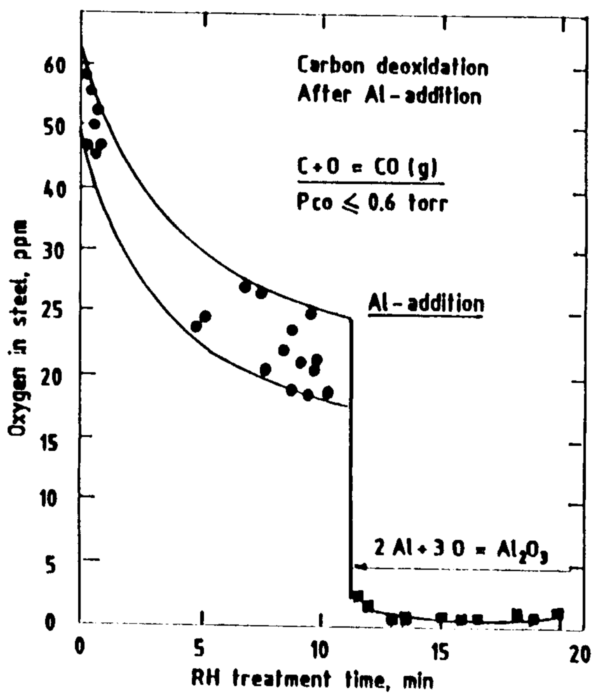

Fig.5 - Typical variation of dissolved oxygen content in steel during RH treatment

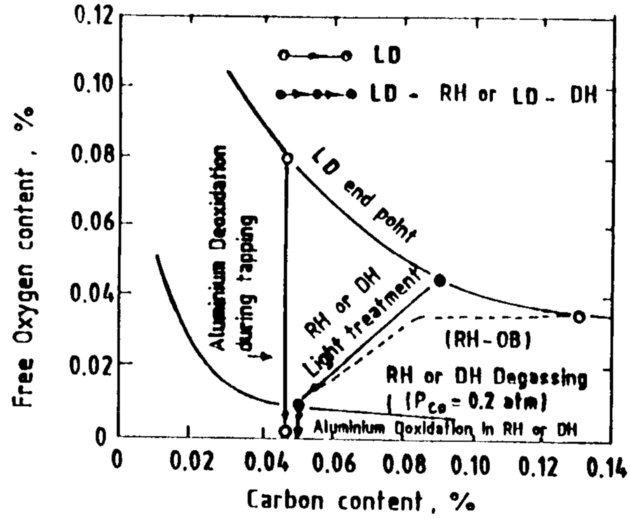

Fig.6 - Use of RH/DH degasser for control of carbon and oxygen levels

It has been reported that the side effect of this light treatment is to reduce aluminium consumption by 1.2 kg/t and the control of aluminium is considerably improved. Tata Steel's product mix also includes grades like API for sour gas application which have to be HIC resistant and normally, require a hydrogen content of below 2 ppm. Similarly, the special application plates requiring guaranteed ultrasonic soundness and impact properties must have a high degree of cleanliness and low hydrogen levels which can only be achieved through vacuum treatment.

Conclusions

Even in converter steelmaking based essentially on hot metal (rather than electric furnace steelmaking based on scrap where tramp elements is another important issue), the presence of residuals in steel like sulphur, phosphorus, oxygen, nitrogen and hydrogen are detrimental to varying degrees for casting and processing of steel as well as its service performance. In Tata Steel, the technical challenge to improve productivity and product quality, especially in the long product area, has already been met by judicious processing of steel through the LD-VAD-WEU ingot route as well as the LD-Billet Casting route.

Keeping in mind the conditions prevailing in the Indian steel industry, Tata Steel is preparing for the period beyond the immediate future and for a sea change in India's industrial scene. The major challenges to be faced are to meet higher product and quality specifications, provide better service levels and more new products to a growing set of customers, especially those who have free access to steel from the international market at very competitive prices. Therefore, for the Third Phase Modernisation programme at Tata Steel presently underway, which foresees the production of 1 mtpa of flat products, the steelmaking facilities required have been critically examined based on the product mix. It will consist of a new LD Shop with bath agitation facility, a ladle furnace, a vacuum degasser, slab casters followed by a state-of-the-art hot strip mill. It is important to note that emphasis has been laid on the appropriate choice of process routes through a combination of secondary steelmaking steps which will ultimately ensure the production of quality steels to match the end product requirements at optimum "through cost".

Tata Steel has thus made itself "ready" to become a producer of 3 mtpa of quality products both in the long and flat product segments by the year 1994.

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Recent Studies in Thermo-Mechanical Processing of Microalloyed Steels

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Abstract

Development of high strength steel constitutes a major R&D programme at the Steel Authority of India Limited (SAIL). The first phase of activity, involving controlled rolling (1975-80) resulted in the successful commercial production of Nb-microalloyed high tensile (minimum 450MPa tensile strength) plates and channels and angles for structural applications. In the second phase thrust was given on accelerated cooling immediately after controlled rolling. This led to the development of line-pipe steels in API X-60/X-65 grade for the oil and natural gas sector. Current emphasis is to make use of the clean steel concept for the production of low-sulphur fully deoxidized thermomechanically processed plates with higher yield strength and adequate toughness. Recent research results obtained in SAIL on thermomechanically processed steels microalloyed with Ti where the focus is on the development of acicular ferritic/bainitic microstructure has also been described.

THERMO-MECHANICAL CONTROLLED PROCESSING (TMCP) which was recognised as early as the sixties and came into practice in the seventies has made available today high strength steels for use in a wide variety of applications. Today thermomechanical processing techniques, comprising both controlled rolling and accelerated cooling, are being applied in varying degree in steel plants all over the world. The early work on TMCP mainly revolved around controlled rolling and was used predominantly for the production of high strength conventional ferrite-pearlite steels. The influence of accelerated cooling, was used to advantage only in the last decade facilitating production of transformation strengthened acicular ferritic or low carbon bainitic steels, particularly for linepipe applications. More recently, efforts are on to control not only the cooling rate after finish rolling, but also the cooling start and cooling finish temperatures leading to excellent low temperature impact toughness, weldability and strength properties in steels.

The Indian scenario has seen rapid growth of TMCP over the last two decades resulting in the production of a variety of speciality steels with stringent end-applications. This has been largely due to a major R&D programme on TMCP at the Steel Authority of India Limited (SAIL). The present paper describes the developmental efforts made and some of the major steel products developed utilising state-of-art TMCP technology

Microalloyed HSLA Steels

Development of Microalloyed Plates- The beneficial influence of small additions of microalloyed elements (niobium, vanadium and titanium) and controlled rolling was fairly well established in the early seventies. This led to a steady growth in demand by the construction and engineering industries in the country for plates and structurals having higher yield strength, improved weldability and toughness. Moreover, due to the sudden increase in the cost of energy following the 1973 oil crisis, emphasis was laid on products with high strength to weight ratio. In order to meet this challenge, a broad R&D programme on the development of high strength microalloyed HSLA steels was conceived at SAIL using the TMCP technology. The first experimental heat was made in 1975 at Rourkela Steel Plant and in the first phase about 9000 tons of HSLA steels plates were produced for use in the expansion of Bhilai Steel Plant. These steels were microalloyed with niobium and had a strength (Y.S.) level of 300 MPa(min). Subsequent to this, higher strength level steels have been developed having yield strength levels upto 450 MPa and marketed under the tradename SAIL-MA. The present production level of SAIL-MA plates is to the tune of 25,000 tons annually.

Development of Microalloyed Sections- There is a growing demand for steel sections in the country for the construction of transmission line towers, railway bridges, high rise buildings and other structural applications. Till about a decade back, most of these requirements were met by mild steel (IS:226) and Hyten grades of steels. However, the development of HSLA steels with superior strength to weight ratio, impact toughness and weldability properties shifted the demand pattern sharply towards HSLA steels in place of the traditional mild steel variety.

Microalloyed sections are today produced at Bhilai Steel Plant, Bokaro Steel Plant and Indian Iron & Steel Co.Ltd., Burnpur. Fig.1 shows a schematic representation of the TMCP schedule followed for the manufacture of joists. The blooms (185 x 160mm) were soaked at 1250°C for 1 h and rolled to 150 x 75mm joists in a semi-continuous mill in 12 passes and air cooled.

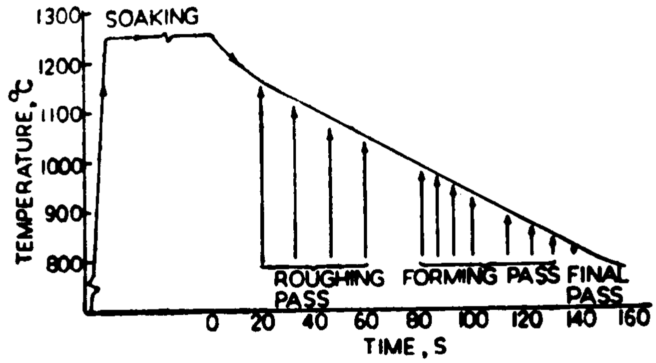

Fig.1. Schematic illustration of TMCP schedule for the manufacture of joists.

The typical mechanical properties and Charpy impact energy (CIE) at 0°C achieved were: YS-553 MPa, UTS-642 MPa, ε_T-31%, Bend-1 t and CIE(0°C)-200 Joules. The properties are superior to that obtained by previous workers (1-2). Such values of yield strength and toughness were, however, reported by Gray (3) and Kozasu et al.(4) in HSLA steels containing high Nb (0.07-0.2%) contents. The excellent strength and toughness property combination can be chiefly attributed to the fine ferrite grain size (average 8 µm). The present production level of SAIL-MA structurals today is to the tune of 10,000 tons annually.

Linepipe Steels

In order to achieve maximum utilisation of its natural gas resources, the Government of India approved plans for setting up of six gas-based fertiliser plants in the country. This led to a large demand for linepipes suitable for gas transmission. These demands are in the grade of API X-60 (min.yield strength of 413 MPa). The above preference is in line with worldwide trends(5-6) in the last decade to adopt higher operating pressures and thus greater efficiency. In view of the huge demand for higher grades of linepipes (API X-60), a major programme was carried out jointly by Rourkela Steel Plant and R&D Centre for Iron & Steel of SAIL with the broad objective of establishing technological capability for production of high strength microalloyed linepipe steels and pipes using TMCP. A time bound programme was undertaken to develop the X-60 grade of steel.

Based on the present understanding, the chemical composition (by wt%) for the production of API X-60 grade steel was chosen as follows: C:0.06-0.10, Mn:1.15-1.30, Si:0.30-0.40, Nb:0.03-0.05, V:0.05-0.08, Al:0.025-0.04 and S:0.015 max. The steel was made in a basic oxygen (LD) furnace. Misch metal was added in the mould at the rate of 1.5 kg/ton of steel after full deoxidation of the steel with Si and Al. The steel was cast into ingot and subsequently rolled into slabs of 170 mm thickness. After extensive trials at Rourkela Steel Plant, the following optimised parameters were established for the thermomechanical processing of 9.5 mm hot strips of API X-60 grade line pipe steel (Fig.2). It might be noted from the above data that a low reheating temperature of 1180°C was preferred. At this temperature, using the solubility tables compiled by Aronsson(7), it can be seen that all the Nb and V will go into solid solution for the chosen chemistry. Moreover, most of the Al will remain in solution (0.035%), while any amount in excess of it will remain in the form of undissolved AlN thereby helping in restricting austenite grain coarsening during soaking. The total deformation in the roughing stand was 80%, the degree of deformation varying between 10-15% in each pass. The total deformation in the finishing stand was roughly 70%, which is equivalent to a rolling reduction of 3.5. Such a large reduction in the second stage of controlled rolling is essential to obtain further refinement of the austenite grain size and thereby attain higher yield strength and superior low temperature toughness.

The microstructure obtained in the thermomechanically processed hot strip was fairly uniform throughout the thickness. It was essentially ferrite with a fine grain size of roughly 7 µm(Fig.3). The yield strength of the strip was typically 550 MPa. The coiling temperature played a significant role in controlling the yield strength (Fig.4). Although the data showed some scatter, YS increased with decreasing coil temperature down to about 630°C. The YS/UTS ratio in the

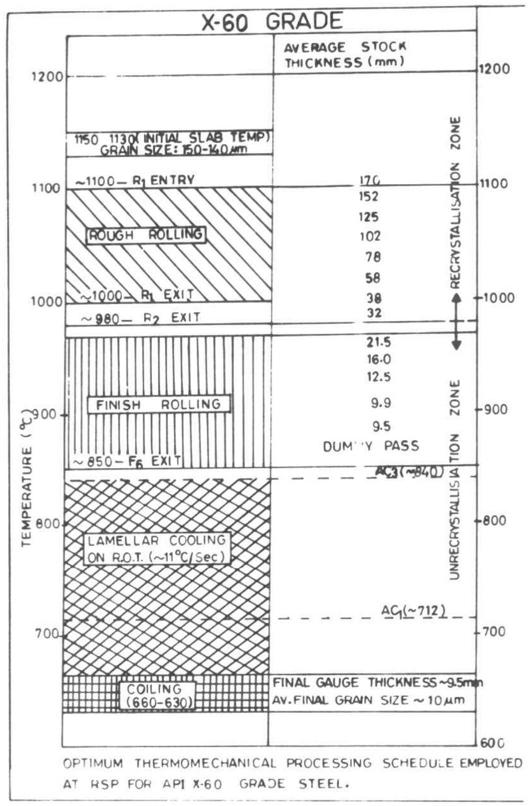

Fig.2. Thermomechanical processing schedule employed at Rourkela Steel Plant for X-60 grade hot strip.

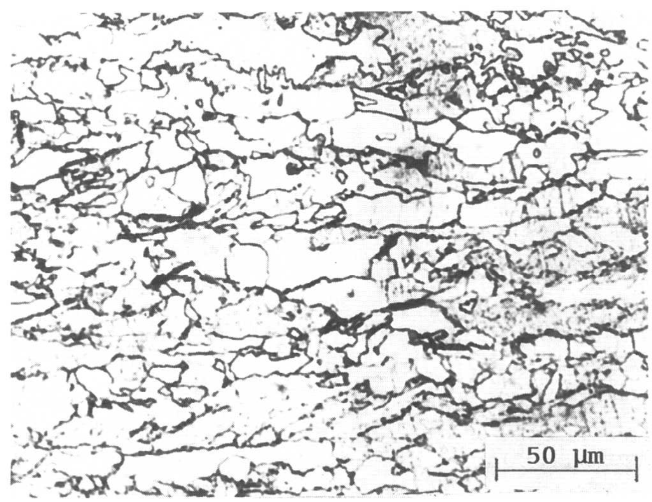

Fig.3 Typical microstructure of thermomechanically processed X-60 grade hot strip.

as-hot-rolled strip was of the order of 0.88. Furthermore, the percentage elongation was typically around 35% and Charpy impact energy at 0°C of the order of 100 Joules.

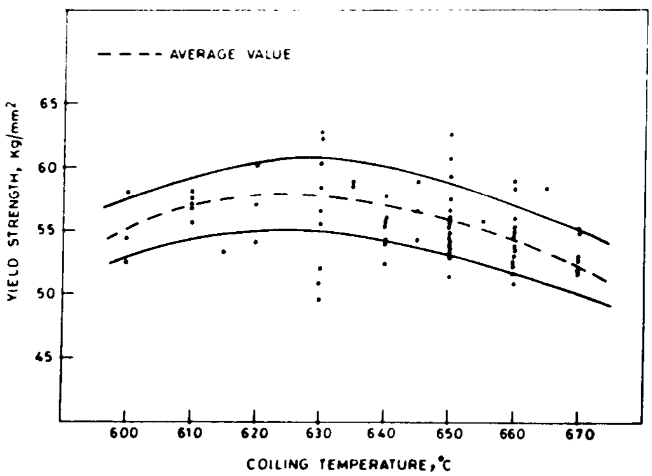

Fig.4 Variation of yield strength with coiling temperature of hot strip.

The yield strength measured on flattened samples from pipes was on the average 470 MPa i.e. about 80 MPa less than that of the as-hot-rolled strip. Such loss of strength was first observed by Bauschinger(8). Orowan(9) has shown that strong barriers to movement of dislocations, such as precipitates, create back stresses owing to dislocation pile-ups which could be wiped out by reverse straining (e.g. on flattening) thus leading to permanent softening. Thus in control-rolled and control-cooled steels, particularly where a significant strength is derived through precipitation hardening as in the case of V, as much as 50% of the strength coming from precipitation hardening may be lost in pipemaking(10). The UTS value of pipe samples was around 620 MPa. The percent elongation was of the order of 25% and the YS/UTS ratio about 0.76. The typical Charpy V-notch impact energy for the parent metal, weld zone and HAZ were, respectively, 80, 45 and 60 Joules at 0°C, well above the minimum requirements of 31 Joules. Drop weight tear test (DWTT) on samples from pipes were conducted at 0°C and room temperature, as per standard method. Hundred percent shear fracture occurred in all cases against a minimum requirement of 85% at 0°C . Full scale hydrostatic tests were conducted on sample pipes by subjecting the same to an internal pressure to the extent of 157 bars (equivalent to minimum specified yield strength of 413 MPa). The pressure was sustained for a minimum of 15 seconds. None of the pipes so tested indicated any leaks. Spirally welded pipes made from trial production of this grade of steel (11) were extensively tested by Gas Authority of India Ltd.(GAIL) and were found to satisfy all specified stipulations under API X-60 specifications. This led to Rourkela Steel Plant bagging, under stiff international competition, a commercial order for supply of 22,000 tons of linepipes for gas transmission.

