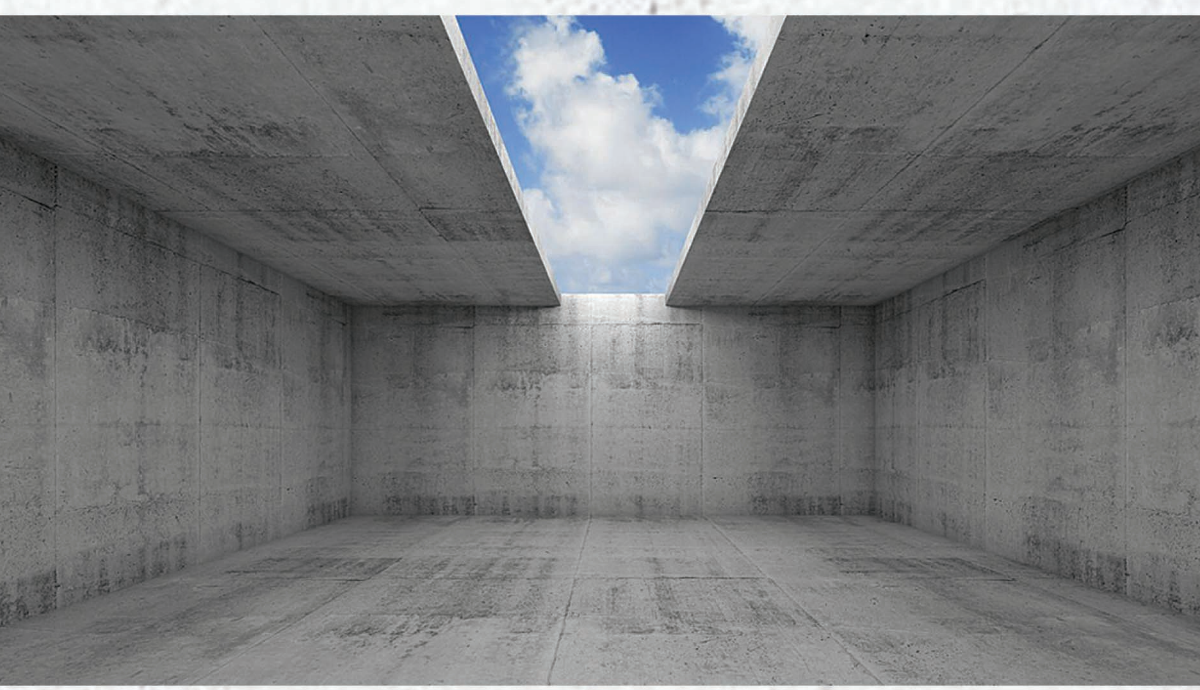
N. V. NAYAK • M. P. MOKAL

HANDBOOK ON QUALITY AND PRODUCTIVITY IMPROVEMENT OF CONCRETE



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HANDBOOK ON QUALITY AND PRODUCTIVITY IMPROVEMENT OF CONCRETE

N. V. Nayak
Manish P. Mokal

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Dedicated to

Mrs. Suman Nayak wife of Dr. N. V. Nayak

&

Mr. Prabhakar Mokal father of Mr. Manish Mokal

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FOREWORD

Quality concrete is always the part of any construction since our profession is integral part of the final product that we deliver to the public. Since the finished structures last for a longtime, they become our life's contribution to the society. Yet as pointed out in the beginning of the book, the quality and productivity of concrete have been scattered and not dealt separately. The importance of the topic is hardly to emphasized as is done through this important contribution for the first time in the literature.

Indeed, this is very important for the reader to understand and remember while following this book over all the contributing chapters. The value of the book is mainly in delivering the important items related to production of quality concrete in all chapters in a logical, systematic and realistic sequence, which must be noted. As mentioned in the preface and the first chapter to introduce the important information that follows, it is probably the first attempt in the literature to bring out the quality and productivity under one book by covering all of them in a logical and sequential fashion. Thus, this book may prove to be a valuable gift to readers, either as student or young professional and experienced engineers.

The emphasis on "practical guidelines" from the authors' own experience is even more important to note and will be useful for the reader. Often, such books are contributions of various individuals with expertise in their own way and that is where this book is considered a valuable contribution for the literature on concrete. The authors also have considered "sustainability" issue in this book and younger readers should certainly make a note. As critical as it has been an issue in concrete construction always, it has caught attention of our profession and is very critical to note. It is my sincere hope that authors would consider such issue in the near future to reflect their forward thinking.

Finally, the value of this book will be enhanced to make it user-friendly to students (and future engineers) by adding exercise, problems and project exercises, which they have witnessed in their rich career and observed and acted to come up with the best solutions (but not unique). This will make the students think of alternate solutions with their own young mind, but with a fresh look at the problem of quality concrete at large.

I congratulate the authors for such a useful and obviously timely contribution to the professionals and students (at all levels) alike.

Gajanan M. Sabnis

Distinguished Member, ASCE
Prof. Emeritus, Howard University
Washington, DC

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PREFACE

Although the topic of Quality and Productivity has been part of many books on concrete, this is the first to cover guidelines for improvement both in quality and productivity. There are many publications on quality improvement of concrete, but very limited publications on productivity improvement of concrete at batching plant and probably no book on the same subject.

Many simple and practical innovations, have been presented which the authors have implemented on many of their projects to significantly improve the quality of concrete as well as productivity of concrete at the batching plant.

Such innovations have been fully illustrated practically in all chapters on the understanding that professionals in practice will adopt them and the professionals in academia will educate their students of such innovations and stimulate their minds for many more such innovations.

Innovations themselves serve no benefit unless they are implemented in practice. Unfortunately implementation on field takes long time in India compared to countries like USA, China, U.K., Canada, Japan, etc. It is partly because of our mind set, partly because of resistance from the concerned authorities for the change from the earlier adopted practices.

Of the 12 chapters, the first chapter highlights the significance of quality and productivity of concrete and the overview of later chapters.

Chapter 2 deals with the cement and their types. This chapter clearly brings out need for the use of blended cement rather than OPC in production of concrete. It also stresses on production of blended cement concrete at site in computerized batching plant rather than pre-blending at manufacturers end. Pre-blended cements generally have less supplementary cementitious materials (SCM) than permitted by National standards. Further, full economical benefit is taken by the cement manufacturers. When blending is done at site, the economical benefits also get transferred to clients. SCMs generally help in producing more sustainable, durable and economical concrete. Chapter also highlights innovative method of opening cement bags on "hopper platform" thereby reducing the wastage of cement greatly and maintaining high quality of concrete.

Chapter 3 deals with water. It highlights how low water binder ratio helps in obtaining high strength and highly impermeable concrete. In this chapter, a simple innovation is illustrated which is highly effective in ensuring w/b ratio of concrete in Transit Mixtures (TM) does not change by entry of rain water in TM during rains. Authors are very confident that this innovation will be adopted rapidly in India and abroad.

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Chapter 4 deals with air content in concrete in greater details than majority of Indian books on concrete. It highlights the benefits of entrained air and disadvantages of entrapped air in detail. It also provides guidelines in getting close to desired entrained air content in Concrete.

Chapter 5 highlights the merits of Supplementary Cementitious Materials in producing sustainable, durable and economical concrete. Further, authors recommend strongly blended cement concrete for all structures including super structures except for some special cases. In this chapter authors have described Indian Innovations in developing and manufacturing ultrafine secondary cementing materials like ultrafine slag (UFS – commercially known as Alccofine) and Ultrafine Fly Ash (UFFA). The authors also discuss that these products, UFS & UFFA, are at par to performance of micro-silica (MS) with no disadvantages of MS and also more economical. Authors have presented path breaking innovation in this chapter which has beneficial effect in resisting attack on concrete placed in industrial waste area. This innovation indicates that in industrially polluted area, one should use blended cement content blended with permissible high percentages of GGBS. Blending with fly ash or using OPC alone are not effective. Based on limited R&D literature available, authors feel that for blended cement concrete the test “NT Build 492” may be more suitable than RCPT to determine permeability of hardened blended cement concrete.

Chapter 6 deals with aggregates, fine and coarse. With availability of natural sand getting scarce, by increasing banning of dredging by various states and central agencies, authors have given adequate guidelines for the use of manufactured sands, industrial waste like copper waste and iron slag, etc. as sand.

Authors also, with an eye on the diminishing resources of natural sand are advocating use of construction and demolition (C&D) waste and use of recycled concrete aggregates for concrete production. Authors have cited Indian Codal and developed countries standards provision with the hope that it will change the mindset of Indian authorities and practioners.

In chapter 7, chemical admixtures are dealt in details describing various types of chemical admixtures, their merits and demerits, etc. The need to select robust and compatible admixture for cement type selected has been highlighted. For long lead of TM with concrete, authors have given guidelines for split dozing. Since corrosion of steel is the main cause for distress/failure of many structures particularly in marine environment, corrosion inhibiting admixtures have also been described in this chapter. This chapter rightly highlights best practices to be adopted for storage of chemical admixtures drum and/or preventing entry of dust, cement particles etc. into the opened admixture drum in use at the batching plant, by simple technique. The chemical admixtures (plasticizers) are invariably supplied in liquid form. They contain around 60% water. This water content is generally neglected while designing concrete mix proportioning. Authors in this chapter rightly advocate accounting this admixture water content in mix proportioning at least, to begin with, for high performance concrete.

Chapter 8 deals with concrete temperature. Its significance in mass concrete is highlighted. The need to limit core temperature to 70˚C and maintaining temperature difference between core and outer surface within 20˚C has been stressed. The benefits

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of supplementary cementitious materials mainly fly ash and GGBS and also provision of larger size aggregate as MSA in reducing concrete temperature has been clearly brought out in this chapter. Further typical calculations for chilling plant capacity to meet the placement temperature have been provided as illustration. In addition, insulating the concrete surface by thermocol, thick plastic sheets or keeping wooden shuttering in place to control the temperature difference between core and outer surface has been recommended.

In chapter 9, very useful guidelines have been provided to substantially improve the quality and productivity of concrete at the batching plant. An appropriate layout at the batching plant with adequate protection of aggregates from rain water, dust, etc. help in producing improved quality of concrete with higher productivity.

Very simple innovations such as provision of markers at the batching plant, extended hopper of transit mixer and higher capacity screw conveyors help in doubling the production of concrete at the batching plant practically to rated capacity. This generally results in doubling productivity of batching plant. If the productivity of all the RMC batching plants globally increases by 10%, one can project that the cost benefit will be of the order of Rs. 24,000 millions annually.

Chapter 10 provides guidelines for transportation, placement and compaction of concrete to provide dense, compact concrete with no segregation or honey combing. Since majority of concrete, now a days is transported and placed by concrete pumps, the same is covered in depth. Further, a detailed chart for “troubleshooting for quality issues” is provided for quick solution of problem encountered.

Considering the importance of curing on strength and durability of concrete and realizing that curing is greatly neglected in Indian practices, a separate chapter on curing has been provided in this book. Since water curing (external) is most ideal and at the same time it is very scarce, innovative methods have been illustrated for 24x7 curing for required duration of 14 days with negligible wastage of water. In certain areas, when availability of suitable water for curing may be scarce, it will be prudent to use “internal curing” as suggested in this chapter. Such internal curing will eliminate the possibility of damage to concrete resulting from inadequate external curing.

In the concluding chapter 12, other issues which affect the quality of concrete are presented. The proper quality cover blocks and cover as per design which are very often neglected greatly help in improved quality of concrete. Cover needs to be specified in the design to combat corrosion due to chloride and carbonation, etc. thus keeping the cost to the optimum. Good quality formwork enhances greatly to provide good quality concrete as described in detail. This chapter also presents the checklist to help beginners in proper preparation, installation and removal of formwork. The advantages of controlled permeability formwork (CPF) are highlighted. Chapter also includes simple innovations for casting concrete cubes without broken edges and with minimum air voids although it is unfortunate such practices are rarely followed in India. This chapter also recommends slowly moving to the use of “performance specifications “from the present “prescriptive specifications”.

As noted earlier, it is the first Indian “Handbook on Improving quality and productivity of the concrete”. Some readers may find some limitations in the presentation. Some of the limitations may result from the limited literature survey

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(to overcome this, a list of references has been provided at the end of each chapter) in limited time and space available, some other limitations may result from the fact that some part of the subject matter may be over or under-stressed for some of the readers as presentation is clearly affected by personal views, judgment and experience of the authors. The constructive suggestions will be welcome and duly considered during the future revisions.

March 6, 2018

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To bring out this book, authors have liberally used various publications including articles, journals, books, etc. Every attempt is made to acknowledge the same in the text in appropriate places. If anything is left out, it is inadvertent and we apologize for the same. We thank the authors and publishers of such publications mentioned herein or otherwise.

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The “Handbook on Quality and Productivity Improvement of Concrete“ would not have seen the light of the day without the active support of Narosa Publishing House Pvt. Ltd. The Publishers have reposed their full confidence in the subject as well as the contents of the book. The authors wish to put on record their appreciation in bringing the book in the present format.

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CHAPTER 1

QUALITY AND PRODUCTIVITY OF CONCRETE - THEIR SIGNIFICANCE

1.1 Introduction

Most concrete professionals are aware that concrete quality depends on the quality of the materials used, manufacturing, transporting, placing, compacting and testing. Generally, checking the raw materials at regular frequency, calibration of batching plant, checking grading and moisture of aggregate, maintaining required workability of concrete, casting samples and testing them are considered as good quality control practices. Majority of concrete manufacturers follow these quality control measures in an effort to maintain quality of concrete. But simply following the age-old quality measures is not enough in today's ever demanding concrete industry [1].

The concrete industry today has matured from just looking at concrete strength as the acceptance criteria to demanding many more parameters with strength being one of them. The workability, retention, pumpability criteria has changed significantly which requires much more than just checking the grading and moisture of aggregate. Durability has become an important parameter to be fulfilled for accepting concrete which requires more understanding and control over various properties of raw material and mix design.