Bainitic Microstructures and Associated Properties in Titanium Microalloyed HSLA Steels

In recent years, a lot of emphasis has been directed towards development of Ti-microalloyed HSLA steels containing small additions of boron involving controlled rolling and accelerated cooling (12-14). The present paper discusses the influence of processing variables such as austenitizing time, finish rolling temperature (FRT) and cooling rate on the microstructure and mechanical properties of a control rolled Ti-B microalloyed HSLA steel(15).

The composition of the steel investigated was : C-0.06%, Mn-1.35%, S-0.01%, P-0.013%, Si-0.31%, Al-0.03%, Ti-0.08%, Cr-0.05% and B-0.0007%. The steel was homogenised (austenitized) at 1200°C for 1/3 h before control rolling in a 150 ton experimental hot rolling mill. The total deformation in the roughing stage was 62%, the degree of deformation varying from 12-25% in each pass. The total deformation in the finishing stage was 68% with a cumulative rolling reduction of 3.2. Two finishing rolling temperatures, 850 and 800°C were used, followed by air cooling (AC) or spray water cooling (SWC).

The microstructure, ferrite grain size and volume fraction of second phase obtained for the Ti-B steel subjected to different processing conditions are listed in Table I. The mechanical properties of the steels are shown in Table II. Finish rolling at 850 and 800°C followed by air cooling resulted in a polygonal ferrite-pearlite microstructure. The strength-ductility-toughness combination of the steel finish rolled at 800°C was found to be superior to the steel finish rolled at 850°C, both for 1 and 3 h austenitization times. However, the microstructure and properties obtained under different processing conditions for the two austenitization times (1 h and 3 h) are similar, indicating that austenitization time has little influence on the product microstructure and associated properties.

The cooling rate was found to have a significant influence on the microstructure and mechanical properties of the Ti-B steel. A change in cooling rate from air to spray water cooling led to a change in microstructure from ferrite-pearlite to ferrite-bainite. This is associated with an increase in strength, decrease in ductility and impact toughness properties and an increase in ITT (Table II). Figure 5 (a-b) are optical micrographs of steels finish rolled at 850 and 800°C respectively, followed by spray water cooling. Finish rolling at a higher temperature (850°C) resulted in a coarse bainitic structure while a lower FRT (800°C) yielded a polygonal ferrite-massive bainite structure. The above classification into coarse bainite (B_c) and massive bainite (B_m) structures is in accordance to that reported by Yoshikawa, Kawashima and Konno (16). The coarse bainite structure is associated with higher strength level but inferior ductility and ITT (Table II).

Figure 6 (a-b) shows the influence of processing parameters, microstructure and tensile strength on the impact transition temperature. The transition temperature increases linearly from -72°C (800-AC, ferrite-pearlite) to -35°C (850.SWC, coarse bainite). Thus the ferrite-pearlite structure exhibited the best toughness properties, followed by ferrite-massive bainite structure and the coarse bainitic structure respectively.

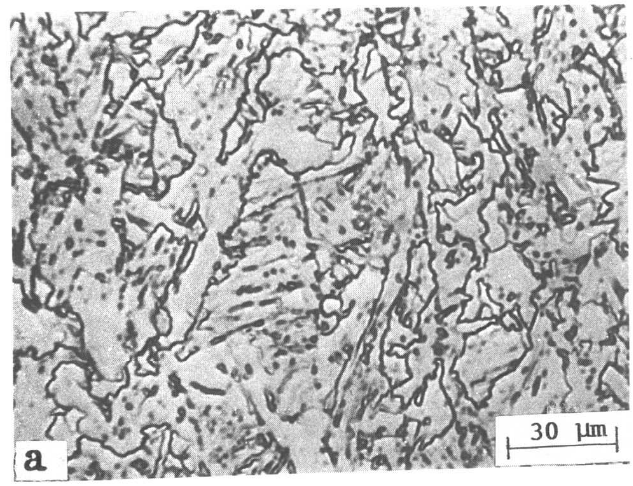

Fig.5 Optical micrographs showing typical (a) coarse bainite and (b) massive bainite structures for steels rolled at 850 and 800°C respectively, followed by spray water cooling.

Figure 7 (a-b) represents TEM photomicrographs taken from a polygonal ferrite-massive bainite (800-SWC) steel. The high dislocation density within the ferrite and fine precipitates pinning the dislocations may be noted, Fig.7 (a). The dislocations appear mostly in tangled form. Fig.7 (b) shows the substructure within the massive bainite region. Large carbide particles can be seen at the interface of ferrite laths in addition to finer

Table I : Microstructure, grain size and volume fraction of second phase obtained for Ti-B steel subjected to different processing conditions

Processing Variables			Microstructure		Ferrite Grain Size (μ m)	Volume % of Second Phase (V_f)
Austenitization Temp. (C) Time (h)	FRT (C)	Cooling Rate	Primary Phase	Secondary Phase		
1200 - 1	850	AC	Polygonal ferrite	Pearlite	6.0	6.0
1200 - 1	850	SWC	Ferrite	Coarse bainite	-	-
1200 - 1	800	AC	Polygonal ferrite	Pearlite	8.5	7.1
1200 - 1	800	SWC	Polygonal ferrite	Massive bainite	8.4	29.6
1200 - 3	850	AC	Polygonal ferrite	Pearlite	9.0	6.0
1200 - 3	850	SWC	Ferrite	Coarse bainite	-	-
1200 - 3	800	AC	Polygonal ferrite	Pearlite	8.8	3.7
1200 - 3	800	SWC	Polygonal ferrite	Massive bainite	7.6	32.0

AC : Air Cooling; SWC : Spray Water Cooling

Table II : Mechanical properties of Ti-B steel subjected to different processing conditions

Processing Variables			Y.S. (MPa)	UTS (MPa)	El (%)	RA (%)	I.E. (J)		I.T.T. 55J(C)
Austenitization Temp. (C) Time (h)	FRT (C)	Cooling Rate					RT	-40 C	
1200 - 1	850	AC	335	430	39.0	76	334	345	-
1200 - 1	850	SWC	433	615	27.2	72	-	-	-
1200 - 1	800	AC	373	456	39.6	76	-	-	-
1200 - 1	800	SWC	392	610	27.8	72	173	109	-55
1200 - 3	850	AC	343	434	34.0	75	316	326	-58
1200 - 3	850	SWC	452	624	24.0	72	133	35	-35
1200 - 3	800	AC	360	445	39.2	78	343	332	-72
1200 - 3	800	SWC	360	565	27.6	69	133	72	-52

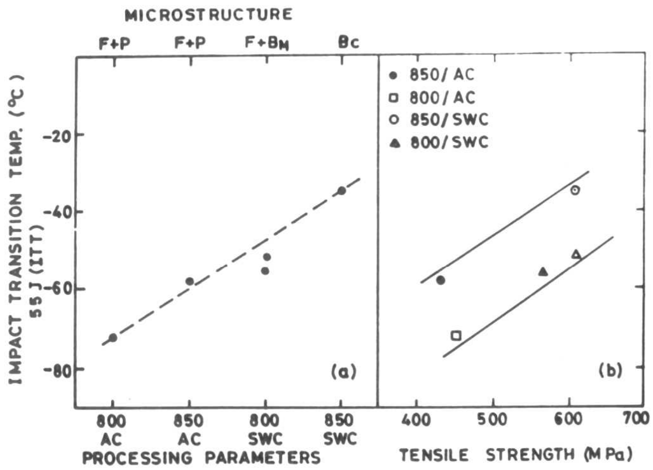

Fig.6 Influence of (a) processing parameters, microstructure and (b) tensile strength on impact transition temperature.

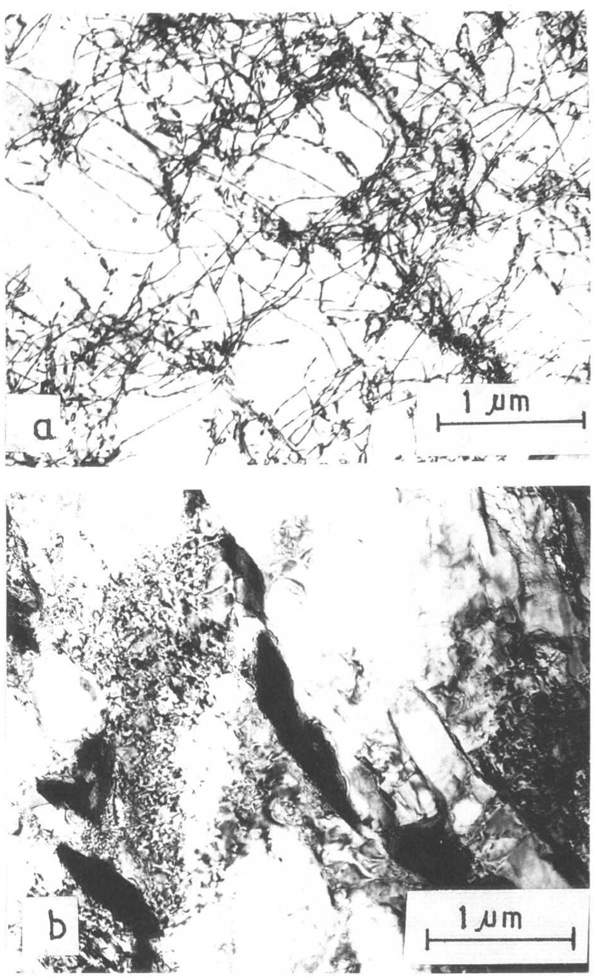

Fig.7 TEM micrographs taken from a ferrite-massive bainite steel showing (a) high density of tangled dislocations within ferrite and (b) substructure within massive bainite.

carbide precipitates within the laths. Similar type of substructure has been reported by Guoquing and Weixun (17). Energy dispersive analysis of precipitates in the polygonal ferrite region of the same steel was also carried out. Analysis of the coarse precipitates revealed them to be of TiS types while the finer precipitates were found to be Ti_2S or $Ti_4S_2C_2$ compounds.

Summary

High Strength Microalloyed Plates/ Sections - Microalloyed plates and matching sections are today commercially available from SAIL under the trade name SAIL-MA in a range of basic grades designated by their yield strengths, i.e., SAIL-MA:300/350/410/450 where the number indicate yield strengths in MPa. These steels basically have a ferrite-pearlite microstructure.

API Grade Linepipes - API X-60 grade steel was successfully developed at Rourkela Steel Plant of SAIL for the production of spirally welded pipes using a low carbon steel microalloyed with Nb and V. A thermomechanical processing schedule involving controlled rolling and lamellar cooling was established to achieve a fine ferrite grain size of roughly 7 μm and satisfy the stringent property requirements as per API specifications. Excellent properties have been achieved, i.e. typically 550 MPa YS, 620 MPa UTS, 35% elongation, 100 Joules Charpy impact energy value at 0°C.

Steels with Bainitic Microstructures - The results of the current R&D programme in SAIL on bainitic HSLA steels are briefly as follows:

[a] Variation of austenitizing time (1200°C, 1&3 h) does not have any significant influence on the microstructure, grain size, volume fraction of second phase and associated mechanical properties for Ti-B steels subjected to different processing conditions.

[b] Finishing rolling at 850 and 800°C followed by air cooling resulted in a similar ferrite-pearlite structure. However, a lower FRT(800°C) resulted in superior strength-toughness combinations as compared to higher finish

rolling temperature (850°C).

[c] Finish rolling at 850 and 800°C followed by spray water cooling resulted in ferrite-coarse bainite and polygonal ferrite-massive bainite microstructures respectively. The polygonal ferrite-massive bainite structure exhibited comparable strength level but superior ductility-toughness properties in comparison to the ferrite-coarse bainite structure.

[d] Analysis of a few typical precipitates in the ferrite region of the ferrite-massive bainite steel indicated the presence of TiS, Ti_2S or $Ti_4S_2C_2$ compounds.

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The authors wish to thank Shri S.K. Roy, Director and Shri S.R. Jain, Chairman, SAIL for their keen interest in the implementation of the programme on thermomechanical processing of high strength steels.

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Role of Standardization in Development of Steel Based Materials Industry in Developing Countries

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ABSTRACT

In the process of industrialisation in developing countries, most of them import designs, know-how, complete plants and material for manufacture of industrial and consumer products and often parallelly for production of the raw materials (required for use in the manufacture of the former). Each country may obtain these imports from many different industrialized nations. Most often these countries land with multiplicity in the variety of materials used in terms of their types, specifications, sizes, process of their manufacture and methods of working them. In most developing countries, having a low material usage, an unnecessarily high variety of materials may lead to material requirements being fragmented into a very large number of items, each required in relatively small quantity only. This type of situation has often led to uneconomical manufacture, inconsistent qualaity, delays and shortages in availability of the indigenous materials and various other problems leading to a slow growth of the materials manufacturing industry. This paper examines these aspects and discusses how application of standardization and related techniques at international, national, industry and company levels, especially with reference to steel product-mix, can result in improved productivity, upgraded quality and economical manufacture for the development of materials industry.

IN MANY DEVELOPING COUNTRIES, THE process of industrialisation started in collaboration with enterprises from industrialised nations in form of joint ventures or technical collaborations and involved the developing countries importing anything ranging from complete manufacturing plants down to SKD or CKD (semi- or completely- knocked down) assemblies, raw materials, designs or manufacturing data. Most manufacture in these countries started with initial assembly of products from SKD and CKD parts gradually working to the indigenous (local) manufacture of some of the components and finally to a stage where most of these are produced locally. Of course this last stage itself is far from "full" industrialization as the countries may still continue importing machinery and equipment, tooling and raw materials. This situation is common in varying degrees in most developing countries, though to a lesser extent in relatively more developed developing nations like (say) India and Brazil.

It is the raw materials production aspect that is discussed in this paper. Also, since steel (both iron and steel for purposes of this paper) is one raw material which is most commonly used, this paper uses its example to discuss various aspects of standardization and specifically rationalization of raw materials.

Most developing countries start production of raw materials concentrating on those that are required regularly and in large quantities and those that would preferably utilize indigenous basic raw materials. It may however be noted that even though steel is required for use in general construction and structural work, the production and consumption of steel is relatively very low in most developing countries as seen from table 1.

TABLE 1: Consumption and Manufacture of Steel in few Selected Countries.

Country	Consumption (kg)			Production (Mil. tons)		
	1973	1980	1987	1973	1980	1987
USA	572	508	417	137	102	81
USSR	450	(NA)	582	131	148	162
Japan	573	629	582	119	110	98
UK	403	245	259	28	11	17
Brazil	52	117	99	7	10	12
India	11	17	20	7	9	12
China	24	44	64	25	37	56
Indonesia	(NA)	16	21	(NA)	.5	(NA)
TOTAL WORLD				685	691	681

Source: 1973 figures from International Iron & Steel Institute
Others: Statistical Office of UN, NY (Statistical Book)

The production (and consumption) figures are mentioned here to show that low quantities used or produced in developing countries has direct relevance to the problems of development and growth of the steel industry in these countries. The reasons for the low consumption of a basic raw material like steel can be attributed to various socio-economical-political reasons that are not discussed here - neither are the reasons like low productivity or those connected with technology infrastructure and management aspects. What is relevant and discussed is the effect of a large unnecessary variety of different steels in terms of specifications and sized that are used in these countries that cause constraints in development and growth of materials industry.

Variety in Materials

Except for very few developing countries that may have collaboration with one country only (e.g. a country collaborating technically with USSR only - hereafter USSR indicates thepre-1992 USSR), most developing countries with free economies may have many collaboration agreements with companies from many countries. For example in countries like Brazil or India, industrial collaborations in few product areas like (say) machine tools, automobiles, household appliances and even simple hardware items may have been established with companies from USA, Japan, Canada, USSR, and West and East European countries. Each company (even from the same country) brings its own specifications of components and its own raw material types, specifications and sizes which differ in varying degrees from those of other companies for same overall application. There may not be a problem due to this, if quantities required in each variety were adequate for economical manufacture but this is not the case. In most developing countries, an excessive variety leads in the already low material requirements to be further fragmented into a very large number of items, each required in relatively small quantities only. This type of situatuion often leads to uneconomical manufacture, inconsistent quality, delays and shortages in availability of indigenous materials and various other problems during manufacture of industrial products and also leads to a slow growth of the materials manufacturing industry.

Taking few specific example would illustrate the various aspects of variety proliferation (in steel products in terms of specifications and sizes) and need to control it. In this paper examples of this aspect at national, industry, and company levels are elaborated.

Variety Reduction and Control at National Level.

In early 1960s an investigation in India by the Bureau of Indian Standards (BIS) - previously known as Indian Standards Institution-indicated that over 1500 wrought steel specifications were being used in the organized engineering sector in the country - the actual number could have been much more as such investigations are not always complete. These specifications were those quoted by major users for procurement of steel locally or for import for manufacture of components for them and consisted of steels to Indian and to foreign national and association standards (like DIN, ASTM, SAE, BS, GOST...), to company standards of foreign collaborators (like Mercedes Benz, General Motors, GE..), and to brand names.

Normally the number of specifications of steels when considering the size of the country and the diverse usage does not indicate a major problem; for example if one had considered the number of steels in a similar way in USA taking into account ANSI, ASTM, AIISI, SAE, and other industry standards and specific requirements as per company standards of (say) GM, Ford, GE to name a few, and brand name materials, that number would be considerable times higher. The difference in the situation was that in USA, coordination done by ANSI in the various standards on steels through indicating equivalence among different specifications did have the effect of a reduction in the number of specifications. Also another more important difference was that in USA the quantity requirements were much larger in each steel due to higher production of goods in the country. Compared to that, in India at that time, the requirements varied from several thousand tons to as low as few kilograms per specification and size per annum. The situation was further aggravated due to requirements by industry of many more different sizes of steel sections; this was because even though India had gone metric, the collaborations were with foreign companies some of whom used FPS system and others used metric. Also the collaboration agreements at the time often did not allow changes of specifications and sizes without much correspondence and investigation, thus preventing quick unification.

With such a large number of specifications and sizes resulting in small quantities in each steel item, in many cases it was not economical to manufacture them locally thus causing delays in development and growth of steel (and especially alloy steel) manufacture in the country. Also valuable foreign exchange had to be used for importing steels instead of on more needed newer technology, machinery, testing equipment or of products. Further to facilitate procurement in bulk, more-than-required quantities were purchased causing higher inventories and long storages leading to deterioration, and occassionally obsolescence. The production of industrial and consumer products was normally effected adversely.

A concerted effort was made by the Bureau of Indian Standards (BIS) in conjunction with steel producers and major users to reduce the variety from 1500 specifications to about 150 by early 1970s. National standards were issued by BIS to encourage the use of these preferred steel specifications. The Government also introduced means to gradually limit the manufacture of only such steels; while this may look like a restrictive practice adversely effecting development of new or better materials, in actual fact it was an appropriate solution at that time (for a limited

limited time) and had beneficial effect on the national production and economy and development of alloy steel industry. The Government parallely still encouraged research and development still continued on various aspects of steel products and economy.

The emphasis on variety reduction and variety control of alloy and special steels mentioned above had been started by the national standards body in India (BIS) after its "Steel Economy Program" (whereby lighter steel sections for structural purposes were standardized by BIS), had achieved substantial savings for the country in 1960s. Armed with these successful results, the BIS was able to propagate the need for rationalization and the industry was more cooperative in participation in such work. The BIS issued at that time an important standard on "Schedule of Wrought Steels" that listed steel specifications which prefferable should be used and produced in the country.

Variety Reduction and Control in Automotive Industry

Efforts in India

The Indian example can be further examined in relation to the automotive industry. In 1970s India was manufacturing some 250,000 (2-, 3-, and 4- wheeled vehicles to desings taken initially from some 15 companies from USA, UK, (West) Germany, and Italy. By the way this situation of manufacturing a small quantity of vehicles in a large number of brands is still prevalent in some other developing countries even now- e.g. in Indonesia some 170,000 vehicles are produced in 25 brands- 90 models- from about 10 countries. This high variety combined with low quantity production can obviously cause many problems and it was with this in mind that the Government of India had put a restriction on the brands of vehicles to be manufactured; (this restriction had some beneficial and also some adverse effects on production, prices and quality of vehicles). However from the view point of steel requirements there were many problems even with this much variety and the problem due to low requirements of steels in many specifications had to be tackled and required a reduction in variety of steel items required. Initially the automobile manufacturers were wary of coordination among each other or of modifying their specifications with a view to reduce variety but due to import restrictions, that discouraged imports of materials and due to strong coordination role of the national standards body (BIS), and with gradual improved knowledge on materials usage in automotive OEM and steel producers, finally concerted efforts were made to attempt rationalization of steels in the automotive and ancillary industry. Through these coordination efforts of BIS among the OEM, the automotive industry, the steel producers and the national laboratories like the National Metallurgical Laboratory, it was possible to come up with a tentative list of rationalized steels for the automobile and ancillary industry in early 1970s. In the late 1970s the BIS issued an Indian standard which would be used to ensure adoption of the rationalized steels by all concerned. Details of this are given in the next paragraph.

Standard on Steel for Automotive Application

The Indian Standard (IS:9175 - Part 1 - 1979) on "Rationalized Steels for the Automobile and Ancillary Industry" listed some 33 steels based on their major consumption by the automible and ancillary industry. The standard gave only designations and chemical composition of these steels and these were elaborated in detail in various other Indian standards. The steels covered were those required for automotive production except for steels required for normal body work or chassis frame and except for spring steels, stainless and heat-resisting steels, and ball bearing and tool steels which were all to be covered later. The standard went further than normal standards by giving information that could help users of the standard to investigate the adoption of Indian Standards in place of steels used by them previously. The information contained for each steel was:

- Designation of steel
- Chemical composition
- Equivalent foreign standard steels
- Suggested replacement for steels used

Few typical entries from the standard are given in Annex I to show this aspect. While the information was useful for each automotive and ancillary manufacturer to attempt rationalization of its requirement to the preferred specifications covered in the standard, the Government of India, through a Gazzette notification also made it compulsory for consumers to place orders in terms of the Indian Standards steels listed and also directed the producers to confine the booking of orders in terms of these steels. Obviously standards are of no use unless they are adopted or implemented. Since in India only certain safety and envoirnmental standards (consisting of less than 5% of the total Indian Standards) are mandatory, the adoption of standards on raw materials has to be voluntary. None-the-less in the case of the standard on steels, the Government was able to play a major role in ensuring implementation through --

- restricting overall imports thus making users try to use indigenous materials
- asking the Government steel plants (which formed the major portion of steel production in the country) to take orders from industry in terms of Indian Standards
- convincing the users that such restrictive measures are required temporarily of the benefits to industy
- encouraging and propagating the implementation of standards in industry through the national standards bodies.

The above montioned standard was a fore-runner of similar standards in other sectors of industry (other than automotive).

The overall effect of this rationalization has been definitely beneficial and has encouraged the private sector as well as the government steel plants to initiate manufacture of some hither - to imported steels once the number of specifications were reduced and quantities in the fewer rationalized ones became larger. This raised the quantities of some steels adequately but naturally not all. There are still steels that due to low quantities or other technical reasons have to be imported but this sort of situation is expected and has to be allowed to maintain quality and economy. It may be mentioned that the steel economy program in India also aimed at encouraging standardizing of alloy steels that could be manufactured using indigenous raw materials. For example many of chrome molybedinum steels specified earlier were encouraged to be replaced by nickle steels. This was achieved through cooperation between the national standards body, the national research laboratories (like National Metallurgical Lab,), the steel plants and the major steel users like the automotive OEM.

Rationalization Through Specific Programs in Industry.

In the examples given from India, the effort was initiated by the Government bodies, the national standards body, and occasionally industry. Similar efforts of rationalization have been started in other countries with beneficial results. It has however been noted that not all developing countries are aware of the need and benefits of such work and of the means to achieve meaningful rationalization. The author himself has been involved in UNIDO projects where the concept of rationalization had to be demonstrated by actual programs before the national standards body or industry paid attention to it.

In one particular Middle East country, the large scale engineering industry consisted of many government owned companies making engineering goods for industrial and consumer use with foreign collaborations. It used various steels for production of components). Inspite of the few products in relatively low quantities, in a representative 15 companies investigated over 3000 items of steel plates, sheets, flats rounds, channels, angles, etc were used in requirements ranging from several thousand tons to few kilograms per specification (and per size). The variety reduction/rationalization program initiated in this country found that these steel items were being procured in over 525 seemingly different specifications and in 1300 sizes. The program examined the different steels and by use of rationalization techniques finally made a recommendation to reduce the number of specifications by about 58% in the first stage of investigation through unification and variety reduction of steels. Through unification, different foreign specifications were equated because they were found to be functionally interchangeable. By variety reduction, some specifications in small quantities were replaced by others used in larger quantities even if they had "superior" properties and were costly but provided overall economy. The investigation had to involve examination of each specification from point of view of properties, cost, workability, etc. before final decision of rationalization were made. Similar investigation of sizes was done and in case of steel rounds, for example, the number of sizes was reduced by 51%. Furthermore, rationalized specifications and sized were internationalized to ISO standards to facilitate global procurement which will assist developing countries in more economical procurement. The country in question has a steel industry and it was recognized after the program that this rationalization would encourage the initiation of manufacture of some steel items not undertaken till then.

The results of these rationalization programs were recorded in "Guides for Use of Steel Products in Industry" which were different from national standards or national codes of practice in that they were practical guides prepared after actual investigations of steels used in the industry. Annex II gives some details of the type of guide found beneficial in developing countries. Annex III gives some indications benefits/results of such an industrial materials rationalization program mentioned.

Programs in Industrial enterprises.

For rationalization to succeed at industrial and national levels, the individual industrial enterprises have to undertake such work in-house and also participate in overall material rationalization work which some of them may consider to be costly. To initiate such work, companies would have to know of national, industrial and of other companies' efforts and beneficial results obtained and economies achieved to be convinced to undertake such work. As mentioned earlier, this type of awareness has to be created in some countries by their national standards bodies (NSBs) and in others through UNIDO or other international organizations programs run in conjunction with the NSBs or other government organizations or associations.

The efforts put in by company in-house efforts would lead to variety reduction in materials procured, stored, and used by the Company and results of such work shared with others (through national standardization work or at other forms) would yield national results that will in turn benefit the industrial enterprises themselves. The author himself has been involved in work in some companies and knows of others where through regular variety control efforts, varieties were prevented from proliferating and through variety reduction projects, 50 to 70% reduction was achieved. These standardization/ rationalization projects assisted the industrial enterprises in higher productivity, consistent quality, lowered rejection rates and greater profitibility.

Means to rationalize.

As can be seen from the preceding discussion in this paper, the rationalization of materials in developing countries has a more important role to play in the development of raw materials based industry and has to b e tackled in a slightly different way from rationalization work done in industrialized countries now; (of course most of the latter would have passed through similar situations, ages back). Some of the pertinent means to achieve rationalization in developing countries are mentioned below:-

- it is recognized that rationalization aspect has to be given a special attention during making standards by indicating preferred or secondary preferred items (specifications or sizes) of materials. When standards are issued, guidance should be provided on how to ensure adoption of rationalized materials
- it is possible that organized and formalized rationalization programs in specific categories of materials or for specific industries would be required to be conducted and the NSB or an industrial association would have to act as catalytic agent and as coordinator among parties involved
- the results of such rationalization work, however encouraging and obvious they may be, would not result in actual benefits in terms of economical production or development and growth of the material industry unless they are carried to their logical end i.e. they are implemented and used to meet the overall objectives - one of them being to create more demand in fewer specifications and sizes of materials. In a developing country the results would have to be followed-up by the authorities responsible for industrial development
- the individual large users of materials have a significant role to play in this overall objective of getting local raw material industry developed. This requires a need to cooperate with other enterprises to attempt to unify requirements. Such enterprises would need to get all relevant information on materials they use and designate people and procedures and undertake such work to be able to attempt rationalization of materials within their own enterprises and assist in industry or national level efforts
- the concept of internationalization of materials in developing countries has to be thought of to facilitate their economical production or procurement (imports) or of even exports. The concept involves use of international standards (like ISO) wherever beneficial for procurement, export or production instead of using specific national, company or brand name materials
- rationalization in only one aspect of standardization that has been emphasised here that will prevent excess variety and facilitate optimum variety that will encourage economy and development. Standardization of materials will involve the elaboration of standards on materials that cover properties or chemical composition, methods of testing, method of working them or working with them, application of materials, change of properties with time and other aspects.

Standardization Work needed in area of Materials.

It may also be mentioned that standardization and rationalization of materials combined with standardization of components, standardization in planning of materials, their procurement, storage, preservation, packaging and transportation, heat treatment & related processes along with standardization in areas of quality control of materials and other such areas has shown to assist in ensuring consistent and high quality at lower costs that in turn have resulted in improved productivity and higher profitability.

Conclusion.

It can be seen from the above discussions and examples given that application of standardization and related techniques at various levels can result in improved productivity and economical manufacture for the development of materials industry. It is for the developing countries to strengthen efforts at their national, industry and company levles to rational, industry and company levels to rationalize raw materials on their own or get assistance from international organizations to guide them in initiating such work.

ANNEX 1. CHEMICAL COMPOSITION OF RATIONALIZED STEELS FOR AUTOMOBILE INDUSTRY

[Example of Indian standard 9175 - (Part 1)- 1979]
Typical entries of Selected Rationalized Steels.

Sl. No.	Designation	C%, Si% Mn%, Ni%	Cr% Mo% Mn%	Relevant Indian Standard	Equivalent Foreign Std. Steel	Suggested Replace-ment For
1.	30C 8 (C 30)	C% .25-.35 Si% .10-.40 Mn% .60-.90 Ni% --	Cr% -- Mo% -- S,P% --	IS 1875 IS 3930	En 5;SAE1030 AISI C 1030	SAE 1033 AISI 1033
2-9						
10.	13C10S25 (13S25)	C% .08-.18 Si% .10 max Mn% .80-1.20 Ni% --	Cr% -- .20-.30 Mo% -- S,P% .20-.30, .06 max	IS 4431	DIN 1651,	SAE 1112 10721,10S25 1113, AISI B1112,B1113, DIN 1651, 9SMn23 (1.7013)
11-32						
33.	15Ni5Cr4Mo4 (15NicrMo12)	C% .12-.18 Si% .10-.35 Mn% .60-1.00 Ni% 1.00-1.50	Cr% .75-1.25 Mo% .08-.15 S,P% ---	IS 4432	BS 970 EN353 815M17	DIN 17210 15CrNi6

Designations of steels based on IS 1762 - Part 1-1974
(This annex is not an exact extraction from IS 9175 (Part 1) - 1979 - but roughly indicates coverage)

ANNEX II - GUIDES FOR USE OF MATERIALS IN INDUSTRY

TYPICAL CONTENTS PAGE OF A GUIDE ON STEELS

1. INTRODUCTION (OBJECTIVES, COVERAGE)
2. DATA GIVEN ON EACH RATIONALIZED STEEL
3. GENERAL INFORMATION ON STEELS
4. CLASSIFICATION OF STEELS
5. TERMINOLOGY
6. HEAT TREATMENT CONDITIONS
7. ELEMENTS AND THEIR EFFECTS
8. CLASSIFICATION OF MACHINABILITY
9. CLASSIFICATION ON WELDABILITY
10. UNIFICATION AND VARIETY REDUCTION CONCEPT
11. COMPARATIVE COSTS OF STEELS
12. GUIDE ON APPLICATION OF STEELS
13. NEED FOR INTERNATIONALIZATION
14. INDIVIDUAL DATA SHEETS ON RATIONALIZED STEELS **
15. CLASSIFICATION OF WROUGHT SHAPES
16. DIMENSIONAL RATIONALIZATION
17. CONCEPT OF COMPANY STEEL SPECIFICATIONS
18. GENERAL INFORMATION ON STEEL USAGE & PROCESSES
    - FORMABILITY
    - ELONGATION VALUES
    - HARDNESS/TENSILE STRENGTH
19. INDEXES FOR EQUIVALENCE OF STEELS

** Gives designation, application, chemical composition, heat treated conditions, properties (strength, bending etc.), testing methods, machinability, weldability, equivalence with other important steels., etc.

ANNEX III - RESULTS OF MATERIALS RATIONALIZATION PROJECT (TYPICAL)

STEEL RATIONALIZATION PROJECT

EXISTING PROBLEMS	BENEFITS ENVISAGED
TOO MANY STEELS (525) (CONSIDERING PARTS PRODUCED)	SPECIFICATIONS REDUCED (525 TO 210)
SAME STEELS TO DIFFERENT NATIONAL STANDARDS	INTERNATIONAL STANDARDS USED WHERE POSSIBLE DIN WITH 'EQUIVALENT' USED ELSEWHERE
SOME STEELS ARE SPECIFIC COMPANY (FOREIGN) SPECS.	NEAREST INTERNATIONAL STD'S RECOMMENDED. ACTION INITIATED ON SPECIALS.
MANY INCOMPLETE AND INVALID SPECS.	SPECS./DESIGNATIONS FOR RATIONALIZED STEELS GIVEN. LATEST DATA PROVIDED
KNOWLEDGE ON 'EQUIVALENCE' OF STEELS NOT UNIFORM OR READILY AVAILABLE	'SIMILAR STEELS' CHARTS COMPILED AND ISSUED TO USERS.
UNECONOMICAL PURCHASE AND STORAGE/ HANDLING (QTY: 1 KG TO 1200 TONS)	RATIONLIZATION & EQUIVALENCE INFORMATION WILL ENABLE ECONOMICAL MATERIALS MANAGEMENT COULD SAVE MILLIONS OF $ IN LONG RUN. *
TOO MANY STEEL ITEMS (3000)	THESE GET REDUCED
MANY NON-STANDARD SIZES	STANDARD SIZES RECOMMENDED
INCOMPLETE INFORMATION ON SIZES TOLERANCES/FINISHES	COMPLETE INFORMATION WILL BE GIVEN
LACK OF INDEPTH KNOWLEDGE ON STEELS	KNOWLEDGE WOULD BE BUILT-UP
LACK OF DATA ON STEELS	STEEL GUIDE WILL GIVE UPTODATE DATA IN BRIEF.
LACK OF KNOWLEDGE ON TECHNIQUES OF RATIONALIZATION	PERSONS TRAINED IN RATIONALIZATION METHODOLOGY

* INTER-COMPANY LIASION POSSIBLE CONSOLIDATION OF REQUIREMENTS, EXCHANGE OF STEEL, REDUCTION OF OBSOLESCENCE, UTILIZATION OF SURPLUSES POSSIBLE.

Improving Quality and Productivity through Natural Gas Bottom Blowing in Iron and Steelmaking

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Abstract

Pilot plant trials carried out the Mexican Iron and Steel Research Institute (IMIS) demonstrated that when natural gas is bubbled into an oxidized liquid steel bath, its behavior is similar to that of an inert gas. This is mainly due to a low methane cracking level in the melt and to a very fast reaction between the hydrogen and dissolved oxygen.

This article presents the results obtained during thirteen campaigns of the combined blowing technique using natural gas at the BOF-1 melting shop (80 tons.) of Altos Hornos de México (AHMSA), nine campaigns at AHMSA'S BOF-2 shop (130 tons.) both located in Monclova, Coah., and six campaigns at SICARTSA (130 tons.) located in Cd. Lázaro Cárdenas, Mich.

In this paper are also presented the results obtained with the electric arc furnace process at IMIS and DEACERO. The effect on desulphurization with natural gas in hot metal ladles transfer are also reported.

Higher metallic yield, a reduced hot metal scrap ratio, and improved desulphurization and dephosphorization are among others, the most important benefits of these processes. The economical savings of this technology is around 2.5 U.S. Dls. per ton. of steel for both processes combined blowing in converters and bottom gas injection in electric arc furnaces.