The subject of quality control has therefore to be studied in greater depth by understanding the significance of change in properties of each material, their interaction and the desired outcome.

In this book, we are also discussing how to increase productivity of concrete at the batching plant. Even for normal concrete say M30, majority are happy if they achieve productivity of say 50% of the rated capacity. In this book, guidelines have been provided how to increase the productivity of batching plant close to the rated capacity.

1.2 Quality and Productivity of Concrete – Definition

Quality of concrete can be defined as concrete which consistently satisfies all the required parameters – fresh and hardened properties, as required. The quality of concrete acceptance is not limited to the passing of samples tested for various parameters, but also includes the health of concrete structure, wherein the presence of cracks, honeycombing, voids, improper curing indicates that the quality of concrete is not satisfactory. Durability of concrete during the service life is also an important

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measure of quality control. Hence concrete mix design, transportation, placement, curing, etc. need to be suitably designed and executed. The quality control measures planned and executed must include all parameters right from raw material to finished product.

Productivity of concrete is not limited to only production of concrete in the batching plant but includes ability to transport, place and compact the required quantity of concrete as per the project plan. The entire infrastructure for each activity must be planned to collectively produce the quantity of concrete required. The Quality engineer must account for the broader picture of quality and productivity of concrete.

Quality of fresh concrete can best be assessed by determining the S**tandard Deviation (SD)**. If one can get the standard deviation reduced from say 5 MPa to 2 MPa at the specified age (usually 28 days), it is very good improvement in quality of concrete. By following guidelines given in this handbook it should be possible to achieve such a result. Authors have achieved such results on some of the projects and for majority of projects; they could get standard deviation of close to 3 MPa. Even they could achieve standard deviation close to 1 MPa with captive batching plant and lead of transporting concrete from batching plant to location limited to 300 metres. This is an excellent improvement.

However, assessment of long term performance/durability improvement of concrete in structures is much more difficult. Many more factors such as environment, misuse of structures, failure to carry routine maintenance etc. effect the durability of concrete in structures. No single parameter like standard deviation has been arrived yet.

But by following the guidelines given in this book, one can achieve significant long-term improvement in quality of concrete in structures.

1.3 Assessment of Quality Control at Site

The assessment of quality control at site can be done by monitoring the following:

1. Amount of rejected concrete (as a percent of the concrete produced) for noncompliance with project specifications such as slump, air content, density, and temperature, where applicable
2. Cost to repair, replace, or mitigate hardened concrete issues (cores, etc.) because concrete did not meet specification or performance requirements.
3. Number of quality-related non-conformities including variability in compressive strength as measured by standard deviation
4. Perception of company's quality by customer through an annual customer survey (ranking as Excellent, Very Good, Good, Fair, and Poor)

The first two measures are fairly obvious. Rejected concrete, is a direct loss of money and man hours to the project. Costs to repair hardened concrete can involve core tests, evaluating defects, and so forth, and can become very expensive and time consuming for repair including methodology to be adopted for repair or concrete to be dismantled. The third measure is easy to track, and the idea behind it is that every non-conformity

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raised involves a cost and time to address it, even if it does not lead to the cost as much as that can be tracked for the first two measures [1].

The standard deviation (SD) is a direct indicator of the consistency with which concrete is produced at batching plant and transported to placement location. Lower standard deviation of concrete means that the controls exercised during incoming raw material inspections, concrete production, transportation, sampling and testing are better. That itself eliminates a major part of non-conformity issues.

The degree of quality control of fresh concrete as per authors can be classified based on standard deviation as given in Table 1.1. This is applicable for concrete strength up to 50 MPa.

Table 1.1 Degree of Quality Control of Concrete Vs Standard Deviation

Quality Control Classification	**Out-standing**	**Excellent**	**Very Good**	**Good**	**Fair**	**Poor**	**Extremely poor**
Standard Deviation (MPa)	≤ 1.5	1.5 to 2.5	2.3 to 3.5	3.5 to 4.0	4.0 to 6.0	6.0 to 7.0	≥ 8.0

Note: This is slightly modified and extended format that is given in ACI 214R-11 [2].

Acceptance criteria of concrete in the field as per IS 456 is (f_{ck}+3) or (f_{ck}+0.825×SD).

f_{ck} = characteristic strength in MPa

SD = standard deviation in MPa as achieved in the field testing

Thus, lower the SD, better is the quality control exercised at site. It also allows the QC Engineer to optimize the cement content as the target strength also reduces with lower SD.

The last measure, which is the perception of a company's quality in the eyes of the customer, is very important and should be monitored annually. Typically, if customers believe that they will get a quality product with few worries, they may pay more for it. The owner, engineer, and architect are more willing to trust and even to take the advice of the contractor when problems do occur. They may even consult and seek the help of the contractor on matters of specifications and desired concrete performance. The bottom line is a happier, satisfied customer, which will inevitably lead to more business and a higher profit.

Unfortunately, there is no standard method accepted and utilized in India. It is just a perception. Bigger size company with high revenue is considered **good in quality**. The Ready-Mix Concrete Association of India has made an attempt to rate concrete manufactured by different ready mix concrete producers but unfortunately as per the authors it is far from satisfactory.

1.4 Current State of Affairs Regarding Quality

Broadly the concrete quality can be categorized in two parts:

- Quality of concrete produced
- Quality of concrete in structures

The good quality concrete produced in the batching plant can end up as a bad product if placing, compaction and curing are not done properly. It is important to identify the key points for both the categories in order to achieve a good quality product.

In the first category, the key parameters are:

- Inspection of incoming raw materials
- Proper storage and handling of raw materials
- Grading and moisture correction before start of concrete
- Concrete Mix Design
- Temperature control during production.
- Control workability (by adjusting admixture dosage) during production of concrete
- Final adjustment of workability at the point of pouring (if required)

In the second category, the key parameters are:

- Proper transportation of concrete
- Proper placing and compaction of concrete
- Proper curing of concrete

In the first category first three parameters are tested by QC technicians and not the QC Engineer. These are simple tests which the laboratory technician can easily do. The last two parameters are extremely important and the decisions must be taken by the Quality Engineer and not the laboratory technician unless he has complete knowledge of the subject.

The mix design and temperature control are carried out by the QC Engineer who designs the mix considering the workability, retention, strength and durability parameters. Unless all the parameters are achieved the mix is not approved for use. The other two parameters are generally left to the supervisor at site who oversees the placement, compaction and curing of concrete. It is observed that most quality lapses occur where the supervisory staff is involved, mainly due to lack of knowledge, casual approach of the staff. Unless the QC Engineer keeps a strict watch on the supervisory staff, the causal approach may lead to lapses.

1.5 Why is Quality Control Important?

Quality management systems in concrete construction should be the essential part of the construction project. Quality management system is nothing but a set of documents that provides detailed guidelines on quality management of concrete production and construction. It establishes systematic way of setting quality processes and roles and responsibilities to get required or improved quality.

Quality of concrete production depends on many factors. From the selection of concrete constituent materials to the curing of the structural member, every step must be carried to maintain the quality requirement of the project. Any deviation from the required quality may result in substandard structure. Quality of concrete construction includes steps for maintaining the required strength of concrete within the deviation

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permitted and construction of a durable structure. A concrete member may have the required strength as per the cubes cast, but if it is not compacted properly and cured thoroughly for the required duration will reduce the life span of the structure. So, durability should also be an important part of the construction management system.

Benefits of Concrete Quality Management System:

1. Quality of concrete production and construction activities will be tracked by quality management documents and become a record for future reference.
2. Quality management system improves perception of customers towards company due to credible quality personnel and quality practices.
3. Good quality construction reduces the wastage of materials, permits smooth function of the team and keeps down the construction cost.
4. It improves job-site concrete handling, curing, sampling and testing procedures to reduce potential liability to the company.
5. Minimizes cost of repair and maintenance of the structure after construction due to quality works.
6. It opens the area of improvement for quality construction rationally for other projects based on the documents from previous projects.
7. Improved system will lead to improved durability.

Quality control has a direct impact on the progress (delays due to stoppage of work), economics (possibility for optimization, reduced cost in repairs & reworks) and reputation of the organization. The prime target of any contractor is to design concrete which is economical (optimum cement content with maximum use of supplementary cementitious materials, SCMs), durable (maximum use of SCMs with low water binder ratio) and sustainable (least impact on environment).

Economics can be achieved only when the concrete is designed at the optimum level. This requires that the concrete be designed and redesigned till the achieved properties of concrete barely exceed the desired properties. To achieve this, variation in the raw material should be minimum and batching, mixing, sampling and testing process must be adequate. Unless strict quality assurance and control measures are implemented, optimum design cannot be achieved.

Durability of concrete not only requires concrete mix design to satisfy all requirements, but the transportation, placement, compaction and curing, workmanship, must also be monitored and controlled. Strict supervision is an essential part of quality assurance.

1.6 Sustainability in Construction Through Improved Quality and Productivity of Concrete

Concrete is by far the most widely used material only next to water around the world, because of the economic and widespread availability of its constituents, versatility, durability, and adaptability. It literally forms the basis of our modern society; we live in concrete houses, we travel on concrete roads, we store water in concrete dams, which is then distributed through systems of concrete waterways, conduits, and pipes to provide our drinking water, or is used to generate electricity. Concrete as noted

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earlier, by far the most widely used material in the world, with over 12 billion cubic metres of concrete produced annually. A world without concrete is almost inconceivable!

Concrete is made from cement, supplementary cementitious materials (SCMs), aggregates (gravel or crushed stone & sand), water and chemical admixtures. In 2015, 3.5 billion tons of cement was produced worldwide (Fig. 1.1, [3]). The annual production quantity will reach 4-5 billion tons within a decade. In addition to Portland cement, the concrete industry uses vast quantities of two other materials: about 10 billion tons of sand, gravel, and crushed rock, and over 1 trillion litres of fresh water per year go into the production of concrete. This too has a considerable environmental impact.

During production of Portland cement on an average, about 0.9 ton of CO_2 is liberated per ton of cement produced. (For any particular plant, the amount of CO_2 may be somewhat more or less than this, depending on the plant efficiency, quality of the raw materials, proximity of the plant to the raw materials, etc.) This amounts to about 7% of the world's CO_2 emissions. When it is eventually mixed with water for use in concrete, each ton of cement can absorb up to 400 kgs of carbon dioxide thus leaving an overall positive carbon footprint of about 500 kgs. While this is less than the amounts produced by the generation of electric energy from coal-fired power plants, or the amount used in transportation, it is still significant, and so efforts must be made to reduce the amount of CO_2 associated with the cement and concrete industries.

Thus, if we wish to control the extent of pollution and environmental degradation to acceptable limits, we must pay much attention to the way in which we deal with our environment. This leads inevitably to the concept of sustainable development, which is most commonly defined as:

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland, 1987) [4]."

1.6.1 Steps to achieve sustainability

Though sustainability predominantly addresses environmental impacts, economic impacts are also a part of sustainability. No sustainable technology can be really sustainable unless it is also economical. The focus on making concrete sustainable is by means of reducing the cement consumption in concrete and reducing the overall wastage, which not only reduces the greenhouse gases issue but also reduces the cost of concrete. Cost of fly ash is roughly 25% of cement cost and that of GGBS is roughly 45% of cement cost. These values can be taken as all India average at present. There are several approaches to make concrete more sustainable, including:

- Designing the most optimum and durable concrete mixes
- Maintaining high quality standards
- Improving productivity and reducing wastage

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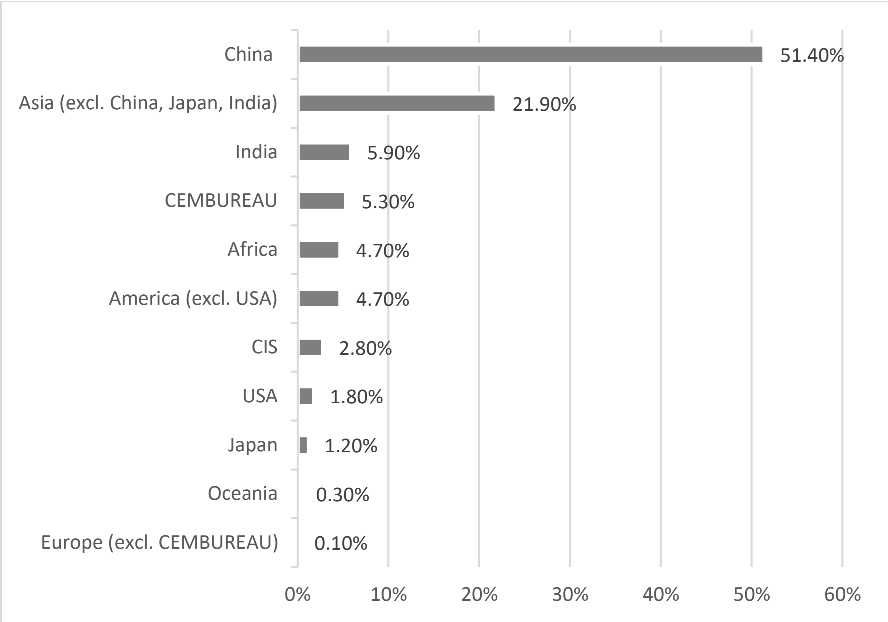

Fig. 1.1 Worldwide cement production in 2015

1.6.2 Designing most optimum and durable concrete mixes

For designing optimum and durable mixes, some of the measures to be taken are:

- use of SCMs as replacement of portland cement for improved durability, sustainability and long-term strength
- using less water, and thus less total cementitious material.
- using higher size of aggregate in concrete wherever possible, thus reducing total cementitious content. Reduction in cementitious content is approx. 10% when maximum size of aggregate (MSA) is increased from 20 mm to 40 mm
- using nano SCMs like silica fume, metakaolin, ultrafine fly ash and ultrafine GGBS for improved durability and designing high strength concrete
- using recycled concrete, and other industrial wastes, as aggregate sources
- use of appropriate chemical admixtures
- use of higher strength concretes
- improving structural design and building codes

The clear focus now must be on the durability of the concrete, if we truly wish to achieve sustainability. A structure built with durable concrete will necessitate less repair work, will delay and decrease significantly any rehabilitation work, and will lengthen the life cycle of the structure. The money spent on rehabilitating the old structures can be diverted towards other social needs as well as developing new infrastructures to cater to the ever-increasing demand.

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Let us look at some of the approaches discussed earlier to achieve sustainability and their impact on the economics.

One of the most effective way to improve durability and sustainability of the structure is to replace cement with SCM like fly ash and GGBS. Fly ash and GGBS are waste material of thermal and steel industry. If not utilized they need to be dumped into landfills thus blocking large hectares of cultivation lands. They also contain some elements which when leached into ground water cause contamination. The cost of these SCMs in comparison to OPC is also lower. Thus, replacement of cement with SCM has a manifold impact on the economy: the areas required for landfills is reduced, water contamination is reduced thus helping the agriculture industry and the overall cost of concrete per cubic metre is less than that of concrete made with only OPC alone. Since OPC content is reduced, the CO_2 emission to atmosphere is reduced. Thus, we have a highly sustainable concrete which is lower in cost, highly durable and having a much higher service life.

Water is a precious resource which needs to be very judiciously utilized. Less water used in concrete per cubic metre means that extra amount of water remains available for other useful purposes. Also, lower the water content in the mix, lesser is the cement content required for a given strength. Since cement is the costliest material going into concrete, the impact on economic of concrete is positive. Achieving required workability even at low water contents is possible by using right chemical admixtures.

Higher the size of aggregate in concrete, less is the amount of paste as the total surface area of aggregate is less. Approximately 30 kg of cementitious content can be reduced if maximum size of aggregate (MSA) 40 mm is used in place of MSA 20 mm. This will lead to lesser consumption of cement. Thus, cost per cubic metre will reduce. Also, cost of producing 40 mm aggregate is slightly lesser than that of 20 mm.

Concrete reclaimed from the demolition of old concrete structures or pavements may be processed to produce aggregates suitable for use in new concrete. Other industrial waste that can be used as aggregate are copper and iron slags, rubber, glass, wood waste, asphalt milled waste, etc. These industrial wastes if not utilized will be dumped causing environmental hazards.

1.6.3 Maintaining high quality standards

The quality standards of concrete at site is judged by the standard deviation achieved for the cubes tested. If the standard deviation is low, it means that the concrete quality is high. Concrete is designed in the laboratory based on the target strength calculated and not the characteristic strength.

The target strength is calculated using the equation Eqn. 1 given below:

$f_t = f_{ck} + 1.65 \times S.D.$ Eqn. 1

f_t = Target Strength, MPa

f_{ck} = Characteristic Strength, MPa

S.D. = Standard Deviation, MPa

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In absence of established standard deviation, the values as specified in the standards are taken for calculating the target strength. Table 1.2 gives the assumed standard deviation as given in IS 456 [5]. Once the actual standard deviation is established based on test results of at least 30 cubes, the concrete mix can be redesigned for the actual standard deviation achieved.

Table 1.2 Assumed standard deviation as per IS 456

Grade of concrete	Assumed SD (MPa)
M10 – M15	3.0
M20 – M25	4.0
M30 – M50	5.0

Note: The above values correspond to good quality control at site. For concrete lacking good quality control (such concrete is not recommended for permanent structures), the assumed values of SD to be increased by 1.0.

Lower standard deviation can be achieved by the following:

- Raw materials to be procured from the same source
- All raw materials must be inspected before acceptance
- Batching Plant must be calibrated to avoid variation in weighing of raw materials
- Check efficiency of batching plant mixer to ensure that uniform mixing and concrete production is done
- Ensure that no extra water is added to concrete during transportation and placement
- Ensure proper sampling of concrete is done for casting of cubes
- Check the dimensions of cube moulds periodically in order to ensure the correct shape and size of cubes cast
- Ensure that cube moulds are properly cleaned and oiled before use
- Ensure cubes are filled in layers as specified and tamped & compacted thoroughly
- Demoulding of cubes is done timely and cubes put in curing tank maintained at required temperature of 27±2°C immediately
- Ensure that Compression Testing Machine is properly calibrated and the technician is trained for carrying out the test as per specified standards

Standard deviation can be used as an effective tool for optimizing the cement content in the mix, especially if the initial target strength of the mix is very high. An example of how standard deviation can help in sustainability is explained below. First let's look at a case where concrete is designed as per IS 456 [5]. Assuming M40 grade concrete is to be designed based on target strength requirements given in IS 456.

Characteristic Strength = 40 MPa

Target Strength as per IS 456 = 40 + 1.65 × 5 = 48.25 MPa

Assuming actual S.D. achieved in field = 3 MPa

Revised target strength will be 40 + 1.65 × 3 = 44.95 MPa

Thus, the target strength of M40 grade concrete can now be revised to 44.95 MPa once consistent S.D. is established at site. Once the target strength is revised, the total cementitious material concrete will be reduced to that extent. It must be noted that the acceptance criteria for concrete as given in IS 456 or MoRTH [6] for 28 days compressive strength is that the cube results should be greater than $f_{ck} + 3 = 40 + 3 = 43$ MPa. Thus, the concrete shall be deemed pass only when the average compressive strength is greater than 43 MPa.

1.6.4 Improving productivity and reducing wastage

Improving productivity and reducing wastage are very important steps for achieving sustainability. When we improve the productivity of batching plant, we tend to produce more concrete at a lower energy consumption.

Most of the times it is observed that the batching plants operate at 50-60% efficiency, a 60 cum/hr. batching plant produces approx. 30-35 cum/hr. concrete. This is an absolute underutilization of batching plant. Hence innovations and improvisations need to be done to achieve close to 90-100% efficiency at least for concrete upto M50 grade.

Breakdown of equipment is another important reason for underutilization of equipment. Regular maintenance must be done to reduce the breakdown time of equipment to less than 10% of operational time.

Wastage of raw material as well as concrete must be monitored judiciously. Raw material wastage during handling can be easily controlled if strict supervision is kept. Concrete from the batching plant must be ordered exactly as is required in the field and the last transit mixer should not be dispatched at full capacity but as per the final concrete quantity requirement. Controlling wastage has a direct impact on the raw material usage as well as economics.

1.7 Summary

In most industries, especially in manufacturing and process industry, the concept of quality management is old and used extensively. Nowadays, application of quality management is not only becoming popular but also mandatory in construction industry. Just knowing some quality control methods or procedures will not serve the purpose. We must adopt and implement the quality control methods and tools that are available to us.

Implementation of Quality Control in concrete construction will lead to improved productivity, increased profits and better reputation.

The completion of any project depends to a certain extent on the timely production of concrete with the desired quality. If the entire plant capacities are not designed to cater to the productivity needs, the project will get delayed. It is important to understand the productivity requirements at the start of the project and deploy the equipment with adequate capacities (crushing plant, batching plant, transit mixers, concrete pumps,

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concrete pipelines, etc.). It is important to achieve both quality and quantity of concrete for successfully complete the project.

Greenhouse gases have a serious impact on the global warming issues and construction industry, especially cement industry contributes significantly towards greenhouse gas emissions (approx. 7%). Sustainability in construction can be achieved by designing the most optimum concrete mixes, maintaining high quality standards and improving productivity and reducing wastage. Durability of concrete structures plays a very important role in long term sustainability and economics of structures.

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CHAPTER 2

CEMENT – IT'S EFFECT ON QUALITY AND STRENGTH OF CONCRETE

2.1 Introduction

Cement is one of the most important building materials used in concrete. Indian cement industry is at present producing varieties of cements like Ordinary Portland Cement (OPC 33, 43, 53 grades), Portland Pozzolana Cement (PPC), Portland Slag Cement (PSC), Sulphate Resisting Cement (SRC).

The concrete mix is designed using a certain type of cement from a supplier in the laboratory and the mix design, after satisfying all fresh and hardened concrete properties, is implemented in the field for production. It is expected that the results achieved in the field should be in line with the ones achieved in the laboratory. Consistency of results in the field depends on many parameters:

- Consistent quality of cement and other raw materials
- Consistent batching and mixing in the batching plant
- Consistent transportation, placement, compaction and curing

To obtain good concrete quality, concrete users need to target a low standard deviation of concrete strength. In order to reduce the standard deviation of concrete strength, the variation in material properties need to be lowered.

If the physical and chemical properties of cement keep on varying from batch to batch, it is difficult to produce consistent quality concrete. If cement is purchased from different suppliers, that makes it further difficult to control the variation in the properties of concrete produced.

2.2 Choosing the Right Type of Cement for Various Applications

Design parameters, type of construction, ground conditions, durability requirements and environmental conditions are some of the factors which dictate the selection of appropriate cement for an application.

The major factors affecting the choice of cement are as follows:

1. Functional requirements of the structure – its load carrying capacity, reversal of stresses, shrinkage, creep and deflection etc.
2. Ground condition – Type of soil, quality of ground water, alternate wetting & drying, ground water table and swampy lands etc.

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3. Environmental and exposure conditions – Mild to extreme as per IS 456 - Rainfall, existence of sulphates, chlorides, industrial waste, etc. in subsoil, groundwater, atmosphere, etc.
4. Speed and method of construction – Precast, pre-stressed components, slip form, repairs and rehabilitation needs.
5. Durability requirements, services life, corrosion, cracks and deterioration etc.

2.3 Codal Provisions

All Indian codes have been recently revised incorporating the use of SCMs in concrete. The Table 5.7 in Chapter 5 summarizes the codal provisions.

Table 2.1 below gives a broad indication regarding use of different types of cement for various applications. ACI 318 gives the following limits as specified in Table 2.2 [2]. The table recommends use of SCMs in concrete from durability point of view. For further details and better understanding of the subject, one may refer to ACI 318. It is seen that use of SCMs, especially fly ash and GGBS is beneficial to concrete for enhancing workability, sustainability as well as economics. Use of fly ash or GGBS can be done either by using preblended cements like Portland Pozzolana Cement (PPC) or Portland Slag Cement (PSC) or by blending them directly in computerized batching plant mixer.

The second option has various benefits over the first option.

- Preblended cements have replacement levels of SCMs lower than the upper limits permitted in the codes. PPC has approx. 25-30% fly ash and PSC has approx. 40-50% GGBS. These replacement levels are low and do not offer complete advantage of using SCMs, neither in terms of durability and sustainability nor in terms of economics.
- When blending is done in batching plant, the replacement levels can be higher as per national and international codal provisions and complete advantage of using SCMs can be extracted.
- Use of fly ash in concrete improves the workability, pumpability and cohesiveness mainly because of the spherical shape of fly ash. This advantage is lost when PPC is used as the spherical shape is destroyed due to grinding in cement kiln.
- Combination of fly ash and GGBS can be used in the same mix provided it is more economical.
- By site blending and by utilizing higher percentages of SCMs, we make the concrete more durable, more economical and more sustainable. By using preblended cements like PPC or PSC, the economic benefit is mainly taken by the cement manufacturers.

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Table 2.1 – Use of different types of cements for various concrete applications

Structure	Properties				Recommendation
	Work-ability at pouring point	**Early Strength**	**28 days strength**	**Durability Requirements**	
Piles	Very High (Slump more than 180 mm)	Usually not required	As per characteristic strength. Can be designed for 56 or 90 days strength instead of 28 days particularly with SCMs	High – subject to surrounding sub-soil /water and environment. In case of marine piles – very severe exposure and in tidal zone extreme exposure. Other piles as per IS 456 exposure condition.	Recommended to use PPC / PSC or use 35-50% fly ash, 70-85% GGBS or a combination of fly ash & GGBS upto 85% to achieve high durability as well as long term strength
Foundations (Open, raft), Pile caps	High (Slump 100-150 mm, if pumping is adopted)	Not required	As per characteristic strength. Can be designed of 56 or 90 days instead of 28 days	High – subject to surrounding sub-soil /water and environment.	Recommended to use PPC / PSC or use 35-50% fly ash, 50-85% GGBS or a combination of fly ash & GGBS upto 85% to achieve high durability as well as long term strength
Piers, Pier caps, columns	High (Slump 100-150 mm, if pumping is adopted)	Not required	As per characteristic strength. Can be designed of 56 or 90 days instead of 28 days	High – subject to surrounding environment	Recommended to use PPC / PSC or use 35-50% fly ash, 50-85% GGBS or a combination of fly ash & GGBS upto 85% to achieve high durability as well as long term strength
Mass concrete (Dams, barrages)	Low (slump 50-70 mm)	Not required	Usually designed for 90 or 180 days	High – need impermeable concrete. Heat of hydration to be controlled to avoid thermal cracks	Recommended to use 50% fly ash or 85% GGBS or combination of SCMs. Higher % of SCMs help in reducing heat of hydration and subsequent rise in temperature of concrete

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Precast beams, Pre-stressed girders, beams and slabs	High (Slump 100-150 mm)	Early strength is required for pre-stressing, lifting segments, removing props and supports	As per characteristic strength.	High – subject to surrounding environment	Recommended to use OPC with 35% Fly Ash or 50% GGBS. With addition of 5-7% Ultrafine SCMs like SF, UFS or UFFA, fly ash and GGBS can be used upto 50% and 70% respectively and still achieve early strength. Higher the % of SCMs (along with ultrafine SCMs) in concrete, lower will be the creep, which is advantageous in prestressed concrete
Shotcrete	High (Slump 180-200 mm)	Immediate setting and early strength required to support tunnel surface	As per characteristic strength	High – subject to surrounding environment.	Recommended to use higher OPC content with 5-7% Ultrafine SCMs if required. Usually fly ash or GGBS is not used in shotcrete as it will delay the initial setting of shotcrete

Notes: 1. *SF – Silica fume, UFS – Ultrafine Slag (Alccofine), UFFA – Ultrafine fly ash*
2. *It is advantageous to use maximum size of aggregate (MSA) 40 mm for foundations and substructures, MSA 20/10 mm for precast and superstructures and MSA 80/150 for dams and barrages*

Special Note on use of Sulphate Resistant Cement (SRC)

Use of SRC is recommended for underground structures in sulphate-salts abounding environment, effluent treatment plants, sugar and other chemical industries, where civil works are likely to be subjected to sulphate attack. The sulphate salts, present in soil or water, react with tricalcium aluminate hydrate and form tricalcium sulphoaluminate. This compound has a volume more than twice the original volume of C_3A hydrate and this induces stresses in concrete leading to cracks and disruption of concrete. Being a specially formulated cement, with lower C_3A content (<5 percent), SRC is free from these effects. This cement is available in the market under different brand names.