GAS STIRRING PNEUMATIC PROCESS use nitrogen, argon or carbon dioxide in order to promote bath agitation. Argon is normally used during the post-stirring stage and a less expensive gas, such as nitrogen or CO_2 is used during the oxygen blow period in converrts or during the scrap melting in EAF.

Pilot plant trials carried out at the Mexican Iron and Steel Research Institute (IMIS) demonstrated that when natural gas is bubbled into an oxidized liquid steel bath, its behavior is similar to that of an inert gas. This is mainly due to a low methane cracking level in the melt and to a fast reaction between hydrogen and dissolved oxygen.

The main expected reaction is:

$$CH4 = \underline{C} + 4\underline{H} \quad ...... (1)$$

All experiments have shown, however, that there is no net hydrogen or carbon pickup in the melt. We could therefore say that next reactions occur:

$$\underline{C} + \underline{O} = CO \quad ...... (2)$$

and

$$4\underline{H} + 2\underline{O} = 2H_2O \quad ...... (3)$$

There is an evidence of diminution in the oxidation level of the bath. However, this effect is achieved mainly by the improved mass transfer between the gas bubbles-metal-slag system. With an oxidizing slag, the net effect of natural gas bottom blowing is decarburization to very low levels and a final oxygen content equal to that predicted by thermodynamic calculations.

Considering equation (2) and (3) from a volume point of view, we could expect that one volume of injected methane produces three volumes of product (one volume of CO and two volumes of H_2O) if the cracking of methane reaches 100 percent. However, there are evidences that cracking of methane inside the steel bath is not complete. The natural gas which is not cracked inside the bath is burned at the surface of the melt.

This paper presents the results obtained during more than 15,000 heats of combined blowing in converters, more than 1,000 bottom blowed heats in EAF and more than 100 desulphurized heats in iron transfer ladles using natural gas as stirring gas.

The main characteristics of these installations where this technology has been tested are presented in table 1, and the results are described as follows:

Table 1. Characteristics of Steel with Natural Gas Stirring

	OXYGEN CONVERTERS			EAF
	AHMSA BOF-1	AHMSA BOF-CC	SICARTSA BOF-CC	DEACERO
Furnaces	3	2	2	1
(TLS/heat) Capacity	80	130	120	50
Production (thousands of tonnes per year)	1100	1200	1150	250
Steel types:				
Killed (%)	45	100	100	100
Semikilled (%)	40	-	-	-
Rimmed (%)	15	-	-	-
Casting type	Ingot	Continuous Casting	Continuous Casting	Continuous Casting

Oxygen converters. Four gas-injection elements were installed in 80 tonne converters and eight injection elements in 130 tonne converters; these elements were positioned in a straight line along the trunnion axis for ease of installation and to reduce the time of contact with slag during sampling and tapping.

Instrumentation for individually controlling and monitoring the flow of argon, nitrogen and natural gas was installed. The combined blowing practice for the production of low carbon semi-killed steels production at AHMSA-1 is shown in figure 1. Natural gas is bottom blown during the refining period and during delays when the refractory lining temperature is not lower than 800^{0}C. Argon is used both during a reblow and during the final post-stirring stage.

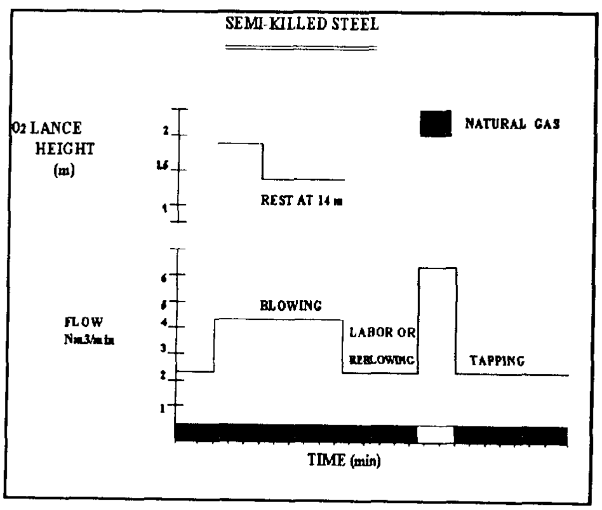

Figure 1

The wear of the bottom lining was uniform and the areas surrounding the tuyeres did not suffer any additional wear [1].

Bottom stirring with natural gas permits a fast and improved gas-slag-metal interaction, and one of its benefits is the lower level of dissolved oxygen in the bath, as shown in figure 2. Values are lower than the LD carbon-oxygen relationship.

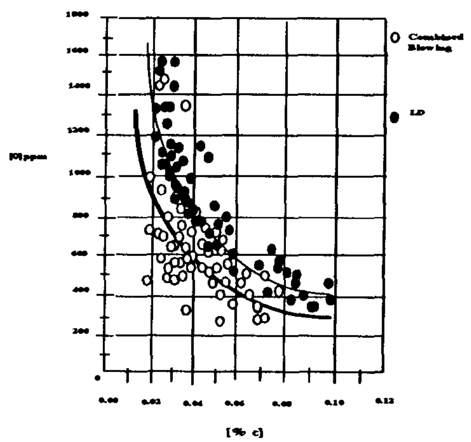

Figure 2

This fact has important consequences on the metallurgy of the process, as can be appreciated from table 2, which compares the oxidation level at tapping between the normal LD operation and the combined blowing process.

Table 2. Comparative results between LD and Blowing Processes

HOT METAL	COMBINED BLOWING	LD PROCESS
[%C]	4.60	4.50
[%Mn]	0.59	0.59
[%P]	0.14	0.13
[%S]	0.040	0.028
[%Si]	0.78	0.96
T (C)	1352	1347
END POINT		
[%C]	0.062	0.063
[%S]	0.028	0.024
[%Mn]	0.167	0.100
[%P]	0.017	0.010
[O] ppm	425	585
T (C)	1644	1620
TAPPING		
[%C]	0.035	0.041
[%S]	0.025	0.021
[%Mn]	0.125	0.068
[%P]	0.012	0.009
[O] ppm	686	796
T (C)	1654	1649
(%FeO)	21.4	28.3

The decreased FeO content of the slag and the lower slag volume due to lower flux additions, results in an increase in metallic yield averaging 1.6 percent. Additionally, the lower oxidation state enables the reduction of deoxidation and alloying additions.

The manganese yield at turndown, as shown in table 3, was increased from 11.5 to 23 percent. The larger saving in ferro manganese from the first to the third campaign was due to a better performance of the injection system.

Table 3. Manganese Contents of Hot Metal and Steel

	LD	COMBINED BLOWING
Hot metal (%)	0.67	0.65
End point (%)	0.10	0.17
After post stirring (%)	-	0.16
At turndown (%)	0.077	0.15
Yield (%)	11.5	23.08
Saving of FeMn (73% Mn) (kg/heat)	-	80

As shown in table 4, the desulphurization ratio obtained by bottom gas stirring has been improved from 51 to 61 percent during the third campaign at AHMSA-1. Desulphurization experiments were carried out by adding 6.5 kg/tonne of a bulk reagent mixture (10% Al, 40% CaF_2 and 50% CaO) at the end of the blowing period.

Table 4. Sulphur and Phosphorous Contents of Hot Metal, and Steel at Turndown

	LD	COMBINED BLOWING
(%S) Hot Metal	0.54	0.054
(%P) Hot Metal	0.308	0.308
(%S) Steel	0.026	0.021
(%P) Steel	0.019	0.017
Temperature (°C)	1610	1626
Basicity	3.547	3.22
Desulphurization (%)	51.85	61.11
Dephosphorization (%)	93.83	94.48

After a five-minute period of argon stirring, a sulphur content of 0.016 percent was obtained, indicating a desulphurization ratio of 70 percent. The lower oxidation level of steel obtained by natural gas bottom stirring did not results in any detrimental effect on the percentage of dephosphorization; that is 94 percent for LD operation and 95 percent for combined blowing (see table 4). Additionally, as shown in figure 3, it was possible to obtain a higher dephosphorization during the post-stirring period.

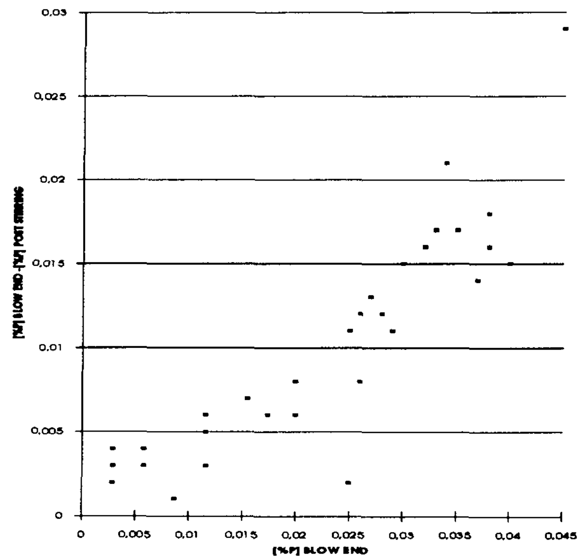

Figure 3

The oxygen, burnt lime and dolomitic lime consumption per tonne of steel, as shown in table 5, decreased by 3.11 Nm^3 , 3.5 kg and 15.97 kg, respectively. This is mainly attributed to an improved metal-slag-gas interaction.

Table 5. Raw Materials

	LD	COMBINED BLOWING
Oxygen (Nm^3/TS)	62.86	59.7
Hot Metal (kg/TS)	851.65	813.5
Scrap (kg/TS)	253.86	291.1
Hot Metal/Scrap	3.354	2.8
Burnt Lime (kg/TS)	71.81	68.3
Dolomitic Lime (kg/TS)	49.84	33.9
Dolomite (kg/TS)	13.87	9.0

The lower hot metal: scrap ratio attained during the combined blowing trials is important evidence of a thermal balance improvement. As shown in table 5, the hot metal: scrap ratio was decreased by 16 percent. This phenomenon is believed to be due to the combustion of natural gas and gases generated above the bath surface.

To evaluate the effects of the different combined blowing parameters on the hydrogen dissolution into the steel, a serial of trials was made at AHMSA-1 and 2 shops.

The hydrogen content in liquid steel was measured by the hydrogen direct reading immersion system (HYDRIS) using disposable sensors submerged for 40-60 seconds. By this method, the hydrogen partial pressure is determined and the dissolved hydrogen content in the liquid steel in parts per million (PPM) is calculated according to Sievert's law.

Figure 4 presents data from three steel grades in conventional LD operation at AHMSA-2. By comparing the chemical composition of these steel grades, it was observed that at higher carbon levels and with manganese additions to the ladle, the hydrogen level is notably increased.

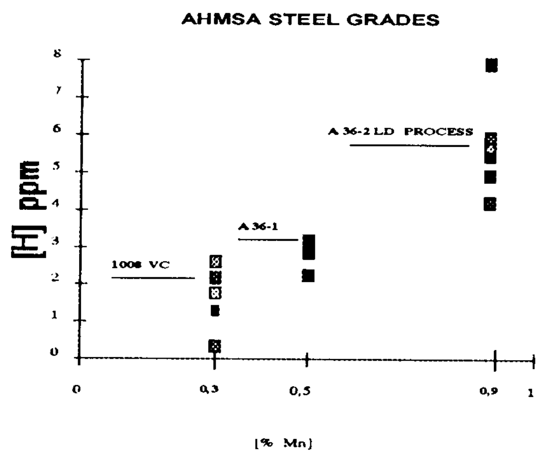

Figure 4

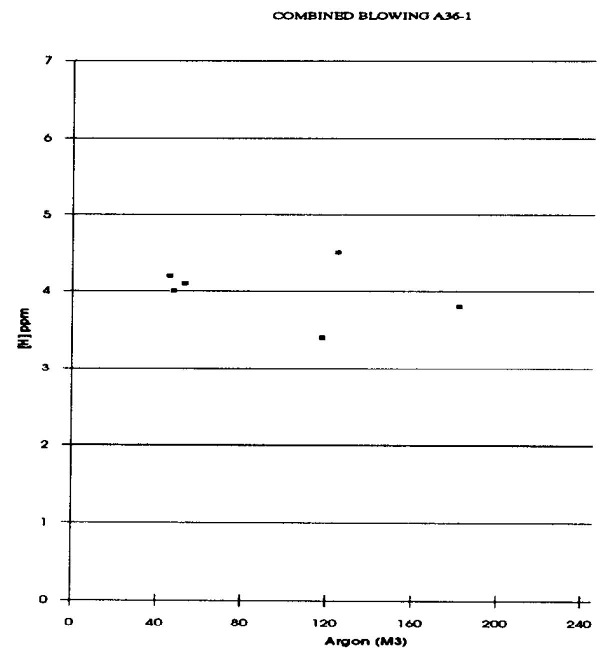

Figure 5

In the case of structural grades ASTM A36-1 and ASTM A36-2 the difference is the manganese content and consequently the ferromanganese additions are assumed to be the main source of hydrogen in steel.

Hydrogen contents in steel made by combined blowing at AHMSA-2 were determined only in A36-1 grade. The 12 readings obtained covered a range of 2.7-4.6 PPM of hydrogen with an average of 3.9 PPM for these heats, in which argon was blown after the main oxygen blow period, it was found that a volume of about 40 Nm^3 was sufficient to obtain the same hydrogen level as that of the conventional LD process (figure 5). The figure also shows that some degree of additional dehydrogenation is possible.

A bottom blowing trial using 100 percent natural gas was also carried out in which in average hydrogen content of 7.3 PPM was obtained. This measurement corresponds to a relatively low level of oxygen at tapping as compared with normal contents obtained in the conventional LD process.

At AHMSA-1, seven measurements were carried out on three steel grades using the combined blowing technique. Results ranged from 4.1 to 5.7 PPM of hydrogen with an average of 4.5 PPM on three of the seven heats, argon was 100 percent bottom blown during a complete heat with practically the same hydrogen level obtained as that for heats where natural gas was blown during the refining period.

Comparison of readings for each steel grade in figure 6 shows that the oxidation level at turndown has a very clear effect on hydrogen level. As the oxidation level decreases, the hydrogen content in the steel increases; in such cases argon blowing enables hydrogen content to be reduced to the normal level of that observed for the conventional LD process.

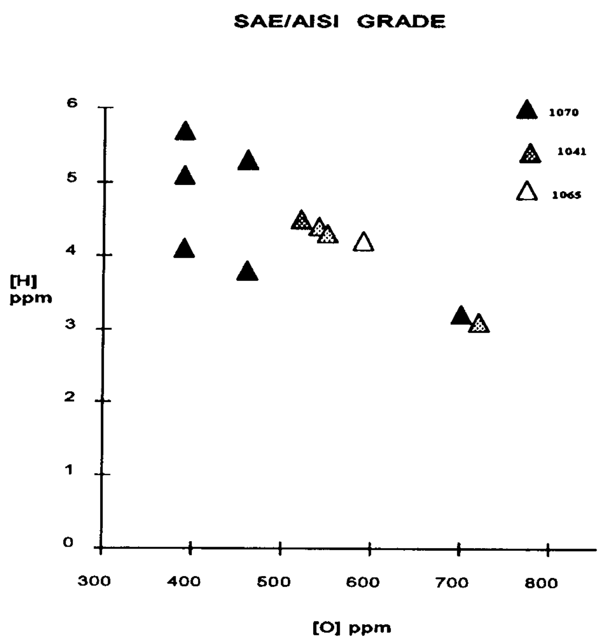

Figure 6

Table 6 shows the minimum economical benefits of IMIS combined blowing technology.

Table 6. Comparative Cost per ton of Steel (TS)

MATERIAL	UNIT COST (U.S. DLS.)	LD US$/TS	COMBINED BLOWING US$/TS
Hot Metal (kg)	0.11	95.4	90.8
Scrap (kg)	0.11	27.2	30.1
Oxygen (Nm^3)	0.03	1.8	1.7
Dol. lime (kg)	0.05	2.5	2.2
Burnt Lime (kg)	0.05	4.0	3.6
Dolomite (kg)	0.01	0.2	0.1
FeMn (kg)	0.46	5.3	5.0
Al (kg)	2.31	1.6	1.4
Carbocoke (kg)	0.30	0.6	0.5
Natural gas (Nm^3)	0.07	-	0.1
Argon (Nm^3)	0.09	-	0.05
Addic. pers. (day/pers./BOF)	100	-	0.05
Elements (4 PCS)	4,500	-	0.22
TOTAL		138.6	135.82
DIFFERENCE			-2.78

Electric Arc Furnaces. From different pilot plant trials at IMIS and industrial trials at DEACERO using several number and configuration of injection elements, we found that for EAF up to 100 tons capacity, with our design, only one injection element is required.

It is well known that in the EAF operation, thermal shocks occur in the refractory and cause severe working conditions for the injection elements. At IMIS, the main objective of the research program has been oriented to the reduction of delays due to damage of injection elements. The main problem to solve has been to avoid the bonding between the injection element and the sleeve through the presence of a filler material between the sleeves and the metallic can of the injection element.

The use of refractories with low thermal conductivity and low expansion coefficient around the injection element have been proved to be an important factor to make the injection element interchange easier.

The last generation of IMIS injection system has allowed injection element changes in no more than 20 min. in the 7 ton EAF pilot plant at IMIS. The injection element which is single tuyere is slot type specifically designed for the EAF where it is going to operate, featuring operation from very low to very high gas flow rates, making the stirring power easier to concentrate during the different stages of the process. During melting, high concentration of kinetic energy is needed to increase heat transfer to reduce energy consumption and melting time. During refining, the stirring power is properly adjusted, allowing adequate physical and chemical interchange between slag and liquid metal in order to improve desulphurization, dephosphorization, decarburization, etc.