However, use of sulphate resisting cement is not advisable where chlorides are also present in the soil or water. Since SRC is not effective in binding the chloride ions, the chloride ion diffusivity of SRC is very high. Chloride ions diffuse much faster in SRC as compared to OPC within the concrete leading to early corrosion of reinforcement steel. Fig. 2.1 [1] gives the chloride diffusion values for various cement combinations. It can be noted that the chloride diffusion value of SRC is 20 times that of Portland Slag Cement. In situations, where both chlorides and sulphates are present, the use of Ordinary Portland cement with C_3A between 5 to 8 percent (moderate sulphate

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resisting cement), or blended cements – Portland Pozzolana cement (Fly ash content not less than 25 to 30 percent) or blast furnace slag cement with slag content above 50 percent – is recommended in IS 456:2000. For marine conditions, use of GGBS is the most effective method for improving durability of concrete.

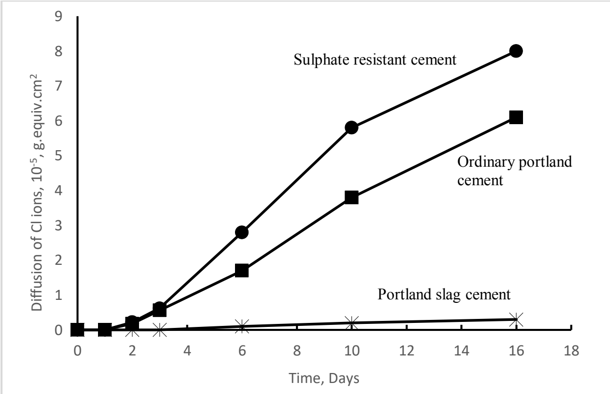

Fig. 2.1 Effect of type of cement on the rate of diffusion of chloride ions

Table 2.2 Limits of cement types for durability as per ACI 318-14

Category	**Class**	**Condition**		**Max (w/b)***	**Min (f_{ck}) MPa**	**Additional Requirements**			**Admixtures**
		Water - soluble sulphate	**Dissolved sulphate**			**Cementitious materials — Types**			**Calcium chloride Admixture**
		(SO_4^{2-}) in soil, % by mass	**(SO_4^{2-}) in water, ppm**			**ASTM C150M**	**ASTM C 595M**	**ASTM C1157M**	
Sulphate (S)	S0	SO_4^{2-} < 0.10	SO_4^{2-} < 150	NA	17	No type restriction	No type restriction	No type restriction	No restriction
	S1	0.10 ≤ SO_4^{2-} < 0.20	150 ≤ SO_4^{2-} < 1500 or seawater	0.5	28	II (OPC 43/53)	Types IP (PPC), IS (PSC), or IT (Ternary Blends) with (Moderate sulphate resistance)	Moderate Sulphate Resistance	No restriction
	S2	0.20 ≤ SO_4^{2-} ≤ 2.00	1500 ≤ SO_4^{2-} ≤ 10,000	0.45	31	V (SRC)	Types IP (PPC), IS (PSC), or IT (Ternary Blends) with (High sulphate resistance)	High Sulphate Resistance	Not permitted

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	S3	$SO_4^{2-} >$ 2.00	SO_4^{2-} >10,000	0.45	31	V (SRC) plus pozzolan or slag cement	Types IP (PPC), IS (PSC), or IT (Ternary Blends) with (High sulphate resistance) plus pozzolan or slag cement	High Sulphate Resistance plus pozzolan or slag cement	Not permitted

In contact with water (W)	W0	Concrete dry in service. Concrete in contact with water and low permeability is not required		None		
	W1	Concrete in contact with water and low permeability is required		None		
				Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement		**Additional provisions**
				Non-prestressed concrete	**Prestressed concrete**	
Corrosion protection of rein-forcement	C0	Concrete dry or protected from moisture		1	0.06	None
	C1	Concrete exposed to moisture but not to an external source of chlorides		0.3	0.06	
	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources		0.15	0.06	Concrete cover

** w/b – water binder ratio, where binder means total cementitious material, including OPC and SCMs*

Notes:

Blended cements governed by ASTM C595 pertain to four classes for both general use and special applications. There are four major classifications:

Type IS – Portland blast-furnace slag cement – up to 95% slag permitted. This type is similar to Portland Slag Cement (PSC) produced as per IS 455 with the only difference that in IS 455, maximum 70% slag is permitted.

Type IP – Portland-pozzolan cement – up to 40% pozzolan permitted. This type is similar to Portland Pozzolana Cement (PPC) produced as per IS 1489 Part 1 with the only difference that in IS 1489 Part 1, maximum 35% fly ash is permitted.

Type IL – Portland-limestone cement – up to 15% limestone permitted

Type IT – Ternary blended cement – up to 70% of pozzolan + limestone + slag, with pozzolan being no more than 40% and limestone no more than 15%

2.4 Variation in Cement Properties

Generally, the variation in physical and chemical properties of cement coming from same cement plant is not appreciable to cause major quality variations in the properties of concrete. There may a few cases where the properties do change, especially the 28 days' strength may vary and a few cement samples may fail. But apart from stray incidents, generally cement coming from same plant from reputed manufacturers do not vary much. Further cement manufactured by various brands generally meet the codal requirements except occasionally for OPC 33 grade.

But one must exercise strict supervision when cement coming to a project is purchased from various cement manufacturers as there could be major changes in the physical

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and chemical parameters and can lead to severe variations, both in physical and hardened concrete properties. Even cement coming from same manufacturer but different cement plants can vary drastically. The Table 2.3 & Table 2.4 below give variation in OPC 53 and PPC cement from different manufacturers as well as cement from same manufacturer but different cement plants.

Table 2.3 Comparison of cement properties of OPC 53 grade from different manufacturers

Properties	Cement manufacturer 1	Cement manufacturer 2	Cement manufacturer 3
Specific Surface (m^2/kg)	297	299	327
Standard Consistency (%)	28.1	30.5	30.2
Initial Setting Time (min.)	165	165	125
Final Setting Time (min.)	240	255	195
3 days comp. strength (MPa)	38.4	37.2	42.1
7 days comp. strength (MPa)	51.9	45.6	51.5
28 days comp. strength (MPa)	72.1	57.7	69.4

In the above table, it can be observed that though the 28 days compressive strength of OPC from manufacturer 1 & 3 are close, there is a big difference in the standard consistency and setting time of cement. This variation can cause major difference in the workability and retention properties of concrete made with same mix design, keeping all other parameters same. Even the admixture formulated for one cement may not be compatible to the other and this has happened in many projects of which authors are aware of. Hence it is desirable to check the admixture compatibility and do the mix designs before procuring cement from other sources.

Table 2.4 Comparison of cement properties of OPC 53 grade cement from same manufacturer but from different plants

Properties	Cement Plant 1	Cement Plant 2	Cement Plant 3
Specific Surface (m^2/kg)	297	313	281
Standard Consistency (%)	28.1	30.3	25.5
Initial Setting Time (min.)	165	160	200
Final Setting Time (min.)	240	250	300
3 days comp. strength (MPa)	38.4	36.6	36.6
7 days comp. strength (MPa)	51.9	47.0	48.4
28 days comp. strength (MPa)	72.1	63.3	64.3

From the Table 2.4 it can be observed that though the 28 days' strength of cement from Plant 2 and 3 is almost same, there is a huge difference in the specific surface, standard consistency and setting time of both the cements. If the same chemical admixture is used for both cements keeping mix design same, there may be a major setting time and bleeding issue with the cement from plant 3. Reducing the admixture dosage may not actually solve the issue and we may need to formulate a completely different admixture altogether.

It may be noted that the robustness of Polycarboxylate ether (PCE) based admixtures is much better than the conventional Naphthalene based admixtures. To a large extent a single formulation of PCE based admixture may cater to various cements with only

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the dosages varying. Table 2.5 below gives details of PPC from different manufacturers.

Table 2.5 Comparison of properties of PPC from different manufacturers

Properties	Cement manufacturer 1	Cement manufacturer 2	Cement manufacturer 3
Insoluble Residue (%)	18.2	28.7	25.7
Specific Surface (m^2/kg)	355	353	382
Standard Consistency (%)	30.10		
Loss on Ignition (%)	0.81	3.73	2.40
Initial Setting Time (min.)	165	120	140
Final Setting Time (min.)	240	215	200
3 days comp. strength (MPa)	30.5	24.0	29.0
7 days comp. strength (MPa)	42.8	31.5	40.4
28 days comp. strength (MPa)	64.3	46.0	61.2
% Fly Ash	20	35	32

Note: Examples given in Table 2.3, 2.4 and 2.5 are actual observed values by the authors.

All the above cements in Table 2.5 qualify as PPC as per IS 1481, but the variation in properties is high. Though the strength of manufacturers 1 & 3 is comparable, manufacturer 1 uses only 20% fly ash whereas manufacturer 3 uses 32% fly ash. From durability point of view, it is advisable to use PPC from manufacturer 3 as it gives high strength as well as higher fly ash replacement which ensures much better durability and sustainability.

The above details indicate that in ideal case, it is advisable to procure cement from a single manufacturer from the same source to avoid issues related to variation in the quality of concrete. But from practical considerations and to ensure that the concrete works do not suffer due to shortage of supply because of plant breakdown or other issues, it is very desirable or rather essential to have cement from 2 to 3 sources. Hence, one should design each mix for all cements to be used in the project and establish the proportions as well as admixture compatibility.

2.5 Guideline for Using Cement While Designing and Producing Concrete

While designing the mix in a laboratory

- Check the 28 days' compressive strength of cement at the time of conducting laboratory trials for establishing concrete mix for any grade of concrete. The compressive strength of cement decides the water binder (w/b) ratio for any grade of concrete. For a given grade of concrete, higher the strength of cement, higher will be the w/b ratio. E.g., For M40 grade concrete – if 28 days compressive strength of cement is 50 MPa, w/b ratio required to achieve target strength of concrete will be approx. 0.34, whereas if the compressive strength of cement is 60 MPa, the same target strength of concrete can be achieved with a w/b ratio of 0.39.
- Check the standard consistency of cement. As a thumb rule, for every 1% increase in standard consistency, there is a 3 kg/m^3 increase in water demand.

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Higher standard consistency increases the water demand of the mix which can be compensated either by adding extra admixture or water during the trials.

- Check the initial and final setting time of cement. It determines the working time available with that cement and how much retarder will be required in the admixture to achieve the desired retention.

During production

- Check the Manufacturer's Test Certificate (MTC) to estimate the 28 days' compressive strength of cement received at site. If the strength is lower than the strength of cement used during lab trials, it is advisable to slightly reduce the w/b ratio to compensate for the lower strength. The variation in strength will usually not be high, so a reduction on w/b ratio by 0.01 should be enough.
- Check the standard consistency of cement received. If the standard consistency is higher than what was during lab trials, the water demand will be higher which must be compensated by increasing the dosage of admixture only. No additional water should be added to compensate for higher water demand as it will reduce the strength of concrete. Usually increase in admixture dosage by 0.1% by weight of total cementitious material should give the required performance.
- If the Initial Setting Time (IST) and Final Setting Time (FST) of cement are substantially different than the cement used during trials, the admixture dosage will vary depending upon the lead time, ambient temperature, concrete temperature and initial workability. The same needs to be adjusted as per the experience of the Quality Engineer and based on relevant tests.

2.6 Handling and Storage of Cement

Cement received at site may be stored either in cement godown, if it is supplied in bags and in silos when supplied by cement bulkers. For consumption of cement, First In First Out (FIFO) system must be adopted.

Cement is very sensitive to presence of moisture and its strength deteriorates by absorbing moisture and forming lumps. Therefore, cement should be stored in a manner that no dampness or moisture is allowed to reach it either from the ground, walls or from the environment. This is particularly important during the humid seasons and in coastal regions. Fig. 2.2 [3] below gives an approx. indication of loss of cement strength with age of cement.

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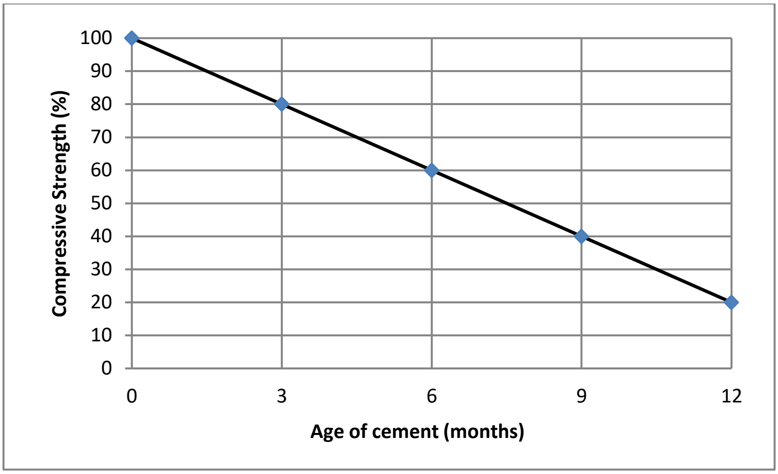

Fig. 2.2 Approx. indication of deterioration of cement strength with age

As per BIS, cement gives best performance if consumed within 90 days from the date of its manufacturing. Beyond this period, it should be tested for compressive strength and loss on ignition and then only used.

Recommended guidelines for construction of cement godown

- The walls must be leak proof; Brick masonry walls must be plastered with cement-sand plastered (water proof) on the external face with 2 coats.
- The roof must preferably be of reinforced concrete construction overlaid with a waterproofing course. AC/GI sheet roof construction may be used provided they are leak proof.
- The floor must be raised by at least 40 cm above the ground level to prevent any inflow of water. The flooring may consist of a 15 cm thick concrete slab or layer of dry bricks laid in two courses over a layer of earth consolidated to a thickness of 15 cm above the ground level. Although not shown on the drawing, the outside ground is drained away from the building to prevent accumulation of rainwater in its vicinity. All these precautions ensure that the floor remains dry.
- For further protection, cement bags should be stacked at least 10-20 cm clear above the floor by providing wooden battens and planking arrangements.
- Preferably, the plinth should be high enough for a lorry to back conveniently to the door so that, the chassis and the building floor is almost at the same level, thus making loading and unloading of bags very easy.
- Windows provided, if any, should be very few and of small size, and normally kept closed tightly to prevent entry of atmospheric moisture from outside.
- The door should also be tight and always kept closed unless in use.

Essential precautions for stacking of cement bags

- No cement bags should be stacked in contact with the external wall. A clear space of minimum 600mm should be left between the exterior wall and the stacks.
- Tarpaulin or polyethylene sheet should be spread before stacking of the cement bags.
- Cement bags should be placed closely together in the stack to reduce circulation of air as much as possible.
- As per IS 4082, cement bags should not be stacked more than 10 bags high to avoid lumping under pressure and for convenience of loading & unloading.
- As per ACI 304, for a storage period of less than 60 days, stack the bags no higher than 14 layers, and for longer periods, no higher than seven layers.
- For extra safety during rainy season, the stacks of cement bags should be covered completely with polyethylene sheets, if it is anticipated that cement would not be required for a prolonged period.
- A sign board for each grade of cement (OPC 43, OPC 53 etc.) in red, yellow or green colour, giving the following important information should be prominently displayed by the side of the stack.

  ✓ Grade of cement.
  ✓ Name of the manufacturer.
  ✓ Date of manufacturing (week and year).
  ✓ Red sign board for oldest manufactured cement.
  ✓ Yellow sign board for cement manufactured between the oldest and the latest.
  ✓ Green sign board for latest manufactured cement.
  ✓ These boards should be rotated accordingly when fresh lot of cement is received.
- Aisles should be clearly marked between the stacks so as to have a clear access to all the stacks and a distance of minimum 600mm should be maintained between two stacks (Fig. 2.3, [4]).
- Take out the bags not only from one tier, but step back two or three tiers as shown in the Fig. 2.4 [4].
- While using, cement bags should be opened by removing the thread and not by cutting the bags (Fig. 2.7).

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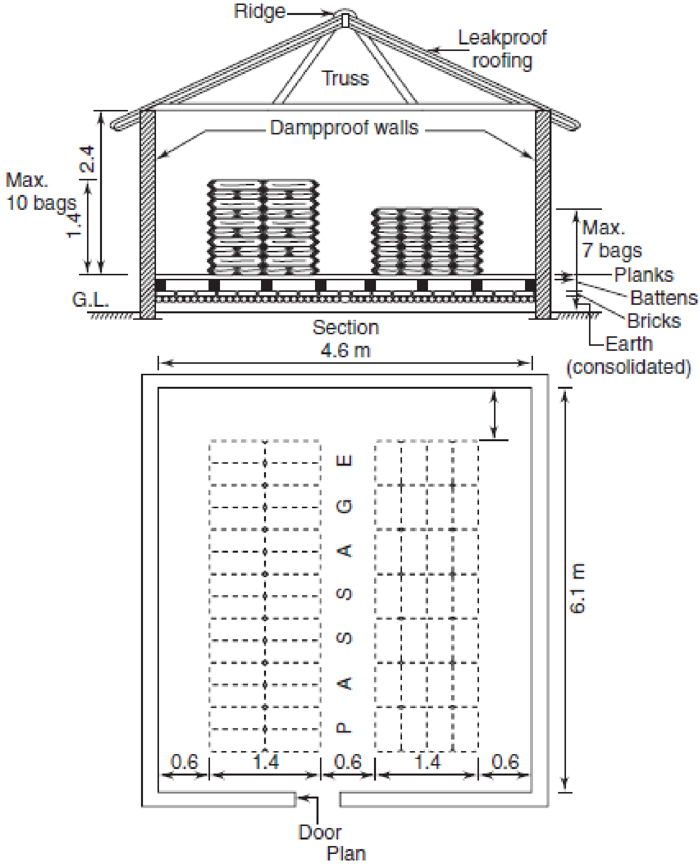


Fig. 2.3 Typical arrangement of cement godown

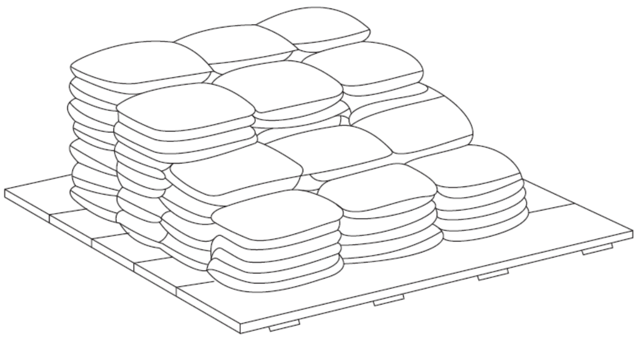


Fig. 2.4 Stepping of tiers while removing cement bags

Precautions while transporting cement bags

The cement bags must be transported from the cement godown to the feeding hopper for filling the silo or directly to the batching plant mixer. The basic do's and don'ts for handling cement while transporting are given below in Fig. 2.5 [5]:

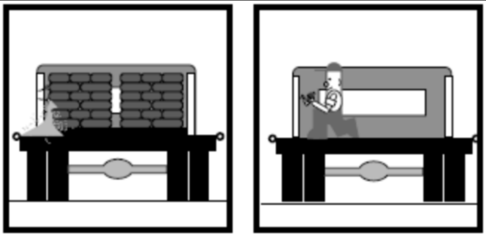
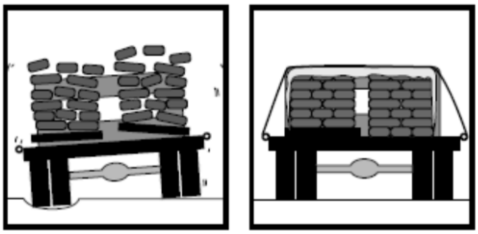
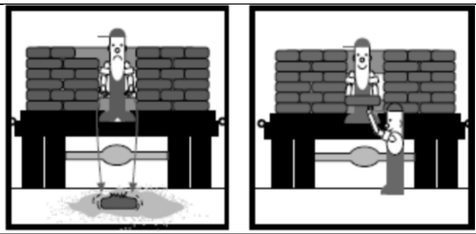
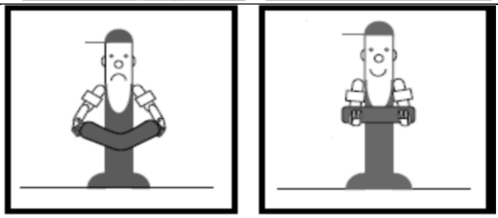
	
	Remove any sharp objects from the vehicle that you will use to transport the cement bags so that the bags are not torn or damaged.
	Load cement bags carefully onto the transport vehicle, making sure that they are covered (i.e. with a tarpaulin) and tied down securely. Always stack the cement bags in the same way (i.e. in alternate directions), even if the bags are not palletized.
	Do not drop the cement bags from the vehicle
	Never carry bags at their ends. Not only will this be very stressful on the arms, shoulders and back, it will also cause the bag to sag and rip. This is why cement bags should always be supported on the underside.

Fig. 2.5 Do's and Don't's of cement handling

Feeding of cement bags to cement hopper

For feeding of cement from a bag, the cement feeding system consists of feeding hopper and cement screw as shown in Fig. 2.6 [6]. Operator puts bagged cement onto feeding hopper by opening the cement bags and cement is transferred into cement silo by means of cement screw conveyor. The following points must be considered:

- Since the hopper is at a height from the ground level, proper access in the form of ramp and platform must be provided for labour to carry cement bags and stack them around the feeding hopper. The ramp should be made with sand bags, M.S. ramp or wooden planks and not with cement bags as is adopted by some.
- Cement bags should not be cut with blade for opening. Instead the thread should be properly removed for opening the bags (Fig. 2.7, [7]) otherwise there will be wastage of cement and cut bag pieces may choke the screw conveyor or even the batching plant.
- The bag should be opened after placing the bag on the platform floor of the hopper for minimum or practically negligible wastage of cement
- The empty cement bags should be properly stacked in a designated place

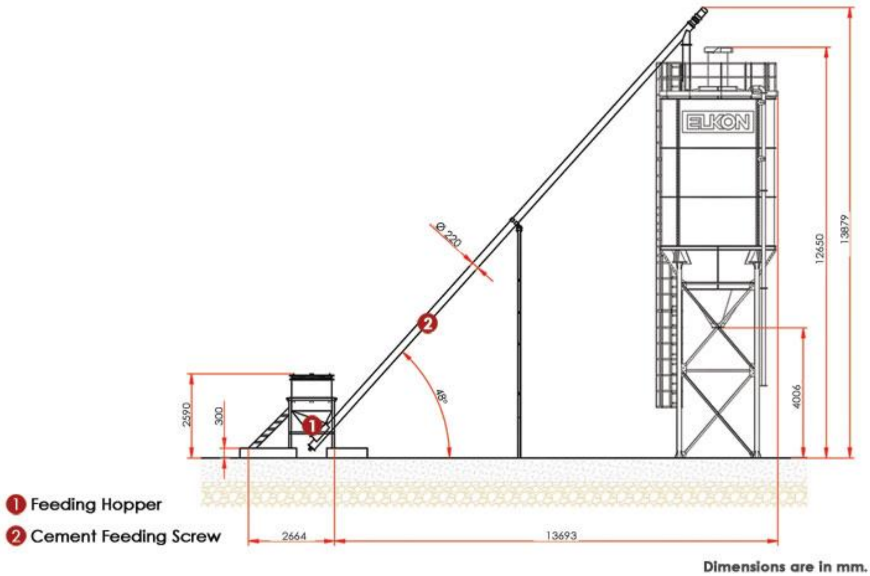


Fig. 2.6 Typical bag cement feeding system

Fig. 2.7 Opening of cement bags by removing thread on hopper platform

2.7 Summary

- Cement plays one of the most important roles in concrete – it imparts strength and durability to concrete
- Storage and handling of cement needs to be exercised properly in order to preserve the quality of cement
- Variation in fineness, standard consistency, IST, FST and compressive strength can cause change in the fresh and hardened concrete properties
- Use of 100% OPC should be avoided except in special cases as it is neither economical, durable nor sustainable
- Use of SCMs should be encouraged in all types of concrete as it will make the concrete economical, durable and sustainable

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CHAPTER 3

WATER – IT'S EFFECT ON QUALITY AND STRENGTH OF CONCRETE

3.1 Introduction

Water is one of the most critical but generally the cheapest constituent of concrete. Water in concrete should be as low as possible, however, minimum amount of water is essential for hydration of cement (minimum water requirement for complete hydration of cement is about 0.23 times the mass of cement). Lower water binder ratio increases the strength and improves the durability of concrete. It is therefore desirable to keep water binder ratio as low as possible but the water content must be adequate to get workable concrete with chemical admixture and to achieve full hydration of cement.

3.2 Quality of Water

In general potable water can be used for mixing and curing of concrete. There could be certain impurities both dissolved and/or in suspension. There are various existing and new sources of water available which may be suitable for complete or partially replacement of potable water for concrete making. It includes reclaimed water, groundwater, treated water from sewer and water treated from ready mix concrete plant etc. Due to the shortage and scarcity of water in many part of the world, water authorities are moving towards identifying new sources of water. In these countries, treated effluents are being used for irrigation purpose as well as for concrete mixing, curing and washing of aggregates, etc. Water from stream and river are often found to be suitable for use in concrete. Sea water may also be used in plain concrete and for curing generally after 3 days of concreting, etc. The permissible limits of solids as per IS 456:2000 are as indicated in Table 3.1 [1].

Algae in mixing water causes marked reduction in strength of concrete. Industrial waste water containing acids/alkalis is not suitable for concrete construction. If the pH value of water is less than 6, it shall not be used in concrete. Vegetarian oil has a detrimental effect on the strength of concrete particularly at the later ages.

As per IS 456-2000, sea water is not to be used in reinforced concrete. However, different opinions exist among experts. Based on the review of available literature, the following conclusions can be drawn with respect to use of sea water in concrete. Sea water can be used in plain concrete (concrete with no reinforcement or with embedded steel parts). Sea water shall not be used in prestressed concrete. It is desirable that sea

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water is avoided in reinforced concrete. Appropriate measures shall be taken to counteract adverse effects of sea water on concrete.