Bottom stirring has been operating 24 hours a day, during 14 days continuously, without any production delay. A typical wearing rate of 0.3-0.5 mm/heat during the first week and 0.5-1.0 mm/heat during the second week of operation was achieved [2].

Besides the injection element, IMIS technology includes natural gas as stirring gas, with the following benefits:

- It has been possible to reduce net energy consumption by 20 kwh/tls; considering the lower oxygen consumption and reduced tap-on times, savings raise up to 40 kwh/TLS.
- It is feasible to obtain lower electrode consumption due to operation under an atmosphere with much less oxygen in the hearth of the furnaces. Savings from 0.1 to 0.3 kg/TLS have been achieved.
- Comparative costs per heat of natural gas are lower than argon. If the steelmaking shop does not have its own argon producing plant, this difference will increase considerably.
- Due to the reducing characteristics of natural gas, it is feasible to produce lower oxygen residuals and

consequently improve quality and yield (from 500 PPM to 100 PPM as shown in figure 7).

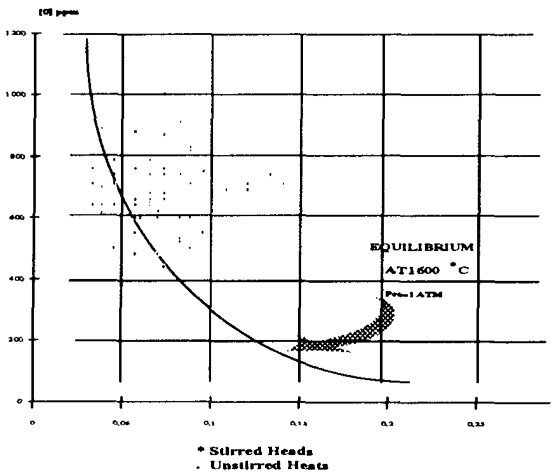

Figure 7

- During melting, the higher rate achieved through high stirring power permits a lower usage of oxygen from lance or burners, resulting in a lower alloy oxidation. A reduction from 0.6 to 3 Nm^3 /TLS is possible of obtaining.
- The high-alloy and stainless steels production in EAF is specially improved by natural gas stirring. During refining, the conventional practice is improved by a vigorous stirring, enhancing a better metal-slag interchange that produces higher metallic recoveries and shorter operation periods. Ferroalloys savings up to 0.5 kg/TLS were obtained.
- Table 7 shows the minimum economical benefits of this technology.

Table 7. Minimum Savings for IMIS EAF Natural Gas Bottom Stirring Technology

SAVINGS	US$/TLS
Productivity (5-10 min.)	0.69
Metallic yield (1%)	0.43
Eelectric energy (KWH/TS)	0.22
Eelectrodes (0.3 kg/TS)	0.21
Oxygen (3.0 Nm^3/TS)	0.09
Ferroalloy (0.5 kg/TS)	0.36
	2.00

Hot Metal Desulphurization. Between blast furnace and converter, there are two places to perform desulphurization in pig iron: torpedo car or hot metal ladle.

Research at IMIS in this matter has been conducted through the addition of several kinds of non-pollutive desulphurizing reagents to the empty ladle just before hot metal charging, followed by natural gas bottom stirring through permeable element along the hot metal charging of the ladle. By this mean, the use of special equipment and lances for powder injection is eliminated, making this hot metal desulphurization process less expensive and more reliable in operation than conventional injection lance desulphurization processes.

Results of industrial trials performed in 100 ton hot metal ladles using different amounts of desulphurizing with sodium metasilicate reagents it was possible to obtain sulphur levels of around .005%S, with a desulphurization ratio of 80% using 8-10 kg/ton of hot metal and a blowing rate of 200 lts of natural gas in less than 15 minutes of stirring.

Conclusions

Development of IMIS natural gas stirring technology has produced the following results:

1. The use of natural gas has proved to be a valuable tool in metallurgical pneumatic processes.
2. Development of safety and reliable devices for natural gas injection into metallurgical vessels.
3. Natural gas, as a stirring media, has demonstrated satisfactory results in safety, stirring performance and uniform wear between lining refractory and injection elements.
4. Process optimization of electric arc furnaces, oxygen converters and hot metal pre-treating.
5. Hydrogen levels in steel using IMIS natural gas stirring technology indicate that three is no significant difference between conventional and combined blowing practices.
6. Development of gas injection systems including instrumentation and automatic control systems.

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Rationalization and Standardization in the Field of Iron and Steel

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Abstract

The last two decades have seen unprecedented scientific and technological developments in all fields. The iron and steel industry has also kept pace with these developments. Special attention has been paid to newer steels, higher and exacting qualities, higher productivity and lower costs. While most of these developments have taken place in the developed countries, some of the developing countries are trying to catch up. One of the important areas overlooked is restriction of the varieties and standardization of the products.

The first country to tackle this area, primarily due to economic reasons was India during 1952-1962 with great success. Over 1500 varieties of steels used at that time in the country were reduced to about 150 and then these were standardized. This work attracted worldwide attention and some other countries initiated similar activity, notable amongst them are Argentina and Brazil. The author assisted many countries in this effort.

The most comprehensive project on standardization of steel and steel products was executed in Brazil during 1977-1983 with the technical assistance of the United Nations. The project included development of standards consciousness in the country, national standards for products, their application standards in related fields such as steel plant equipment, refractories, corrosion, quality control, quality certification and variety reduction. Over 200 priority standards were prepared, about 1000 standards engineers were trained, quality control procedures developed and standards departments established in 15 large integrated steel plants and allied industrial units. The economic benefits were shown to be \$2-4 million in several companies. Steel varieties were reduced by 75%. This paper outlines the project details, the methodology, and the resulting economic benefits.

METALS are the backbone of the modern civilization. The use of metals was initially confined to those found native in nature and the art of metal extraction was initially restricted to the recovery of metals that were easy to melt. "Copper Age" and "Bronze Age" were the early great achievements. Then came the "Iron Age". Aluminum and magnesium were first produced in the 19th century and now we see the largest use of metals, with newer applications being constantly added. Today, the per capita consumption of steel is one of the yard sticks to gauge a nation's progress.

The unprecedented scientific and technological developments in the latter part of this century have called for a revolution in newer steel production technologies, more exacting qualities of steels, steel products and alloys, newer methods of manufacture and finishing, higher productivity, lower cost, and computerized maintenance systems of steel producing units. This in turn has motivated the auxiliary industries to come up with new technologies in their own ambits to cope up with the developments in the main industries.

NEED FOR STANDARDIZATION AND RATIONALIZATION

There is no doubt that all these developments will continue unabated to meet man's ambitions and goals which appear to know no limits. While these developments are needed and welcome, they have also brought problems both to the manufacturer and the user. The bewildering varieties, the ever convincing claims of each inventor and the aggressive promotional sales talks are utterly confusing. The user (including the manufacturer when he wants to use an invention) is at a loss to know what to believe, how much to believe and how much to rely. Such confidence can only be built up over a period of time when the results of research, tests and experience are well established and approved by an independent recognized body. This in fact is termed "Standardization" and the recognized body could be national, international, or an authority designated within the manufacturing or user entity itself. The result of the standardization activity is the "Standard".

DEVELOPMENT

The developed countries realized, after the first and second world wars that standardization and industrial quality played a major role in the industrial and economic development of nations and international trade. After the second world war several developing countries also initiated these activities. This also led to the establishment of the International Standards Organizations (ISO and IEC) to achieve harmonization of standards of different countries and to promote international trade.

An in-depth review of the standardization activities in various countries reveals that most of the developed countries and a few developing countries have done considerable work in the field of iron and steel but in piecemeal, in individual sectors, spread over a number of years. India was the first country to initiate a comprehensive rationalization and standardization program in this field in the early 50s spread over a period of ten years. The results and economic benefits were astounding attracting worldwide attention. The project led to a saving of close to 25% of steel. Over 1500 varieties were reduced to 146. Developed countries started to revise their standards on the basis of Indian standards, and the ISO set up a Subcommittee to formulate international standards on steel profiles with Indian standards as the basis.

THE BRAZILIAN PROJECT

Standardization and Quality. During the early 70s Brazil was producing around two million tons of steel, and had an ambitious program of expanding the production to 12 million tons in the first stage increasing it to 19 million tons in the second stage. At the same time, in 1973, the government formulated its first basic plan for development of science and technology (PBDCT) in which high priority was allotted to standardization and industrial quality. The author was invited to review the national scene and make recommendations to reorganize the national standards system and to make specific proposals for the iron and steel field.

The author's recommendations were accepted and implemented. Brazil also launched, with the technical assistance of the United Nations, the most comprehensive and integrated program of standardization, quality control and quality certification in the iron and steel sector in 1977. Rationalization formed part of this project. It took 6 to 7 years to complete the project at a cost of about $4 million.

It is proposed to summarize the project activities and achievements while detailing the rationalization program.

Broadly speaking, the immediate objectives of the project were to assist in establishing a sound infrastructure for executing standardization and quality activities at all levels - national, industrial, governmental, trade, educational, testing and research; to develop standards consciousness in the country, train personnel, formulate priority standards for steel and steel products, develop codes of practice for their utilization (design, fabrication, welding, etc.); to develop priority standards in related fields such as refractories, steel plant equipment, corrosion, quality control, quality certification and rationalization of steel qualities.

The scope of work in each area was discussed with all concerned major entities and a detailed time bound work program and goals defined. A team of top experts in the respective fields were assembled from all over the world under a project manager. Their arrival in the field, the work program, and duration of stay were all agreed. A counter part team of Brazilians was set up in the project to work with the international experts. A great deal of preparatory work was done in the field before the arrival of the experts to make the maximum use of their stay in the country.

In all 20 international experts worked in the project totaling 244 man-months. The counterpart team consisted of 60 Brazilian engineers and scientists. The training of these personnel totaled 11,500 man-hours. Forty two Brazilians working in the national standards body, government, and industry were sent for training for short periods to other parts of the world from Argentina to Japan. 800 engineers and technical personnel working in the industry and 60 professors working in universities were trained in the country.

Eighty seminars were conducted all over the country in which 4200 persons from the industry, trade, government departments, educational institutions, consumers, and research and testing laboratories participated.

To promote participation of the industry in the national standards preparation and application of standards and quality in the industrial units, 15 large scale units were selected. In all of them technical personnel were trained, standards departments set up and their operation demonstrated. Subsequently, the economic benefits to the enterprises were evaluated which, in each of the units, totaled several million dollars. These pilot projects became models and motivated several industrial enterprises to initiate the standards and quality activities. In fact, today the Brazilian integrated company standards system is one of the best in the world.

In the area of standardization, 100 sub-committees and technical commissions were set up at the national level and over 200 priority standards were prepared. The industry participation in these committees increased from 700 to 2500. Notable amongst the standards prepared were those related to welding, refractories, corrosion, fire safety code, design of fire-resistant metallic structures, steel bridge code and extensive work related to steel plant equipment.

Training and basic assistance were provided to the concerned personnel and institutions to change over to the SI system of measurements.

In the area of quality, the main task was to train personnel, demonstrate pilot projects, establish the basic rules, regulations and documentation for quality control and quality certification.

Rationalization. This is a form of standardization consisting of the reduction of the number of types of products within a specific range to that number which is adequate to meet prevailing needs at a given time.

In the case of steel products, rationalization could be achieved in terms of:

- qualities,
- dimensions, and
- shapes.

The maximum benefits would result from rationalization of qualities and hence this aspect was taken up first.

Varieties of steel qualities build up due to:

- import of steels from other countries using varying production technologies
- bilateral and multinational collaborations to establish national industries
- insistence of foreign collaborators to use their standards
- foreign aid linked with financial loans
- absence of national standards and/or lack of coordination with existing standards
- willingness of the manufacturer to produce all qualities demanded by the user, especially during recession
- reluctance on the part of the user to modify their design or process, and
- unrestricted imports.

The advantages of having unrestricted varieties is that the consumer gets almost exactly what he wants which leads to economy at his end. On the other hand, for the manufacturer the cost of production increases and productivity decreases.

Other disadvantages are:

- increased purchase cost
- blocking of capital as stocks have to be maintained and
- increase in cost due to management, handling and warehousing at all locations.

In order to tackle this question, the first task was to make the user appreciate the need and benefits of variety reduction; then educate him how to select the nearest equivalent steel from the rationalized list and the minimum modifications needed for his design, fabrication or production. These were achieved through several seminars, group meetings, visits to the industrial units and case studies from the work done in India and Argentina.

At the same time, a national plan for execution of the project was formulated and approved by the highest authority in the country. Then the detailed procedures and questionnaires for collection of data were drafted in consultation with all concerned; the procedures for analysis of the data and methodology to select steels for inclusion in the rationalized list were decided. Four engineers were extensively trained in Brazil and Argentina to man the secretariat and guide the work.

Detailed questionnaires were prepared to collect data from:

- steel manufacturers in the country
- steel users
- importers
- exporters

A procedure for analysis of the data thus collected was discussed and agreed. A technical committee consisting of manufacturers, consumers, testing laboratories, research institutions and government authorities was constituted under the national standards body to coordinate, direct and take charge of the work.

The committee decided to formulate the following basic standards to ensure uniformity of understanding and interpretation:

- Terminology
- Classification
- Codification

The standard on terminology was mainly based on international standards.

Classification of steels has always presented problems in every country as well as at the international level. It is difficult to get common agreement because of several but equally valid criteria and it is not always possible to meet differing usages with the same classification. Keeping this in view, steels are generally classified, based on:

- Chemical composition
- Mechanical characteristics, and
- Special characteristics.

Steels based on mechanical characteristics are further subdivided into:

- Structural steels, and
- Mechanical constructional steels.

The third category, namely, those with special characteristics, are for use in special applications and cannot be defined either by chemical composition or mechanical characteristics.

A Brazilian standard on classification of steels was prepared keeping in view all the above principles.

The standard on codification again presented difficulties to satisfy all producers and users. But, an excellent compromise was reached keeping in view the international usage.

Certain basic criteria had to be kept in mind when rationalizing and standardizing steels for use in Brazil. Firstly, these steels had to be compatible with steels standardized and widely used internationally. Secondly, the national industrial units had to be capable of manufacturing them and cater to the domestic market. Thirdly, the steels standardized were not to come in the way of imports when there was such a need.

Rationalization tends to serve more efficiently a particular market. It is obvious that efficiency should be measured from the points of view of both the producers and consumers. As mentioned earlier, reduced variety leads to longer runs of production resulting in higher productivity, better quality and lower cost. On the other hand, the users' needs are met if a large variety is available from which he can choose what he wants so that the use of the product can be optimized for each particular requirement. Naturally, a compromise has to be reached between the two diverse needs. A great deal of consideration and analysis of the steel production, usage and imports is needed.

In Brazil, the analysis of the data consisted of:

- sorting out steels whose consumption was low and did not justify production,
- identifying or developing steels which could conveniently substitute those which are eliminated.

In order to carry out this analysis, the following procedures were adopted.

The questionnaires had to be sent to all the relevant entities. This had to be followed, in many cases by personal contacts and furnishing clarifications. After it was ascertained that most of the replies had been received the consumption of each variety of steel and the usage were determined. Further, several assumptions were made as for example:

- the market is homogeneous
- all items are different from each other
- the consumption figures are specific and do represent the production and use of the relevant items
- producers are in a position to define a minimum tonnage for each item below which it is not economical to produce and likewise the consumer can define an annual minimum consumption, MAC and then come to an agreement.
- the consumer can also establish a minimum or desirable demand meeting percentage, DMP
- it is more logical to include in the rationalized list, the steels of higher consumption than those of lower consumption.

Keeping these in view, the consumptions were arranged in decreasing order and the accumulated curve was drawn (see Figures 1, 2 and 3). If each item had the same consumption there would be a straight line (as indicated in Figure 2). But, this does not happen in practice and as a rule a concentration type curve, as indicated is obtained. The next step was to determine the values for MAC and DMP after analyzing all the data compiled and discussions at the committee level. These were plotted on the consumption curve. The intention was to locate them preferably, in zone C of the curve ABC.

The principle is that if the values of both MAC and DMP are compatible, i.e. the intersection points coincide on the curve the problem is solved. If not, they should be re-examined carefully and a compromise reached. It was possible to reach such an agreement.

The next step was to make a thorough analysis of whatever remained on the non-rationalized part of the consumption curve and a justification established to leave them out. Then, the committee had to concern itself with making recommendations as to which steel in the rationalized list could be used for substituting those now currently used by the consumers. A document comparing Brazilian steels with those of well known foreign

Types vs. Decreasing Consumption

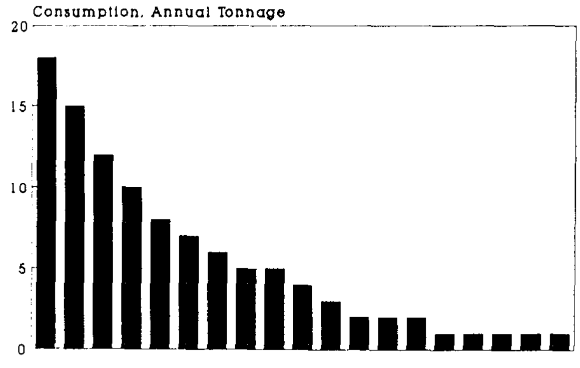

Figure I

Accumulated Comsumption ABC Curve

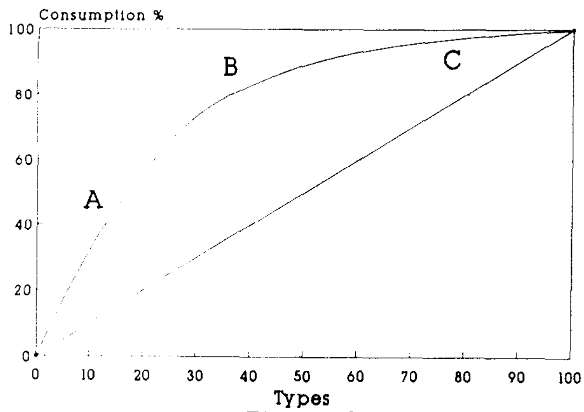

Figure 2

Minimum Annual Comsumption vs. Desired % of Demand Satisfaction

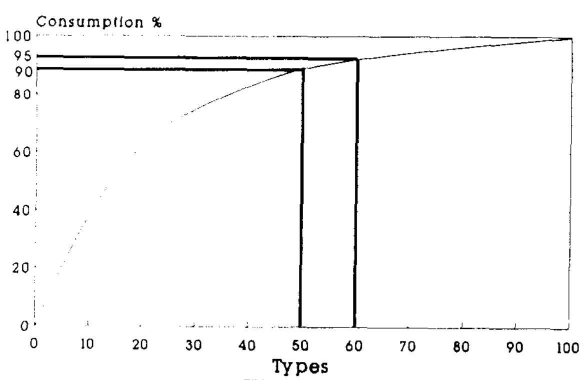

Figure 3

standard steels will be compiled in due course.