Table 3.1 Permissible limits for solids in water used for mixing in concrete as per IS 456-2000

Material	Tested as per	Permissible limits	
		as %	as ppm
Organic	IS 3025 (Pt. 18)	0.02%	200 mg/litre
Inorganic	IS 3025 (Pt. 18)	0.30%	3000 mg/litre
Sulphates (as SO_3)	IS 3025 (Pt. 24)	0.04%	400 mg/litre
Chlorides (as Cl)	IS 3025 (Pt. 32)	0.2% 0.05%	2000 mg/litre for PCC 500 mg/litre for RCC
Suspended	IS 3025 (Pt. 17)	0.2%	2000 mg/litre

Note: *PCC – Plain Cement Concrete*
RCC – Reinforced Cement Concrete

The adverse effects of using sea water in concrete include:

a. High risk of corrosion of any steel reinforcement including embedded steel parts.
b. Possible efflorescence and dampness on concrete surfaces
c. Increased risk of alkali aggregate reaction, if reactive aggregates are used
d. Increased risk of sulphate attack on concrete

Water permitted for making concrete can be used for curing. Sea water and water containing other impurities with higher percentages than indicated in Table 3.1 can be used for curing with initial 3 days of curing with water suitable for mixing in concrete. For initial 3 days such water is not permitted as it may penetrate concrete and cause corrosion and other detrimental effects. However, after 3 days particularly concrete with low water binder ratio, concrete becomes reasonably impermeable and hence other waters as noted above can be used for curing. IS 456-2000 does not permit the use of water containing tannic acid or iron compounds for curing if staining of concrete surface is to be avoided.

3.3 Importance of Water Content and Admixture in Concrete

Water is required in concrete for achieving workability and for hydration of cement (cement means cementitious material) which ultimately gives strength. Primarily, more the water content in concrete, higher will be the workability but higher the water binder ratio, lower will be the strength and durability. It is therefore important to understand the role and contribution of water content, water binder ratio and admixture in concrete to achieve the desired workability and strength.

The first parameter which is checked during concrete mix design trials is the workability. If the workability is not satisfactory then the mix is rejected and revised for improvements. If cohesiveness is not considered for a moment, the workability parameters depends on quantity of two ingredients: water and chemical admixture. More the water or chemical admixture in the mix, higher the workability. But there is a limit to the minimum amount of water or maximum amount of admixture that can

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be added with a benefit. If there is too much water in the mix, it will cause shrinkage and bleeding in concrete. Also for a given strength, the total cementitious material will be higher which will be uneconomical. Thus, less water in the mix is beneficial to concrete, in terms of durability, strength and economy.

If we go on reducing water and increasing admixture (to achieve constant workability), there will be point where further addition of admixture will not impart benefit anymore and make the concrete either sticky (due to too less water in the mix) or bleed (due to too high dispersion by admixture). At this point, there is a need to increase the water content till the issue of either stickiness or bleeding is brought under control. At high workability, cohesiveness is a very important parameter. This can be obtained only when the mix contains enough fines to hold the water. These fines can be from fine aggregate, cement or SCM. It is advisable to adjust the aggregate curve to achieve the desired fine content. But sometimes the fine aggregate may not have the finer fines (passing 125µ). In such case there is no option but to add SCM (if permitted) or cement to achieve the desired fine content.

Chemical admixture is primarily added to concrete to improve workability and retention. More the admixture dosage, higher will be the workability but upto a certain point i.e., saturation point (Refer Chapter 7 for details). When water content is too low, certain admixtures (mainly Polycarboxylate Ether based) when added in high dosage may also cause stickiness to the mix. If bleeding or stickiness is encountered, then either there is a need to reformulate the admixture for better performance or increase the water content in the mix to improve the workability.

3.4 Importance of Water Binder Ratio

Water binder ratio is the most important parameter that determines the hardened concrete properties and certainly the strength and durability of concrete. Water is required for hydration reaction of cement/cementitious materials. The ratio of water to cement, by weight, used in a concrete is known as water cement (w/c) ratio. With the use of SCM in concrete it is now designated as water binder (w/b) ratio. The reason is that the binding/cementing material in concrete is not only cement but also other cementitious materials like fly ash, GGBS, etc. Water binder ratio affects the following properties of concrete:

3.4.1 Strength

The strength of concrete depends on the water binder ratio. Lower the w/b ratio, higher will be the strength. If the water content is more, the total binder content will be correspondingly higher and vice versa. The approximate water cement ratio for a given concrete strength when 100% OPC is used can be calculated from Fig. 3.1. The graph in Fig. 3.1 has been taken from draft of IS 10262 – 2017 which has not been finalized at the time of printing this book. When SCMs like fly ash, GGBS or silica fume, the strength achieved at the same water binder ratio changes in accordance with the percentage replacement. In case of fly ash and GGBS, the concrete strength achieved at a constant w/b ratio goes on reducing as the percentage replacement goes on

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increasing. On the other hand, when silica fume, ultrafine slag (UFS – Alccofines) or ultrafine fly ash (UFFA) is used for replacing cement, the concrete strength increases as the percentage replacement increases. The approximate effect of addition of various SCMs on strength of concrete is as given in Table 3.2 [2].

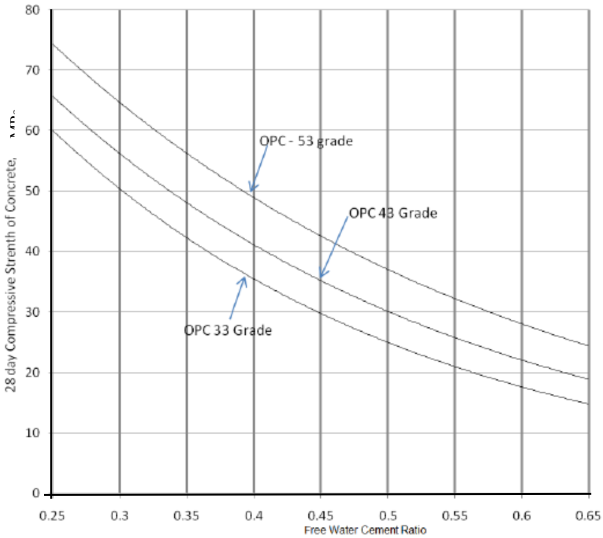

Fig. 3.1 Relationship between water cement ratio and 28 days' concrete compressive strength for different strengths of cement (IS 10262: 2017 - Draft)

Table 3.2 Approximate effect of addition of fly ash, GGBS and ultrafine SCMs on strength of concrete at 28 days

Fly Ash		**GGBS**	
% replacement	**% effect on strength**	**% replacement**	**% effect on strength**
10	(-)7	10	(-)1
20	(-)12	20	(-)3
30	(-)16	30	(-)7
40	(-)29	40	(-)9
50	(-)43	50	(-)11
60	(-)55	60	(-)14
70	(-)67	70	(-)16
Silica fume / UFS		**UFFA**	
% replacement	**% effect on strength**	**% replacement**	**% effect on strength**
2.5	+3	2.5	+1.5
5	+5	5	+2.5
7.5	+7	7.5	+3.5
10	+9	10	+4.5
12	+11	12	+5.5
15	+13	15	+6.5

(+) indicates increase *(-) indicates decrease*

Notes:

1. *The effect on strength is calculated when the total cementitious material and the water binder ratio is kept same.*
2. *If UFFA is increased to twice the UFS, then strength gain will be practically same as with silica fume / UFS.*

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3.4.2 Permeability / Durability

Lower the w/b ratio of concrete, lower will be the permeability. Proper compaction and curing of concrete in the field is extremely important to achieve lower permeability in the structure. Fig. 3.2 below gives effect of w/b ratio on permeability of concrete.

From Fig. 3.2 [3] it may be noted that rate of decrease in permeability from high w/b ratio (say 0.6) to w/b ratio upto 0.40 is significant, but at w/b ratio lower than 0.40, the rate decrease is negligible. Therefore, not much benefit is obtained by reducing w/b ratio below 0.35 or so as far as decrease in permeability of concrete is concerned. It is important to highlight that the ratio of strengths at water binder ratios of 0.35 and 0.65 is approximately 2.7, whereas the ratio of permeability at water binder ratios of 0.65 to 0.35 is approx. 950 times. This shows the significant impact of w/b ratio on the permeability rather than on strength.

It must be noted that for a constant w/b ratio, the permeability will depend on the amount of SCM in the total cementitious material. Higher the percentage of SCM, lower will be the permeability. Permeability is drastically reduced when ultrafine SCMs like silica fume, ultrafine fly ash (UFFA) or ultrafine slag (UFS) is used.

With decreasing w/b ratio, concrete becomes more impermeable at early ages from the time of its placing. Thus, with w/b ratio of 0.4 concrete is almost impermeable within 3 days and takes over 1 year to achieve same degree of impermeability with w/b ratio of 0.7, and with w/b ratio of over 0.7 it remains permeable throughout its life as noted in Table 3.3 [4]. That is the reason authors have stated earlier, that sea water can be used for curing generally after 3 days of concreting on the understanding that water binder ratio of the concrete mix is less than 0.4.

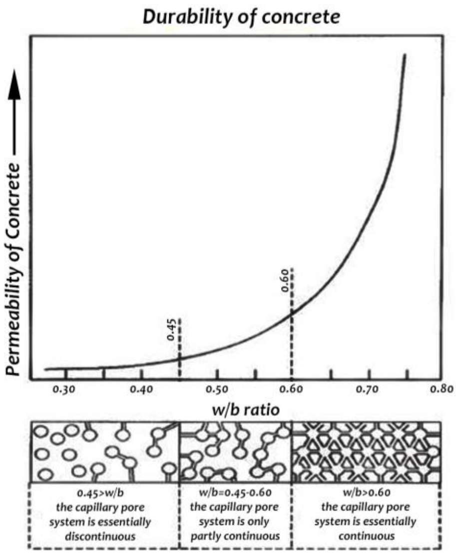

Fig. 3.2 Effect of w/b ratio on permeability of concrete

Table 3.3 Approximate Age at which Capillaries Become blocked in concrete

w/b ratio	Age at which capillary pores become blocked
0.40	3 days
0.45	7 days
0.50	14 days
0.60	6 months
0.70	1 year
Over 0.70	infinite

Thus, the coefficient of permeability at a particular age depends on the w/b ratio and the degree of hydration achieved at that age.

3.4.3 Chloride ion diffusion

Lower the w/b ratio, lower is the chloride ion diffusion value as described in Table 3.4 [4]. Hence the reinforcement is less susceptible to early corrosion and longer is the service life of the structure.

Table 3.4 Relationship between w/b ratio and chloride diffusion value

w/b Ratio	Chloride diffusion permeability (cm^2/sec)
0.40	1.05×10^{-11}
0.50	10.30×10^{-11}
0.61	1000×10^{-11}

Use of supplementary cementitious materials like fly ash, GGSB, silica fume, UFS, UFFA, etc. further reduces the permeability of concrete and makes the concrete matrix denser. Fig. 3.3 shows that for same strength concrete designed with increasing percentage of fly ash, the chloride ion diffusion value reduces drastically. Fig. 3.3 [4] shows that the chloride ion diffusion value of M60 grade concrete with 100% OPC is same as that of M25 grade concrete designed with 37% fly ash. Thus, even lower grade concrete can be designed with high durability by using SCMs.

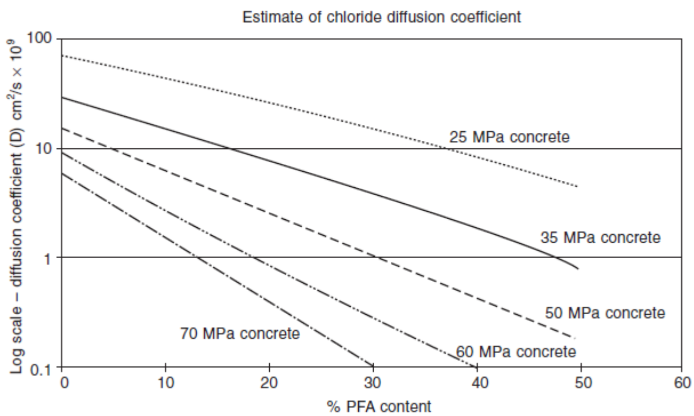

Fig. 3.3 Rate of chloride ion diffusion value of fly ash concrete

3.4.4 Effect on dimensional stability of concrete

Concrete undergoes volume changes during its lifetime because of various reasons. The main reasons are described below:

1. Plastic shrinkage:

Plastic shrinkage occurs very soon after pouring the concrete in the forms. The hydration of cement results in a reduction in the volume of concrete due to evaporation from the surface of concrete, which leads to cracking.

2. Drying shrinkage:

The shrinkage that appears after the setting and hardening of the concrete mixture due to loss of capillary water is known as drying shrinkage. Drying shrinkage generally occurs in the first few months and decreases with time.

3. Carbonation shrinkage:

Carbonation shrinkage occurs due to the reaction of carbon dioxide (CO_2) with the hydrated cement minerals, carbonating $Ca(OH)_2$ to $CaCo_3$. The carbonation slowly penetrates the outer surface of the concrete. This type of shrinkage mainly occurs at medium humidity and results increased strength and reduced permeability.

Carbonation first attack concrete making it to crack, the cracks may slowly get deeper and may reach rebars. Carbonation reduces pH value of the concrete. When it reaches rebars it destroys passivating layer surrounding the rebars. When pH value of passivating layer is reduced to 10.5, corrosion of steel rebars starts.

4. Autogenous shrinkage:

Autogenous shrinkage occurs due to no moisture movement from concrete paste under constant temperature. It is a minor problem and can be ignored.

5. Thermal shrinkage:

During the chemical reaction of cement and water, concrete releases heat that causes concrete expansion in the first few days and as process advances the concrete structures begins to cool down, resulting in shrinkage deformation.

6. Creep:

Creep is defined as the gradual increases in strain or deformation with time under a constant applied stress, after taking into account other time dependent deformations not associated with stress, due to shrinkage, swelling and thermal deformation. Reduction of stress under constant strain also causes creep. The creep of concrete under condition of no moisture movement to or from the ambient medium is termed as the basic creep and the additional creep caused by drying is termed as drying creep. The total creep consists of basic-plus-drying creep.

Water content and w/b ratio of concrete has a considerable impact on the plastic shrinkage cracks, drying shrinkage cracks and creep. The following factors affect the extent of plastic shrinkage:

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- Lower the water cement ratio, less will be the bleed water and higher will be the plastic shrinkage
- Higher the water content in the mix less will be the plastic shrinkage
- Higher ambient temperature and wind velocity will cause higher evaporations causing more plastic shrinkage
- Lower the relative humidity faster will be the evaporation causing more plastic shrinkage
- Higher the cement content of the mix, greater will be the plastic shrinkage

The following factors affect the drying shrinkage in concrete:

- Lower the relative humidity, higher will be the rate of drying causing higher drying shrinkage
- Higher temperature will lead to higher evaporation leading to higher drying shrinkage
- Higher wind velocity will lead to more evaporation leading to higher drying shrinkage
- Higher the stiffness of the aggregates, higher is the restraining effect leading to lower drying shrinkage
- Higher the aggregate/cement ratio, the overall shrinking volume fraction of the concrete decreases leading to lower drying shrinkage
- Higher amount of water in the mix, increases the amount of evaporable water, and thus the potentiality to suffer higher drying shrinkage
- Higher the cement paste content, higher is the shrinking phase of the material leading to more drying shrinkage
- Reducing the w/b ratio will lead to a considerable decrease in the shrinkage strains and the porosity of the cement paste leading to lower drying shrinkage
- Better curing helps in retaining the water in the body of the concrete thus reducing the drying shrinkage
- Large surface area of concrete members leads to higher drying shrinkage

The following factors affect the creep in concrete:

- Higher the ambient humidity, higher will be the rate of drying causing higher creep
- Higher the stiffness of the aggregates, lower will be the creep as aggregate undergo very little creep
- Higher the aggregate/cement ratio, lower will be the creep as the overall volume fraction of the concrete undergoing significant creep decreases. Also concrete made with stiffer aggregate will creep less at same aggregate/cement ratio.
- Higher the SCM content, lower will be the total creep, though initial creep may be more with SCMs like fly ash and GGBS. Addition of ultrafine SCMs will reduce initial as well as total creep.
- Higher w/b ratio will increase the creep as a poorer paste structure will have lower strength, stiffness & impermeability thus undergoing more creep
- Higher the loading stress and time higher will be the creep

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- Higher the strength of concrete, lower will be the creep
- Higher moisture content in the concrete, higher will be the creep as creep is associated with the movement of water within the hydrated cement paste.
- Effect of admixtures differs widely. Specific material should be tested for creep sensitive structures
- Because creep is associated with the movement of water within and out of the hydrated cement paste, creep decreases with increasing volume to surface ratio

3.5 Sources of Water in Concrete

It is understood that the total water content in concrete affects the workability, strength and durability of concrete. The main sources of water in concrete are:

- Water added to concrete during mixing
- Water available as moisture in the coarse and fine aggregate
- Water in chemical admixture added to concrete
- Additional water added to transit mixer before discharge which should be avoided

Other sources of water can be the wash water remaining in concrete batching plant mixer or transit mixer which has not been drained or rain water entering the transit mixer through the hopper during transit. It is very important to check that the batching plant mixer and transit mixer are thoroughly drained before discharge of concrete into it, else it will affect the workability as well as strength and durability of concrete. Hence, it is essential to drain out the water completely. It is important to cover the hopper of transit mixer during rains so that rain water does not enter concrete. Simple arrangement to the transit mixer by providing cover to the top and sides as shown in Fig. 3.4 [5] and Fig. 3.5 [5] can be very effective.

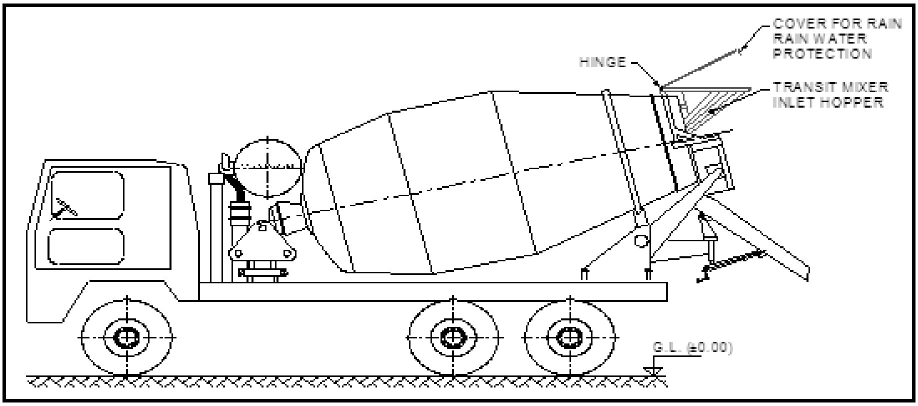

Fig. 3.4 Arrangement for covering Transit Mixer Hopper (top and sides) for protection against rain water

Fig. 3.5 Arrangement for covering Transit Mixer Hopper (top and sides) for protection against rain water

Water added to concrete in the batching plant during mixing is exactly calculated as per the mix design, giving due consideration, for the water correction from the moisture in aggregate. It is important to calculate the exact moisture content in the aggregate before start of each concrete. During rains, the frequency of checking the moisture may be increased. It is to be noted that in computerized batching plant, water correction is made only for fine aggregate and not for coarse aggregate. Hence for good quality control measure it is desirable to provide a shade on the aggregate stockpiles with sprinkling arrangement and batching plant aggregate bins to avoid water entering the bins. A general arrangement is as shown in Fig. 3.6 and Fig. 3.7. This not only prevents rain water from entering the aggregate but also controls the aggregate temperature. It is very desirable to avoid star bins and provide in line bins at the Batching Plant for controlling the rain water falling on to the aggregates.

Fig. 3.6 Providing shade over aggregate stockpile

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Fig. 3.7 Providing cover over batching plant aggregate inline bins

Another source of water in concrete is through use of admixtures. Normally, admixtures have about 60% water and 40% reactive solids. Thus if 4 kgs of admixture is added per cubic metre of concrete, we are adding about 2.4 kgs of water into concrete. This water needs to be accounted for in the total water. But it is unfortunately not done in calculating total water content or water binder ratio. However, authors recommend corrections for such water at least for high strength and high-performance concrete, where strength is very sensitive to water binder ratio.

One of the most undesirable source of water in concrete is the water added in transit mixer to increase the workability of concrete. Adding extra water in transit mixer is a very poor practice followed by some in India which must be stopped. Usually the concrete pump operator adds extra water into the transit mixer in an attempt to increase the workability. Such water added is arbitrary without any calculation and it increase the water binder ratio thus reducing the strength and durability of concrete. In case there is any issue with workability, it must be improved by adding a calculated dosage of admixture by an authorized engineer only. The best way is to add the admixture in two dozes, one at the batching plant and other at the pouring point in the transit mixer. When admixture is put in the transit mixer, transit mixer needs to be rotated full speed for about 3-5 minutes. The transit mixer in transit, rotates at low speed. But when it arrives at the pouring point it should be rotated at full speed for 2-3 minutes.

3.6 Water Used for Concrete and Sustainability

Concrete is the second largest consumed material on earth after water. During concrete production, water is consumed in various activities:

- Water required for production of concrete & curing
- Water used in washing and cleaning of batching plant mixer (BP) and transit mixer (TM)

It is important to control the usage of water to the minimum level to conserve water. Following measures as described in Table 3.5 can be taken to reduce consumption of water.

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Table 3.5 Measures to reduce consumption of water

Activity	Measures to reduce water consumption
Water content in concrete	Use right admixture formulation. This way water content can be reduced by approx. 30% to 40% enabling to have water binder ratio close to 0.3 and still the required workability and retention period can be achieved
Water required for curing	When water is directly sprayed on concrete vertical members almost 75% of water drains out with no utility and the balance water also dries out quickly even with hessian cloth. It is advisable to use sprinklers to avoid wastage of water. Use of hessian cloth spread on the surface will help retain the moisture for a longer period and will reduce the frequency of water sprinkling. Sprinkling can be done continuously and sprinkled water can be collected and reused. Use of effective* surface curing compounds can help eliminate the need to do prolonged water curing, though it is advisable to do at least 3 days of water curing before applying curing compound. Recently self-curing concrete has been developed in which biomaterial or other material having high absorption value are put during concrete mixing, thereby eliminating need for curing water. This is still in experimental stage in India. Little more details on self-curing concrete is available in Chapter 11.
Water used in washing BP and TM	Huge quantity of water is used in washing the plants after completion of concrete works. Instead of discharging the wash water, the same can be retained in the mixer and certain dosage of hydration control admixtures can be added to the water. This will freeze the hydration of the cement particles in the wash water. Before start of concrete the next day, accelerating admixture can be added to this water and the first batch can be produced with the water adjustment.

(*) Note:
Nowadays, good quality effective curing compounds are available in the market. Authors consider curing compounds are effective, if efficiency of curing compound is at least 85% or more with respect to completely submerged cubes in water. Efficiency is measured w.r.t. 28 days strength of cube cured with curing compound and that is cured by submerging in the water tank. With the present practice followed in India, we roughly consume approx. 3 cum. water per cubic metre of concrete produced including curing etc.

3.7 Summary

- Quality of water plays an important role and must satisfy the requirement of IS 456
- Workability of concrete depends on water and chemical admixture content in the mix, whereas the strength and durability depends mainly on water binder ratio
- Moisture correction for aggregate must be done before start of every concrete to maintain the correct water content and water binder ratio
- It is advisable to provide shade on aggregate stockpile and batching plant with star bins to avoid rain water entering the aggregate. Similarly, rain water should not be permitted to enter T.M. through the top opening and sides of hopper of T.M.
- It is a very wrong practice to add water to transit mixer to increase the workability. The workability in transit mixer should be improved by adding right quantity of admixture if necessary by split dozing.
- Necessary steps must be taken to control wastage of water

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CHAPTER 4

AIR CONTENT – IT'S EFFECT ON STRENGTH AND DURABILITY OF CONCRETE

4.1 Introduction

Air is always present in concrete. Air present may be intended i.e. entrained air or unintended i.e. entrapped air. Details of these two types are given in brief in para 4.2 below. The importance of entrained air was first noticed during the 1930s, when certain highway sections were found to be more immune to the effects of freezing and thawing than others. Studies traced it to cement that was milled at plants using beef tallow as a grinding agent. The beef tallow was an unintended air-entraining agent, and it improved the durability of the concrete. Today air entrainment is recommended principally to improve freeze-thaw resistance when exposed to water and deicing chemicals. However, there are other important benefits of entrained air in both freshly mixed and in hardened concrete.

4.2 Entrapped and Entrained Air in Concrete

There are basically two types of air in concrete: entrapped and entrained. It is important to note that entrained air is not the same as entrapped air. Entrapped air is created during mixing, consolidating and placement of the concrete. Air pockets, or irregularly sized air voids, are spread throughout the concrete and have negative effects on product appearance, strength and durability. Proper vibration techniques and tamping are helpful in minimizing entrapped air. Even with best vibration techniques and tamping, around 1% entrapped air remains in concrete.

Entrained air is intentionally created by adding a liquid admixture specifically designed for this purpose. The goal is to develop a system of uniformly dispersed air voids throughout the concrete. Proper use of air-entraining admixtures ensures the development of the correct spacing, size (usually measured in micrometers) and amount of these voids. These voids absorb the pressure created by the expansion of the freezing water. Intentionally entrained air bubbles are extremely small in size, between 10 to 1000 µm in diameter, while entrapped voids are usually 1000 µm (1 mm) or larger. Most of the entrained air voids in normal concrete are between 10 µm and 100 µm in diameter. The air bubbles are not interconnected; they are well dispersed and randomly distributed.

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Non-air entrained concrete with a 20-mm maximum-size aggregate has an air content of approximately 1%. This same mixture air entrained for severe frost exposure would require a total air content of about 6%, made up of both the coarser "entrapped" air voids and the finer "entrained" air voids.

4.3 Properties of Air Entrained Concrete

The introduction of air into concrete mixes has some pronounced effects on the characteristics of both the plastic and the hardened concrete. Some of the major effects of air entrainment in concrete are discussed below.

In fresh concrete, the tiny air bubbles act as a lubricant in the mix which improves its workability and increases its slump. Also, in a sense, the bubbles function as a third aggregate. Because of their small size, the bubbles act as fines, thereby cutting down the amount of sand needed. Since air entrained concrete has higher workability, it is possible to decrease the amount of water to get higher strengths without affecting workability.

Less water means less drying shrinkage – always a desirable feature. Bleeding in concrete is cut approximately to half by entrained air. This reduces considerably the adverse effects of a higher water/binder ratio at the surface of slabs and of laitance forming on concrete surfaces. Air also produces stickier, more cohesive concrete; as a result, less segregation is experienced and more attractive surfaces are achieved.

The resistance of hardened concrete to freezing and thawing in a moist condition is significantly improved by use of entrained air, even when various deicing salts are involved. As the water in capillary pores of moist concrete freezes the volume increases and it produces pressures in the capillaries and pores of the cement paste and aggregate. If the pressure exceeds the tensile strength of the paste or aggregate, the cavity will dilate and rupture. The accumulative effect of successive freeze-thaw cycles and disruption of paste and aggregate eventually cause significant expansion and deterioration of the concrete. Deterioration is visible in the form of cracking, scaling, and crumbling.

Entrained air voids act as empty chambers in the paste where freezing and migrating water can enter, thus relieving the pressures described above and preventing damage to the concrete. Upon thawing, most of the water returns to the pores due to capillary action and the pressure of compressed air in the air voids. Thus, the bubbles are ready to protect the concrete from the next cycle of freezing and thawing.

The most predominant negative effect of entraining air is the loss of strength. For every 1% air entrained in concrete, there is a reduction in strength approximately by 5% as shown in Fig. 4.1 [1]. Every air entrained concrete must be designed taking the above fact into consideration. Table 4.1 [2] below gives the effect of air entraining in concrete on various properties of concrete.