This work took almost two years and resulted in arriving at a rationalized list of 390 steels from the existing 1580 types, a reduction of 75%. When fully implemented (both the producers and consumers fully adhere to this list) the economic benefits to Brazil are expected to come to a few billion dollars considering that the annual production at present is of the order of 25 million tons.

Most of the national standards for these steels have been prepared. It is proposed continuously to review this list and update it to cater to changing technology, pattern of demand and consumption in the country and in the international market. The next tasks are to rationalize sizes and shapes of steel products.

CONCLUSION

The Indian, Argentian and Brazilian projects on rationalization and standardization in the field of iron and steel have clearly demonstrated the substantial economic benefits that accrue to a country leading to faster pace of industrial and economic development. It is essential and worthwhile for other developing countries to execute similar projects.

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Creep Life Prediction Based on Threshold Stress Concept

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Abstract

In this paper a new approach for creep life prediction based on a threshold stress concept is proposed. The approach is based on the analysis of creep and hot tensile data generated on a popular 1Cr-0.3Mo-0.25V steel in the service exposed and the virgin states and also on samples with a wide range of microstructures prepared from the virgin state.

Introduction

Remaining life assessment of critical metallic components is essential for the safe operation of old thermal power plants and other high temperature installations. The available approaches for Creep Life Prediction can be broadly classified into the following :

* Operational parameter appraoch

* Post service examination approach

The first approach depends on the evaluation of the service temperature/stress history for a given component. Once the history is known then combining it with the lower bound value of the standard material data and the life fraction rule an estimate of remaining life can be obtained as illustrated in Fig.1. However, this approach suffers from several limitations :

* The operational parameter data are not always available.

* Standard material data have a wide scatter and often cannot be reliably extrapolated to the rather low operating stresses.

* Life fraction rule used in this approach is not always applicable.

Thus the approach at best can serve the purpose of obtaining a very conservative estimate of creep life.

The second approach based on direct evaluation of the component after prolonged service exposure is undoubtedly more accurate and also does not require detailed knowledge of the service history. Hence it is widely used. Among the numerous techniques available for post service evaluation, the most commonly used are those based on the stress rupture testing. In order to obtain results within a reasonable period of time, these tests have to be accelerated by testing : either at higher stresses or at higher temperatures or both. The short term rupture data so obtained, are extrapolated to ascertain long-term life at lower stresses/temperature as illustrated in Fig2(a-b). This approach has the following limitations :

* Being empirical its validity is limited to the domain of available database, that is the short-term data have only limited extrapolation capacity.

* The procedure is time consuming and expensive.

One inherent expectation in the stress-rupture approach is that some deterioration in the rupture strengths as well as in creep ductility should take place after 10^5 h service exposure. This expectation has been belied both by laboratory data and the plant experience.

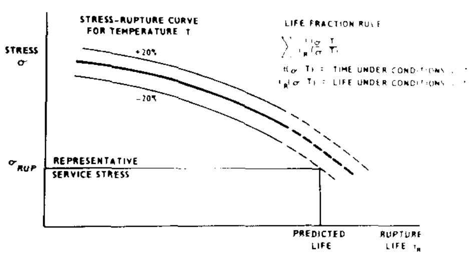

Fig.1 Schematic representation of operational parameter approach[1].

The laboratory data on common grades of Cr-Mo and Cr-Mo-V grades of ferritic steels have shown that the rupture data of the virgin and the service exposed steels converged at low stresses[1-4]. Also, there is no significant loss in creep ductility after 10^5 h service exposure[2,4].

It is also important to note that the critical components are allowed to undergo only a limited creep strain (1 -2%).

In view of the points made above, it appears to be more appropriate to develop life prediction methodology based essentially on the creep deformation data such as Theta-projection[5], Monkman-Grant relationship[6] and creep rate-stress relationship[7].

The Theta-projection requires very extensive creep study to generate creep curves until rupture. Hence, this is expensive and time consuming. However, keeping in view the fact that the strain limitation of 1 or 2%, which accumulates over a length of time almost in a steady state manner in several critical components, all the above approaches become essentially identical. Because, in the final analysis, each of these methods would ultimately depend on the minimum creep rate value to predict creep life. In other words the remaining life is obtained by calculating the time to reach 1% or 2% creep at the prevailing minimum creep rate.

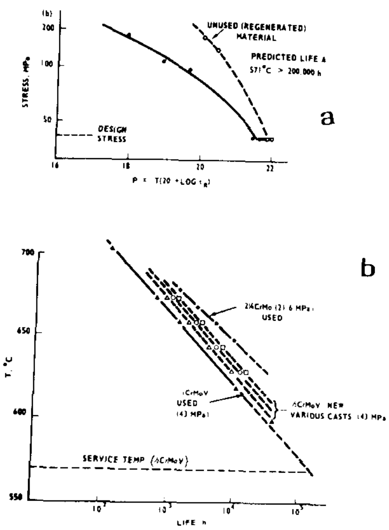

Fig.2 Post service examination approach :
a) Stress vs Larson-Miller parameter plots
b) Temperature vs rupture life plots[1].

In what follows is a brief discussion of an approach which we proposed. In this approach one uses the minimum creep rate coupled with the threshold stress value for creep life prediction. It is shown that the approach is inexpensive and much less time consuming.

Experimental

The new method for creep life prediction being proposed in this paper is based on a systematic study carried out on a sample of the main steam pipe of 1Cr-0.3Mo-0.25V steel. Experimental details and findings have been reported in other papers[4,7]. However, some special features of the experimental approach must find a mention here.

Microstructural changes encountered during long-term creep exposure and their adverse impact on creep properties have been central to the most of the R&D work in the field. Hence, useful conclusions can be derived only when both the creep and the microstructural aspects are simultaneously and extensively studied using a proper mix of samples. In view of this, the uniqueness and completeness of the present study lies in the following :

* Detailed study of the morphological and compositional changes of the carbides in both virgin and the service exposed samples[3,4].

* Extensive creep-rupture and hot tensile properties of samples having widely varying microstructures including the one produced in the service exposed material.

The details of the five samples that have been studied are given in Table 1. The chemical composition is reported in Table 2.

The SE samples was removed from the region close to the boiler end (Fig.3) which had seen the highest service temperature. It is remarkable that the VN and the SE samples belong to the same manufacturing batch.

Our findings of microstructural study[3,4] have brought out a significant point that morphological and compositional changes of the carbides impair the creep strength only at high stresses where the Orowan Bowing is a dominant creep deformation mechanism. On the other hand, creep strength at low stresses customarily experienced by engineering components is not affected appreciably.

The main findings concerning the creep and hot tensile studies which have provided the basis for the new approach are discussed subsequently.

Table 1. Details of the 1Cr-0.3Mo-0.25V steel samples investigated

Sample	State/Dimension	Heat Treatment	Microstructure	Hardness (HV)
VN	Virgin pipe: 273 mm OD x 22 mm thick	Commercially N at 980° + T at 700°	90% ferrite + 10% bainite	156
SE	Same as VN but service exposed: 10^5h, 540°C/40 MPa (hoop stress)	—	90% ferrite + 10% tempered bainite	152
RHV1	15 mm dia bars prepared from the VN material	austenitized at 980°C (1h) followed by oil quenching and T at 700° (2 h)	100% bainite	210
RHV2	-do-	N at 980°C (1 h) + T at 700°C (2 h)	80% ferrite + 20% bainite	190
RHV3	-do-	N at 980°C (1 h) + T at 700°C (72 h)	80% ferrite + 20% tempered bainite	160

N - normalized; T - tempered

Table 2. Chemical composition (Wt%) of the pipe investigated

C	Mn	P	S	Si	Cr	Mo	V	N
0.11	0.30	0.01	0.007	0.35	1.01	0.28	0.23	0.023

The Threshold Stress

The threshold stresses for the five different microstructures were obtained using the Lagneborg-Bergman[8] approach. This is schematically shown in Fig.4 wherein the creep data are plotted in the form of fourth root of the minimum creep rate $(\dot{\varepsilon}_m)^{0.25}$ vs the applied stresses, σ. The line 1 corresponds to the low stresses sensitivity ($n \simeq 4$) obtained at lower

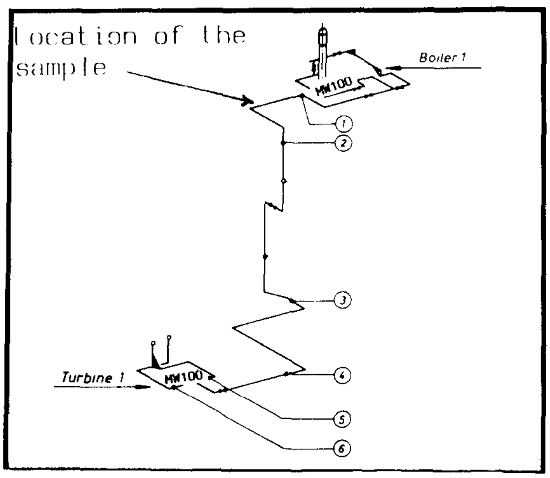

Fig.3 Location of samples for the investigation

stresses and the line 2 corresponds to the high stress sensitivity ($n \gg 4$) obtained at higher stresses. The extension of the line 2 to a strain rate equal to zero gives the value of the threshold stress σ_H. The threshold stress obviously implies that it is the highest value of the applied stress which if exceeded produces run away creep (high value of n).
Figure 5 shows $(\dot{\varepsilon}_m)^{0.25}$ vs σ plot in the high and in the low stress sensitivity regions for each of the five microstructural states. The intercepts of the line A, B, C, D and E with abscissa give the values of σ_H. The transition stress, σ_T, represents stress level above which change in creep deformation mechanism is believed to occur[8].

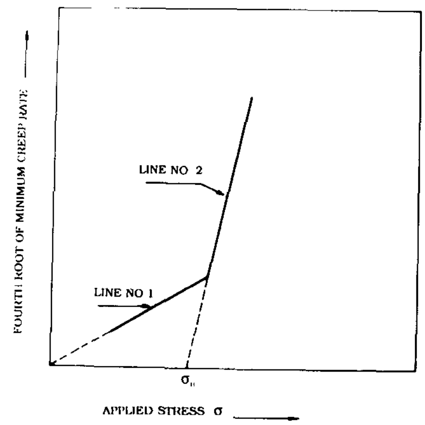

Fig.4 Schematic representation : Determination of threshold stress from creep data for a given microstructure.

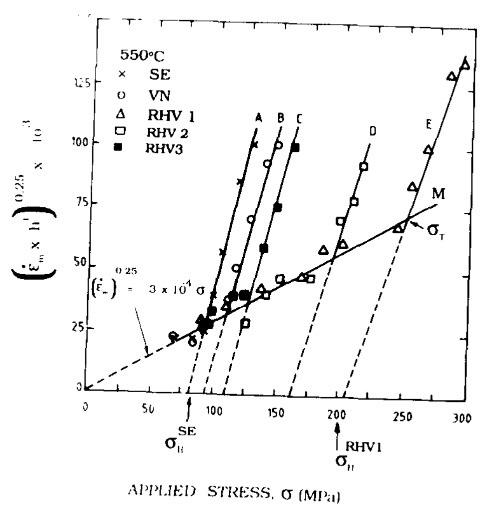

Fig.5 Threshold stress for different microstructures in 1Cr-0.3Mo-0.25V steel.

The figure shows the following important points :

* The values of σ_H for the VN and the SE samples differ only by 12 MPa, which means that a service exposure of 10^5 h produces only a mild degradation. This observation was also in keeping with the insignificant microstructural changes observed after an exposure of 10^5 h in service[4].

* The creep strength varies significantly with change in original microstructures but only at higher stresses. When $\sigma < \sigma_T$ the data points for all microstructures fall on the same line OM.

* The best fit line OM (see Fig.6) passes through the origin.

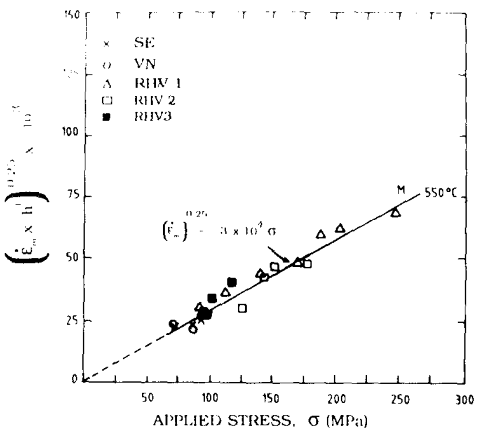

Fig.6 Minimum creep rate in the low stress sensitivity region

The equation of the line OM has been found to be :

$$(\dot{\varepsilon}_m)^{0.25} = M\sigma \qquad \dots \quad (1)$$

where $M = 3 \times 10^{-4}$, $(h)^{0.25}$ /MPa

It may be noted that the line OM is microstructure independent and hence can be used for any given microstructure for life prediction. It is also noteworthy that the 2.25Cr-1Mo steel exhibited a similar trend (Fig.7). However, the difference in respect of lower values of σ_H and M, may be noted. This is understandable in view of the lower creep strength of 2.25Cr-1Mo.

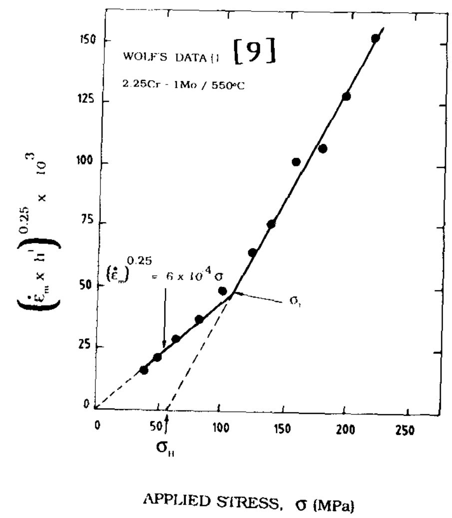

Fig.7 Threshold stress of 2.25Cr-1Mo steel based on data reported in reference[9].

Correlation of σ_H with Hot Yield Strength

σ_H can indicate the extent of microstructural change during creep exposure. It has also been contended that σ_H "can be used as a design-limiting strength property"[3,10]. Notwithstanding this contention, it should be noted that to achieve significantly long life, the stress level in a power plant component used in high temperature service, must be considerably lower than σ_H. On the other hand, σ_H represents an upper-bound value of the permissible stress. Indeed, the service stress at any point of time must always be less than σ_H to avoid runaway creep deformation. Therefore, a simple experimental method to determine σ_H should be useful. The metallographic methods to determine σ are difficult to carry out and yield uncertain results[1].

Hence, the correlation of σ_H with the hot tensile yield strength, σ_Y as observed by us is significant. This is plotted in Fig.8, which indicates that

$$\sigma_H = 0.48\sigma_Y \qquad \dots \quad (2)$$

The fact that the plot passes through

origin probably has a basic significance, which requires further study.

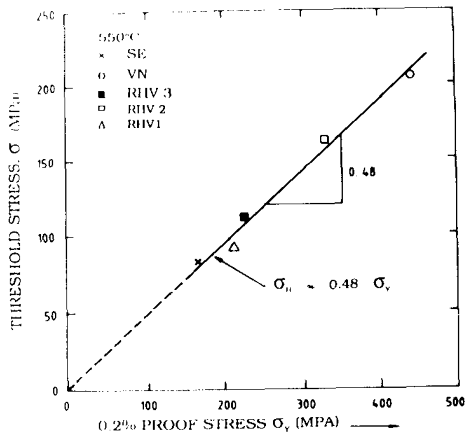

Fig.8 Threshold stress vs hot yield stress at 550°C.

Similar observation has been made in Ni-base superalloys[10] where $\sigma_H = 0.7\sigma_Y$; the authors[11] have also theoretically predicted the tensile Orowan stress and found that it is nearly equal to σ_H . This indicates that the threshold stress is nearly equal to the Orowan stress and scales with the hot yield strength. Also, it can decrease to a lower limit of about one-half of hot yield strength, as temperature increases and/or strain rate decreases[3,11].

Procedure for Creep Life Prediction

Based on the main findings as represented by equations (1) and (2) the following steps can be suggested for a rapid assessment of the remaining creep life of a component made of 1Cr-0.3Mo-0.25V steel and which is subjected to the usual service temperatures 550°C (barring accidental short term excursion to a higher temperature).

1. Determine the hot yield strength, σ_Y , at the service temperature and estimate σ_H from the relationship

$$\sigma_H = 0.48\sigma_Y$$

2. Determine $\dot{\varepsilon}_m$ at six stress levels, three of them between 0.4 to 0.5 times and the other three at 0.6, 0.7 and 0.8 times the hot yeild stress. The maximum duration of one such test is 1500 hours only.

3. Plot $(\dot{\varepsilon}_m)^{0.25}$ vs σ curve in a manner similar to that in Fig.5 and determine σ_H .

4. If σ_H is greater than the service stress, σ , calculate the residual life in terms of the time required to produce the balance amount of strain to make up the maximum permissible strain of 1%. The calculation uses the simple relationship :

$$(\dot{\varepsilon}_m)^{0.25} = 3 \times 10^{-4}\sigma \ .$$

5. If σ_H is less than the service stress, σ , retire and replace the component at the earliest.

At present, the total duration of creep testing using stress-rupture approach for creep life prediction is about 15,000h. This can reduce five fold if the new approach is used. Furthermore, if the equations (1) and (2) are fully established creep testing can be completely dispensed with.

Conclusion

A new approach for Creep Life Prediction based on a threshold stress concept is outlined. The approach appears very promising.

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Challenges of Clean Steel - An Opportunity for Steelmakers

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Abstract

The paper contends that steel with demands for closer 'purity limits, and 'custom-made' approach is a new generation advanced material. Challenges to steelmakers lie in producing them at competitive prices. Future course for steelmakers is to convert prospective threats from competing materials into a 'driving force' for changes in steelmaking and processing to meet such challenges. Role of secondary metallurgy and continuous casting to provide an integrated cost-optimised system for making high-grade clean steels have been highlighted. Facilities adopted at Tata Steel for production of value added speciality steels have been discussed.

THE HISTORY OF HUMAN DEVELOPMENT has a strong link with the evolution of the materials as is evident from the way the 'signposts' for the growth of civilisation have been identified in terms of different materials i.e. the stone age, the bronze age, the iron age and finally, the current multi-materials age. Of the various kinds of materials consumed by mankind, timber and cement have been the most common structural materials in the century[1,2]. Steel occupies the third place only, and may soon be overtaken by plastics (in terms of volume)[1,2]. The threat of competition to steel is not only from plastics but also from aluminium, titanium, ceramics, composites and many other newly emerging materials. Engineers and scientists today are looking for materials which can be tailored to very specific needs, and steel has to be able to hold its own in this arena of competing materials.

Luckily, steel has been a versatile material, proven through the ages, and can cover a wide range of properties as desired by users. In addition, its environmental acceptability and recyclability[3] ensure the use of steel as the base material for many technological and economic developments. Fig.1 illustrates the recycling rates of various materials which, to a large extent, determine the consumption growth of individual materials in the present day economy and in the environment conscious society, and in this respect, the edge of steel over other materials is obvious. There

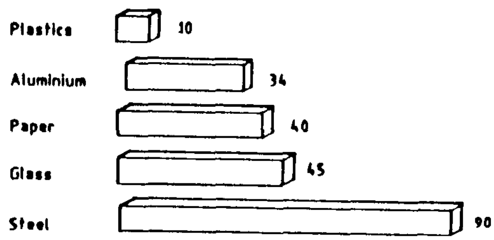

FIG.1: **PERCENTAGE RECYCLING RATES OF VARIOUS MATERIALS**

are other strong attributes of steel such as the availability of large scale manufacturing facilities all over the world, user familiarity of behaviour, etc. Therefore, the problem with steel is not so much of threat from other materials, but, the possible weaknesses from within, i.e.in making steels of superior quality, more versatile in application, and economical in ultimate cost analysis. Clean steel technology fills this bill of making steels more user specific and versatile; the challenge to steelmakers lies in producing them at low cost. The story of steels to be enacted in future is how to convert prospective threats from the competing materials into a driving force for changes in steelmaking and processing to meet such challenges.

Challenges of Clean Steel

The subject of what constitutes clean steel should be approached from the stand point of what satisfies the total requirements of customers. It may be with respect to micro-cleanlines, segregation, internal soundness, surface quality or any other physical - metallurgical demands such as temper embrittlement, hydrogen embrittlement, etc. In terms of steelmaking, this would mean:

1. Control of dissolved gases,
2. Control of sulphur and phosphorus,
3. Modifying inclusion characteristics like shape, size, distribution and composition.
4. Homogeneous chemistry within close ranges of composition, and
5. Control of residuals and their segregation.

During the last two decades, many options of clean steelmaking have been developed, starting from inert gas stirring to various types of vacuum degassing techniques, each having its relative advantages regarding different metallurgical functions to be performed. This is illustrated in Fig.2.

None :- -
Good :- •
Better :- x
Best :- •

Metallurgical functions	Strand Degassing	DH-Degassing	RH-Degassing	RH-OH-Degassing	Ladle-refining furnace Reheat and vacuum degassing	AOD	Argon bubbling CAS	Argon bubbling CAB	Lance-powder injection	Cored wire injection	REM-Canister
Composition control	•	x	x	x	•	•	x	x	•	x	
Temperature control	-	x	x	x	•	x	•	•	-	-	-
Deoxidation	•	x	x	x	•	x	•	x	x	x	•
Degassing	•	x	x	x	x	•	-	-	-	-	-
Decarburisation	•	x	x	•	x	•	-	-	-	-	-
Desulpharisation	-	-	-	-	•	x	-	x	•	•	•
Micro - cleanliness	•	x	x	x	•	•	•	x	x	x	•
Inclusion morphology	-	•	•	•	•	•	-	x	•	•	•

FIG.2: CAPABILITY OF SECONDARY STEELMAKING PROCESSES TO PERFORM METALLURGICAL FUNCTIONS

The fundamental objective for each of these processes is to produce clean steel for a specific purpose at the lowest cost.

Simultaneous with these developments, customers of clean steels are also steadily increasing their quality demands, the goal-posts tend to get narrowed down almost as soon as steelmakers begin to hit the target. This has forced the steelmakers to look continuously for process innovations and improvements to face the challenges. An example of future challenges is the projected purity limits in steel at 2000 AD, which will be[4]:

C : 6 ppm	N : 14 ppm
S : 1 "	O : 5 "
P : 8 "	H : 0.2 "

It is obvious that steel with such close purity limits would be a more advanced material with much better inherent properties than what has been possible so far. Therefore, many fundamental changes will have to be made in the production techniques to fulfil these expectations.

Simlarly, the demand is growing rapidly for steels with improved processability, superior service performance, higher strength to weight ratio, etc. In this pursuit of finding suitable steels for meeting complex needs, customers are sometimes asking for paradoxical quality requirements. For example, while sulphur is known to reduce toughness of steel, automobile industries are asking for forging quality steels with intentionally added sulphur for improved machinability[5,6]. This conflicting requirement would mean engineering the structure and morphology of inclusions to render them less harmful for end applications[5]. It is worth recalling in this context the famous quotation by Prof. Nutting[7] taken from an ancient Chinese adage that: "All elements have their 'Yin' and their 'Yang'". It is for us to find out which element is 'Yin' and which is 'Yang' for a specific application, and tailor the steel accordingly. The arena of clean steelmaking will, perhaps, see many developments of the kind based on 'Yin' and 'Yang' properties of individual elements in future.

Analysis of inclusion behaviour has revealed the overwhelming influence of inclusions in processing, machining, heat-treating, surface-engineering, as well as on the end-use properties like fatigue and fracture[6-8]. The influence of cleanliness of steel on some of these properties are shown in Figs.3-5[6,8,9].

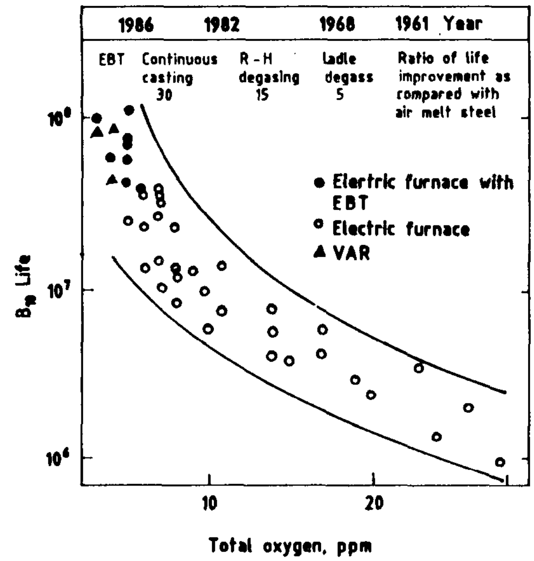

FIG. 3: RELATIONSHIP BETWEEN OXYGEN CONTENT AND ROLLING CONTACT FATIGUE LIFE OF BEARINGS

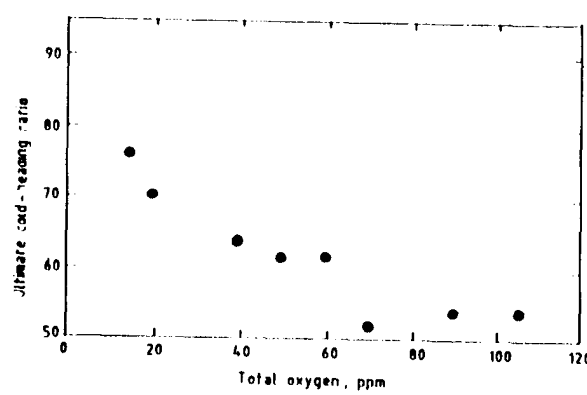

FIG.4: EFFECT OF OXYGEN CONTENT ON COLD HEADING RATIO IN CHQ STEEL

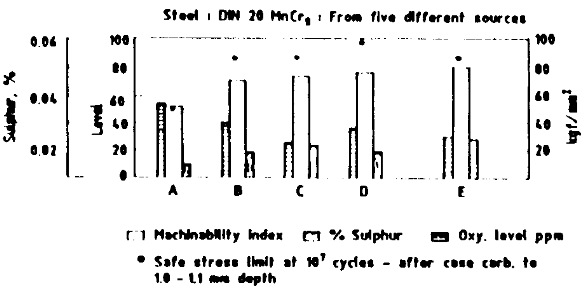

FIG. 5: MACHINABILITY (VOLVO-B TEST) & FATIGUE PROPERTIES OF A STEEL FROM DIFFERENT SOURCES WITH DIFFERENT SULPHUR AND OXYGEN CONTENTS

Therefore, customers in general and engineering industries in particular, are continously upgrading their quality demands to meet the growing pressure from cost and quality of end products. Table-1 shows the trends in quality demands of these industries.

TABLE-1 : PRESENT AND FUTURE QUALITY LEVELS OF CLEAN STEELS

Attributes	*Present level	Future trend
a) Analysis % Control : C	± 0.025	± 0.015 or better
Mn	± 0.05	± 0.03 or better
Si	± 0.03	± 0.02 or better
*1) S	0.025 max. for forging steels	0.020 max. or better (or controlled)
	For flats	0.010 *
P	0.025 max.	0.010 or better
Alloying elements Cr, Ni, etc.	± 0.05 max	± 0.03 or better
V, Mo, etc.	± 0.03 max.	± 0.01 or better
b) Residuals (total)	400 ppm max.	50 ppm max. + Total restriction of harmful elements.
c) Gases : Oxygen	15-30 ppm max.	7-10 ppm max.
Hydrogen	2-3 ppm max.	2 ppm max.
Nitrogen	70 ppm	40 ppm, except for some special application.
*2) d) Inclusion content	JK Chart Level 2 of ABCD type :	New JK Chart /Stahl-Eisen Prufblatt-1570/ New specially developed technique varying with end uses. Emphasis on size, distribution and composition.
e) Segregation	Low (Seg.ratio 1.1 - 1.2)	Free (Seg. ratio < 1.10)
f) Internal soundness	ASTM-E-381	Guaranteed macro and ultrasonicallytested to customers' standard (E-381) level C_1S_1R max.)
g) Surface quality	Free from harmful defects, visual inspection only.	Free from specific defects, tested by MPI/Eddy current to customers' standard.

* 1) Controlled S is in demand for machining grade steels. In future, part of S will be replaced by other elements, e.g. Bismuth, Tellurium, etc.

2) Inclusion assessment for higher grade clean steels will become a key problem. In future, new quantitative method and inclusion indexing system will emerge. It is evident that there cannot be one single scale of index for all end-uses; indexing will take into account specific relevance of individual applications.

Three specific areas of control for steelmakers are emerging from this trend:

a) Closer range of chemistry alongwith the control of residuals. This will ensure better processability in fast moving automated production lines, and also less variability in properties.

b) Least possible segregation and absence of harmful residuals (- like Sn, As, etc) along with the control of phosphorus. This will help in avoiding embrittlement of steel at various stages of processing and use.

c) Very good internal soundness and surface quality of steels.

These are, by and large, physical manifestations of the chemical processes that occur during steelmaking, and, therefore, the ultimate control lies in minimising segregation, level of dissolved gases and non-metallic inclusions.

The concept of clean steel may also differ from operation to operation (e.g. forging, wire drawing, cold-forming, etc.) and end-use to end-use (e.g. bearings, automobile components, fasteners, etc.). Therefore steelmaking routes and facilities have to have the capability to cater to the emerging trend of 'custom-made steels'.

Clean-Steel for Engineering Applications

Non-metallic inclusions in steel are the compounds of metals (- like iron, manganese, silicon, aluminium, etc.) with non-metals (- like oxygen, sulphur, phosphorus, nitrogen, hydrogen). Therefore, gases and inclusions in steel are often treated together for evaluating the impact of cleanliness on steel properties. It is in this respect that gases in steel, particularly oxygen, has received considerable attention from both users and steelmakers.

Presence of oxygen leads to the formation of different types of oxide inclusions. It has been reported[8] that the fatigue strength of steels not only depends on the type of oxide inclusions but also on the process of steelmaking. This is illustrated in Figs.6&7.

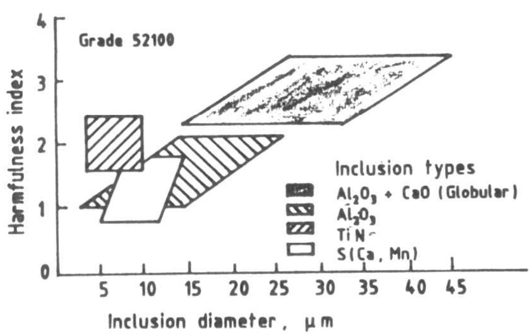

FIG.6: RELATIVE HARMFULNESS OF VARIOUS TYPES OF INCLUSIONS

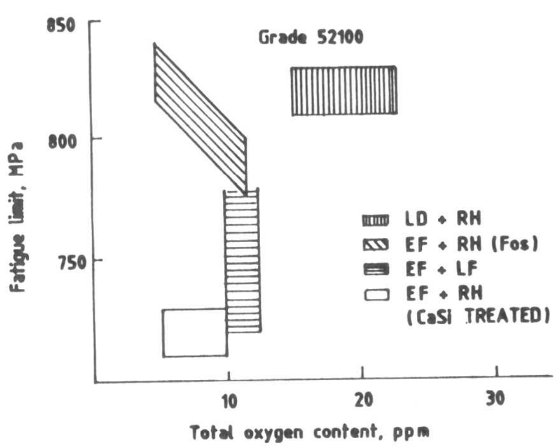

FIG. 7: RELATION BETWEEN ROTATING BENDING FATIGUE LIMIT AND TOTAL OXYGEN CONTENT FOR SEVERAL STEELMAKING PROCESSES

It is possible that different steelmaking processes produce inclusion families which are different in chemical nature and size distribution, and, therefore, cause these variations. These observations make it singularly important to understand customer requirements correctly and only thereafter, choose the steelmaking route.

To standardise the steelmaking process and to consistently produce tailor-made clean steels; there is an urgent need for developing a quick quantitative technique which can assess and characterise the total inclusion population completely and reliably[8,10]. It is feared that with an increase in the quality levels of clean steels, assessment of cleanliness will become a key problem[10]. From the present understanding, there is no one unified scale to express the cleanliness index of steels suitable for different end-uses. An inclusion indexing method will have to correctly reflect the relevance of specific applications i.e.it should be able to differentiate between the requirements for 'rolling bearing contact fatigue', 'bending fatigue', 'impact toughness', 'cryogenic applications', etc.

A quick quantitative technique for total assessment of inclusions could have helped in fine-tuning the steelmaking process. In its absence, steelmakers presently depend on indirect measurements through control of oxygen, hydrogen, nitrogen, sulphur, phosphorus, etc. during heat-making. Therefore for better control and consistency, steelmakers are relying more and more on various secondary vacuum metallurgy processes and on tracking oxygen through-out the process route during steelmaking. At Tata Steel in India; capability for making this new generation of clean steel is being developed through continuous modernisation of plants and processes.

Production Routes of Clean Steel

In terms of operating metallurgical principles, the basic tasks to be performed in steelmaking are: decarburizing, homogenising, degassing, alloying, deoxidising, and controlling slag-metal reactions with measures for complete separation and floatation of reaction products. Towards this end, secondary metallurgy has proven to be very effective and has been adopted, in one form or the other, in most steel plants all over the world. Secondary metallurgy in combination with continuous casting has become a global phenomena as an integrated, cost optimised system for making high grade clean steels.

The relative efficiencies of secondary metallurgy processes in performing different metallurgical tasks has been shown in Fig.2. Nonetheless, many more innovative measures are being added frequently to the existing system of steelmaking (e.g. slag stopper, combined blowing, lance injection, etc.) for improving the efficiency of the proceses. While slag control at tap and during teeming is now acknowledged to be crucial for predictable production of clean steels, considerable attention is also being paid to teeming and casting through measures such as use of inert-gas shrouds, sub-merged nozzles, dams and weirs in the tundish, argon flushing of nozzle stopper rods, etc.

The techniques for pretreatment of hot metal are now well established and this has opened the door for further optimisation of hot metal quality and cost[11]. For example, a typical practice is to selectively desulphurise iron in the transfer ladle from sulphur levels of about 0.045 - 0.055% down to about 50ppm or even lower. In the steelmaking area, the advent of combined blowing has made it possible to reach appreciably low tap carbon with low iron losses in the slag. In such practices the steel in the converter can be made to contain low concentrations of C, P, S, O and N just prior to tapping, thereby providing an appropriate starting material for producing sophisticated grades of steels via ladle treatments and continuous casting.

Continuous casting alongwith various refinements introduced in the last few years has contributed not only to economic steelmaking but also to steel quality improvements in terms of chemical homogeneity, surface quality and cleanliness. This is evident from Fig.8 which shows the number and distribution of non-metallic inclusions in slabs of identical dimensions produced by ingot casting and by continuous casting. Refinements in the latter technology, such as the use of submerged nozzle, nozzle flushing with inert gas, use of large tundishes, tundish with plasma heating and inert-gas bubbling, non-sinusoidal mould oscillation, air-mist cooling in the secondary zone, split-roll for control of bulging and segregation, etc., have added strength to steel technology for future growth. In ingot teeming also, improvements such as argon flushing of the moulds alongwith inert gas shrouding of the ladle trumpet streams have resulted in considerable enhancement of cleanliness. It is therefore

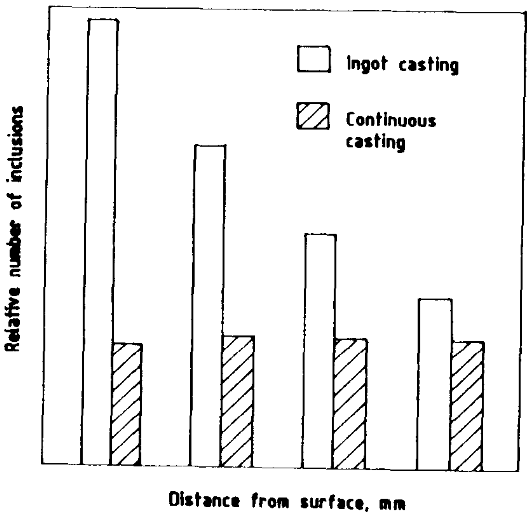

FIG. 8 : NUMBER AND DISTRIBUTION OF NON-METALLIC INCLUSIONS IN SLABS OF IDENTICAL DIMENSIONS MADE THROUGH THE CONTINUOUS CASTING AND INGOT ROUTES

obvious that the drive for making clean steels has brought about many innovations in steelmaking technology and offered fresh opportunities for rejuvenating the industry.

Existing Facilities and Future Programmes at Tata Steel

Tata Steel is an eighty year old steel plant in India, producing a wide variety of steels ranging from plain carbon commercial grades to very sophisticated steels for bearings, crankshafts, cold-heading applications, extra deep drawing grades, etc. As part of continuous modernisation, one of the old Steel Melting Shops was replaced by a L D Shop with 130 t vessels. Important facilities in this shop include bath agitation, computerised process control systems, argon rinsing stations, slag stoppers, bottom pouring, continuous casting and modern analytical equipment. The Shop was also provided with a comprehensive secondary metallurgy unit in the form of a 130 t VAD which was one of two largest units of its kind in the world at the time of installation. The technical specification of the VAD unit is given in Table-2.

TABLE-2 : TECHNICAL SPECIFICATION OF THE VAD UNIT AT TATA STEEL

1.	Type of plant	: Ladle degassing with vacuum arc heating, FINKL system, for the vacuum treatment of molten steel in the ladle.
2.	Heat size	: 130 t normal 140 t max.
3.	Type of pump	: Six stage steam jet vacuum pump. MESSO type, with one starting ejector and one heating ejector.
4.	Steam pressure at manifold at nozzles	: 8.5 kg/cm^2 .g (+0.5 kg/cm^2, -0 kg/cm^2) 8 kg/cm^2 (minimum)
5.	Maximum steam flow rate (stage 1 to 6)	: 12,800 kg/m
6.	Argon pressure at manifold	: 9 kg/cm^2 .g
7.	Flow rate	: Average 50 NL/min Maximum 150 NL/min
8.	Degree of purity	: 98%
9.	Transformer capacity	: 15 MVA (20% overload for 2 h)
10.	Heating rate	: The average heating-up rate will be 3°/min, upon equalisation of temperature in the ladle. The equilisation temperature in the ladle will depend on different conditions and is reached in about 20 min heating.
11.	Pump down time	: The pressure of 1 torr achieved in 8 minutes.

This unit has been successfully adopted from the very beginning for production of manycritical grades of steels and has become the focal point of clean steel technology at Tata Steel. Some of the important grades being produced now through this route are given in Table-3.

TABLE-3 : IMPORTANT GRADES OF STEEL BEING MADE AT TATA STEEL

* Bearing Steels with controlled oxygen.
* Case carburizing steels with controlled oxygen and sulphur for automobile industries.
* Crankshaft quality steels with stringent micro-and macro-inclusion levels.
* Axle Blooms for Railways and Earthmoving equipment with low hydrogen guarantee.
* Seamless gothics with low sulphur and restricted residuals.
* High forming E-34/E-38 HSLA micro-alloyed steel for Long and Cross members for heavy duty automobiles.
* DD/EDD steel for Strips.
* Cr-V and Cr-Mo grade forging steels.
* Cold Heading Quality fastener steels, etc.

These steels have found wide acceptance from a variety of discerning customers such as automobile industries, bearing industries, forging industries, seamless tube makers, etc. Steel with 2ppm max. hydrogen, 15ppm max. oxygen and extremely low residuals are being successfully made in regular runs.

Growing demand for clean steels in India has acted as a driving force for Tata Steel to enhance its capability and to plan for facility upgradation and quality improvement on time-bound programmes. The Company has been continuously modernising its plants and processes over the last ten years and, is presently in the midst of the third phase of modernisation programme. The major facilities being added are:

- *A new LD-Shop with two converters of 130t capacity, complete with ladle furnace, a RH-type degasser and fully automated process control system.
- *Up stream facilities for hot metal desiliconisation and desulphurisation.
- *Two single strand slab casters incorporating advanced features for production of high integrity slabs suitable for direct hot-charging.
- *1 mtpa hot strip mill for production of hot rolled strips and light plates in thickness of 1.6 - 12 mm and width 800 - 1550mm.
- *Advanced computerised process automation architecture all through the process route.

The entire liquid steel tonnage of 1.1 mtpa produced in the new LD-Shop will be continuously cast into slabs of critical grades of steels. Some of these grades are mentioned in Table-4.

TABLE-4 : BROAD CLASSIFICATION OF THE PRODUCT MIX FOR THE HOT STRIP MILL AT TATA STEEL

Classification	Grade
Ordinary	Mild steel plates, deep drawing strips, strips for commercial tube, LPG strips and Corten plates.
Special	Medium and high carbon strips, HSLA strips for long and cross members for commercial vehicles, microalloyed plates with guaranteed toughness, API grade pipe line steel.
Very special	Extra deep drawing, TMBP, special light plates, CRNO.

On completion of the present modernisation programme, there will be an increase in saleable steel capacity at Tata Steel from 2.0 to 3.0 mtpa and perhaps even further in later years.

With the existing facilities, Tata Steel is producing nearly 48% of its saleable steel in special steel grades. On completion of the on-going modernisation, the capacity for making special steel grades will be increased to about 70% of the enhanced production. It is, however, not the quantity alone, the emphasis at Tata Steel is on higher grade steels with superior quality for domestic as well as global supply. The opportunities created by the universal demand for value added steels have acted as a 'change-agent' at Tata Steel for modernisation and rejuvenation of the plant.

Conclusions

It can be stated that the competition from new materials to steel has been a boon to the steel industry rather than a threat. The competitive situation in the materials world has forced steelmakers to identify their weaknesses and come out with major innovations in processes. Development of many efficient auxiliary facilities coupled with the advent of state of the art continuous casting technology, have given the steel industry the much needed confidence and capability to meet the growing challenges of producing clean, superior grade 'custom-made' steels in an economical way.

It is very likely that the marked change in the quality of steel required by today's customers will continue through the nineties and many new quality targets will come up. Steelmakers all over the world, including Tata Steel in India, are alive to this situation, and they are confident of facing this challenge.

Acknowledgement

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Additional Paper

Proceedings of the Applications of the Latest Technological Innovations and Processes for the Production of Iron, Steel, and High Quality Product-Mix Conference, Materials Week, Chicago, Illinois, USA, 2-5 November 1992

High Speed PTA Co-Deposition of Cobalt-Chromium Powders to Form Super Alloy Deposits

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Abstract : Special Alloy Steels and especially superalloys have carved a niche for themselves in the ever-widening armoury of the design engineer for tackling more and more complex needs of the processing industry. Superalloys per se, have still not shed their exotic garbs to mingle with the workhorses -the steels. Steep prices of nickel, chromium and cobalt have also confined the superalloys based on these metals to somewhat esoteric domains. Therefore more practical means of turning ordinary steels into materials with higher capabilities are need. PTA (Plasma Transferred Arc) Deposition is one such technique which provides the user with limitless freedom to apply high performance metallic claddings onto other metals/ alloys.

One of the most attractive features of this simple technique is the fact availability of the cladding material may not restrict the usage. One can synthesize the superalloy in the plasma arc itself, simply by feeding two separate powders with carrier gas lines or by premixing the powders beforehand. Specifically alloyed powders or wires may be available with difficulty, but elemental powders are available everywhere with good purity levels and at reasonable prices.

This paper looks at the feasibility of applying high performance superalloy claddings onto ordinary mild steel substrates using a low power PTA cladding systems featuring a low velocity plasma arc with a multiple powder feeding system. It discusses briefly the equipment, plasma parameters, powders and other relevant details of processing. It examines the deposits visually, provides detailed information on physical properties of the deposits and discusses the results of some of the standard tests used for determining the feasibility of application of such synthesized deposits for industrial use. It provides reference to similar work done by other researchers and comments upon developing new and gainful applications in a variety of industries.

Introduction : PTA deposition technique was chosen for this application because:-

- ease : the process is simple and does not require any elaborate skills not a high degree of automation for producing quality deposits.

- quality : deposits usually feature very good integrity, a low degree of dilution with the substrate and almost total freedom from depletion, segregation, transmigration etc which are common with other electric arc processes such as SMAW or MMAW, GTAW, FCAW or GMAW.

- speed : high rate of deposition is an intrinsic quality.

- freedom : in-situ alloying is possible with PTA deposition, which offers a high degree of freedom to the user, to overcome the fluctuating availability of special alloys and other special materials. Powders and wires both can be used as the deposit material, hence there is greater freedom in use.

Cobalt-Chromium alloys have been used increasingly in the recent years for applications calling for a combination of physical properties such as wear resistance, heat resistance, rigidity and ability to maintain the imparted shape and corrosion resistance against some specific fluids etc.

Since cobalt and chromium both are scarce and their pricing generally high as compared to other industrial metals, producing entire castings from such alloys proves to be rather a costly proposition. Ordinary steel castings when cladded with such expensive and oxidation-prone materials presents several difficulties. Conventional techniques for cladding such as gas welding with filler rods or SMAW using filler rods or wires do not guarantee against oxidation and subsequent loss of material.

PTA deposition with its elaborate inert-gas shielding arrangement ensures total protection against oxidation, and also rules out wastage of the deposit material by way of unused stubs or filler rods or wires etc. Since the deposition process is generally very stable and smooth, there is no possibility of material loss by spatter or incomplete melting etc. Therefore PTA cladding produces the required deposit characteristics reliably with repetibility.

Equipment : A low power PTA deposition system of plasmatherm make was employed for the experiment, the equipment rating was 10 KW. It comprised a DC Power Source with a rating of 160 volts dc open circuit voltage and an arc voltage range of 20 to 30 volts as per the load, a minimum arc current of 5.0 ampere dc, and a maximum arc current of 350 amperes dc at 30 volts; a PTA deposition gun with watercooled design and separate gas supplies for plasmagen, shield gas and carrier gas facility, a compact water recirculator supplying about 10 litres of water, a high precision fluidized bed type powder feeder of dual design, and other accessories.

Figure : 1

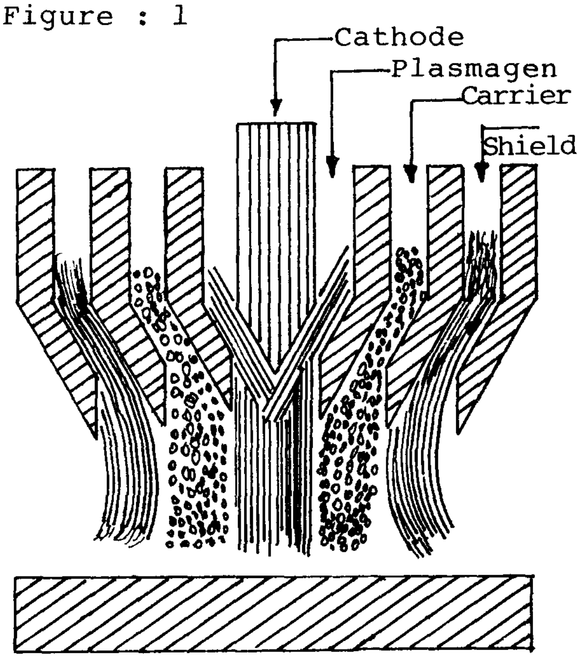

Figure : 1 illustrates the PTA gun design showing different gas supplies.

As shown in figure:1 the inner gas column is purely the plasmagen or the plasma forming gas, surrounded by another inert gas column which is the carrier gas feeding powder into the arc, in turn surrounded by shield gas. The arrangement ensures perfectly well-adjusted gas flows signifying total absence of turbulence which also implies better deposit production.

Experiment : The plasma parameters used for co-deposition were as listed in Table : 1.

Table : 1 Plasma Parameters

Arc Current (Amps)	Arc Voltage (Voltage)	Plasmagen Pressure P.S.I.	Plasmagen Flow Cu.Ft/Hr	Shield Flow Cu.Ft/Hr	Carrier Flow Cu.Ft/Hr
1. 45-48	22-24	20	4.0	2.0	3.8
2. 65-72	24-26	20	4.0	2.2	4.1
3. 68-74	24-26	20	4.2	2.2	4.1

Note : Plasmagen - Argon
Carrier Gas - Argon
Shield Gas - Argon

As shown in table:1 various samples were made with different plasma parameters, but only one was selected for the further study, since the other two deposited with higher arc currents produced some defects discussed later.

The powder flow of chromium and cobalt was also changed so as to provide varying ratios of the elements i.e. 50-50, 70-30 and 80-20 percentage by volume of cobalt and chromium respectively. However considering the cobalt powder was fine (about 400 mesh) as compared to slightly coarser commercial chromium powder (about 350 mesh), only the 50-50 ratio seemed to work well, as lower amounts of the fine cobalt powder resulted in excessive amounts of chromium. Under such conditions it was felt that the final percentage of cobalt in the co-deposited blend would be too lean. Hence the leaner samples were also discarded.

Figure : 2

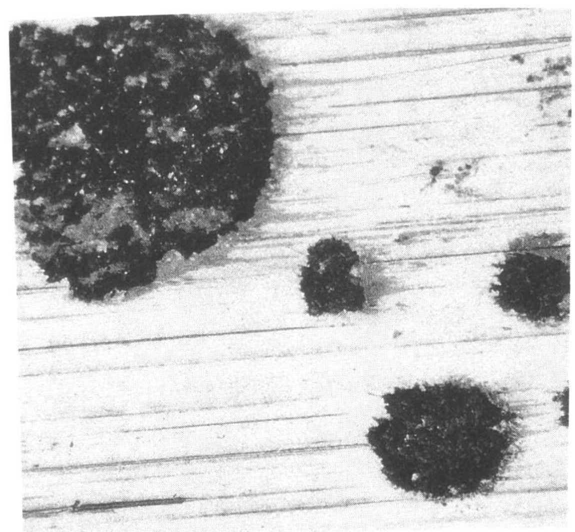

Figure :2 Micrograph of Cobalt-Chromium Deposit.

Results & Discussion :
As shown in figure:3, a photograph of the cobalt-chromium deposit the general appearance provides an idea about the integrity and cohesive nature of deposition. Microcracks, and inclusions especially

the oxides and other such chemical contaminations are absent. The overall proportion of cobalt appears to be on the lower side as compared to chromium- but that could be due to the apparent difference in powder particle size, and also the difference in their values of specific gravity. Perhaps using a coarser cobalt powder may help.

Figure : 3

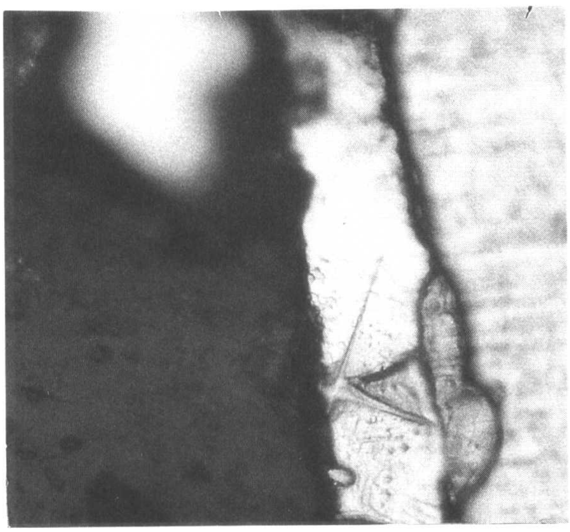

Figure : 3 Micrograph of the deposit at higher magnification (750X).

The mechanical tests like hardness, rigidity at elevated temperatures etc were also measured and found to be good. In conclusion, it appears that PTA deposited Co-Cr superalloy cladding is a highly desirable route to producing excellent materials at low costs. There are innumerable applications for such cladded components in automotive industries for instance a variety of valves which work under high temperature, high impact, high frequency of cyclic loading, thermal cycling, thermal shock etc. Similar applications also exist in ceramic industries, other chemical processing industries where rigidity at high temperature as well retention shape (for instance knife edge) is essential for adequate productivity without too many interruptions and hold -ups.

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