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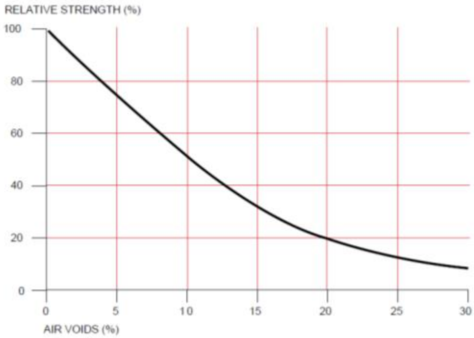

Fig. 4.1 Typical relationship between loss of strength & air voids in concrete

Table 4.1 Effect of entrained air in concrete on concrete properties

Properties	Effect
Fresh Concrete Properties	
Bleeding	Reduces significantly
Slump	Increases with increased air; approximately 25 mm per 0.5-1% increase in air content
Water demand of wet concrete for equal slump	Decreases with increased air; approximately 3 to 6 kg/m^3 per 1% of air content
Workability	Increases with increased air content
Stickiness	Increased cohesion—harder to finish with increase in air content
Finishability	Reduced due to increased cohesion (stickiness)
Hardened Concrete Properties	
Absorption	Little effect
Alkali-silica reactivity (ASR)	Resistance to ASR improves; expansion decreases with increased air content
Bond to steel	Decreases
Compressive strength	Reduces; 1% increase in air content reduces strength by approximately 5%
Creep	Little effect
De-icer scaling	Significantly reduces
Density	Decreases with increased air content
Fatigue	Little effect
Flexural strength	Reduced, approximately 2% to 4% per 1% increase in air content
Freeze-thaw	Significantly improved resistance to water-saturated freeze-thaw deterioration
Modulus of elasticity	Decreases with increased air; approximately reduction of 720 to 1380 MPa per 1% increase in air content
Permeability	Little effect; reduced water-binder ratio reduces permeability
Scaling	Significantly reduces
Sulfate resistance	Significantly improves
Thermal conductivity	Decreases 1% to 3% per 1% increase in air content
Thermal diffusivity	Decreases about 1.6% per 1% increase in air content
Watertightness	Increases slightly; reduced water-binder ratio increases watertightness

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4.4 Air Entraining Admixtures

Air entrainment in concrete can be achieved by adding an air-entraining admixture in the batching plant mixer, by using an air-entraining cement, or by a combination of the two. Numerous commercial air-entraining admixtures, manufactured from a variety of materials, are available. Most air-entraining admixtures consist of one or more of the following materials: wood resin (vinsol resin), sulfonated hydrocarbons, fatty and resinous acids, and synthetic materials. Air-entraining cements comply with ASTM C 150 and C 595. By changing the dosage of air entraining admixture, the amount of air content in concrete can be adjusted as required. The general dosage of air entraining admixture is 0.5 to 1% by weight of total cementitious material. In India, predominantly air entraining admixtures are used for achieving desired entrained air content in concrete. Use of air-entraining cement is not prevalent.

Variations in entrained air content can be expected with variations in aggregate proportions and gradation, mixing time, temperature, and slump. The order of batching and mixing concrete ingredients when using an air-entraining admixture has a significant influence on the amount of air entrained; therefore, consistency in batching is needed to maintain adequate control.

It must be noted that the entrained air content specified for a concrete is always for hardened concrete. It is necessary to understand the loss of entrained air content during transportation, placement and compaction. Usually there will be a loss of 1-2% during these activities. The fresh concrete therefore needs to be designed with slightly higher air content to cater for these losses.

4.5 Factors Affecting Entrained Air Content in Concrete

Table 4.2 [2] gives the effect of concrete constituents and mix design on air content in concrete. Table 4.3 [2] gives the effects of production procedures, construction practices, and environment on control of air content in concrete.

4.6 Summary

- Entrapped air in concrete is undesirable and is mainly due to workmanship issues
- Air entrainment is done in concrete with a purpose of achieving certain properties of concrete – mainly freeze thaw resistance
- Use of air entraining admixture at correct dosage gives the desired entrained air content in concrete
- While designing concrete for a certain entrained air content, it must be understood that there will be a corresponding drop in strength of concrete
- Normally the fresh concrete must have 2-3% more entrained air content than desired air content in hardened concrete to cater to air loss during transportation, handling and compaction.

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Table 4.2 Effect of concrete constituents and mix design on entrained air content in concrete

Characteristic / Material	Effects	Guidance
Ordinary Portland Cement		
Alkali content	Air content increases with increase in cement alkali level. Less air entraining agent dosage is required for high-alkali cements. Air-void system may be more unstable with some combinations of alkali and air-entraining agent used.	Changes in alkali content or cement source may need an adjustment to the air entraining agent. For high alkali cements, the dosage may decrease by approx. 40%.
Fineness	Decrease in air content with increased fineness of cement	For cement with higher fineness dosage of air-entraining admixture requirement will go up. Adjust admixture if cement source or fineness changes.
Cement content in mixture	Decrease in air content with increase in cement content.	Increase air-entraining admixture dosage as cement content increases.
Supplementary Cementitious Materials		
Fly ash	Air content decreases with increase in loss on ignition (LOI). Air-void system may be more unstable with some combinations of fly ash/cement/air-entraining agents.	Changes in LOI or fly ash source require that air entraining admixture dosage be adjusted. LOI has a significant impact on entrainment of air in concrete
GGBS	Decrease in air content with increased fineness of GGBS.	The dosage may increase by significantly for finely ground slag.
Silica fume	Decrease in air content with increased fineness of Silica fume	Increase air-entraining admixture dosage up to 100% for silica fume contents up to 10%.
Metakaolin	No apparent effect.	Adjust air-entraining admixture dosage if needed.
Chemical admixtures		
Water reducers	Air content increases with increases in dosage of lignin-based materials.	Reduce dosage of air-entraining admixture. Select formulations containing air-detraining agents.
Retarders	Effects similar to water-reducers.	Adjust air-entraining admixture dosage.
Accelerators	Minor effects on air content.	No adjustments normally needed.
High-range water reducers	Moderate increase in air content when formulated with lignosulfonates	Only slight adjustments needed. No significant effect on durability.
Aggregates		
Maximum size	Air content decreases with increase in maximum size. Little increase over 40 mm maximum size aggregate.	Decrease air entraining admixture dosage for lower size of aggregate
Sand-to-total aggregate ratio	Air content increases with increased sand to total aggregate ratio i.e. with increasing sand content.	Decrease air-entraining admixture dosage for mixtures having higher sand contents.
Water and workability		
Water chemistry	Very hard water reduces air content.	Increase air entrainer dosage.
Water binder ratio	Air content increases with increased water binder ratio.	Decrease air-entraining admixture dosage as water binder ratio increases.
Slump	Air content increases with slumps up to about 150 mm. Air content decreases with very high slumps. Difficult to entrain air in low-slump concretes.	Adjust air-entraining admixture dosages for slump. Avoid addition of water to achieve high-slump concrete.

Table 4.3 Effects of production procedures, construction practices, and environment on control of entrained air content in concrete [2]

Procedure / Variable	Effects	Guidance
Production procedures		
Batching sequence	Simultaneous batching lowers air content. Adding cement first increases air content.	Add air-entraining admixture with initial water or on sand.
Mixer capacity	Air content increases as capacity is approached.	Run mixer close to full capacity. Avoid overloading.
Mixing time	BP mixers: air content increases up to 90 sec. of mixing. Transit mixers: air content increases with mixing. Short mixing periods (30 seconds) reduce air content and adversely affect air-void system.	Establish optimum mixing time for particular mixer. Avoid overmixing. Establish optimum mixing time (about 60 seconds).
Mixing speed of Transit Mixer	Air content gradually increases up to approx. 20 rpm. Air content may decrease at higher mixing speeds.	Follow truck mixer manufacturer recommendations. Maintain blades and clean truck mixer.
Admixture metering	Accuracy and reliability of metering system will affect uniformity of air content.	Avoid manual-dispensing of air entraining admixture. Provide dispensing unit which is to be calibrated at a frequency of one month
Transport and delivery		
Transport and delivery	Some air (1% to 2%) is normally lost during transport. Loss of air in non-agitating equipment is slightly higher.	If necessary, redose with air-entraining admixture to restore air. Dramatic loss in air may be due to factors other than transport.
Haul time and agitation	Long hauls, even without agitation, reduces air, especially in hot weather.	Optimize delivery schedules. Maintain concrete temperature in recommended range.
Re dosing admixture	Regains some of the lost air. Does not usually affect the air-void system. Redosing with air-entraining admixtures restores the air-void system.	Redose only enough to restore workability. Avoid addition of excess water. Redosing to be done under guidance of QC engineers. After redosing transit mixers to be rotated for 5 minutes. Higher admixture dosage is needed for jobsite admixture additions.
Placement techniques		
Belt conveyors	Reduces air content by an average of 1%.	Avoid long conveyor system if possible. Reduce the free-falling effect at the end of conveyor.
Pumping	Pumping will reduce the air content in mix by 2% to 3% depending on the pumping distance, pressure, etc. Does not significantly affect air-void system. Minimum effect on freeze-thaw Resistance as long as the final air content required in concrete is maintained	Use of proper mix design provides a stable air void system. Avoid high slump, high air content concrete. Keep pumping pressure as low as possible.
Shotcrete	Generally, reduces air content in wet-shotcrete process	Air content of mix should be at high end of target zone.
Finishing and environment		
Internal vibration	Air content decreases under prolonged vibration and/or at high frequencies. Proper vibration does not influence the air-void system.	Do not over vibrate. Avoid high-frequency vibrators (greater than 10,000 vpm). Avoid multiple passes of vibratory screeds. Closely spaced vibrator insertion is recommended for better consolidation.
Finishing	Air content reduced in surface layer by excessive finishing.	Avoid over finishing. Do not sprinkle water on surface prior to finishing.
Temperature	Air content decreases with increase in temperature.	Increase air-entraining admixture dosage as temperature increases.

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CHAPTER 5

IMPROVEMENT IN STRENGTH AND DURABILITY OF CONCRETE BY USE OF SCMs

5.1 Introduction

Use of supplementary cementitious materials (SCMs) as a partial replacement of the cement in concrete is a well-accepted practice in concrete industry in developed countries. Even in India, in recent years it is encouraged widely with due provisions in various Indian standards, though there is reservation in certain quarters including in Indian Railways. SCMs most widely used in India are Fly ash and GGBS (Ground Granulated Blast Furnace Slag). Ultrafine SCM like silica fume has been a popular ingredient in high strength and high-performance concrete for quite some time. Ultrafine GGBS (UFS) and Ultrafine Fly Ash (UFFA) which are Indian inventions are also now available in the country and are slowly gaining popularity. Metakaolin is another ultrafine SCM that is being used in a limited way. The quality of GGBS, silica fume, ultrafine fly ash and ultrafine GGBS are quite consistent. Fly Ash when collected in electrostatic precipitator hoppers is also very consistent. Ultrafine GGBS (UFS) and ultrafine fly ash (UFFA) are found to be far superior to silica fume as noted in para 5.7. The quality of metakaolin (MK) and rice husk ash (RHA) is still not very consistent though metakaolin consistency has improved quite a bit recently.

5.2 Pozzolanic Reaction and Concrete

A pozzolana is a natural or artificial material containing reactive silica. By themselves, pozzolanas have little or no cementitious value. However, in a finely divided form and in the presence of moisture they chemically react with alkalis to form cementing compounds. Pozzolanas must be finely divided to expose a large surface area to the alkali solutions for the reaction to proceed. The silica in a pozzolana must be amorphous or glassy, to be reactive. The chemical reactions are as given below:

Primary Hydration Reaction:

Cement + Water → Calcium Silicate Hydrate + Calcium Hydroxide

Secondary Hydration Reaction:

Pozzolana + Calcium Hydroxide + Water → Calcium Silicate Hydrate

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The secondary hydration reaction is a slow process and goes on for a very long time. It helps the concrete to gain appreciable strength even after 28 days. During secondary hydration, the calcium hydroxide, which is otherwise a weak element in the concrete matrix, gets replaced with calcium silicate hydrate (CSH). CSH is the compound which imparts strength and impermeability to concrete. Thus, concrete with SCMs progressively gain strength and impermeability over time.

5.3 Quality of Supplementary Cementitious Materials in India

SCMs can be generally categorized as fine SCMs (fly ash and GGBS) and Ultrafine SCMs (silica fume, ultrafine fly ash, ultrafine GGBS, metakaolin and rice husk ash). The physical and chemical properties of the above are given in Table 5.1 and Table 5.2 below. Once a mix design is finalized with a particular proportion of a SCM, the performance in the field depends on the variation in chemical and physical properties from batch to batch. The possible variations are given in Table 5.3 below.

Table 5.1 Physical properties of fine and ultrafine cementitious materials

Fine & Ultrafine Pozzolanic Materials	**Cementitious (Pozzolanic) Material**	**Specific Surface Area (m^2/kg)**	**Average Particle size (μ)**	**Bulk Density (kg/cum)**	**Specific Gravity**
Fine Pozzolanic Materials	Cement	260 - 300	20	1300 -1400	3.12
	Fly Ash (FA)	300 - 500	20	900 - 1100	2.3
	GGBS	300 - 500	20	1000 -1200	2.9
Ultrafine Pozzolanic Materials (Average Particle size to be less than 10 μ)	Ultrafine Fly Ash (UFFA)	700 - 900	4	600 - 700	2.3
	Ultrafine Slag (UFS)	1000 - 1200	3	600 - 700	2.9
	Silica Fume (SF)	15000 -20000	0.15	200 - 300	2.2
	Metakaolin (MK)	8000 – 15000	2	1000	2.4 – 2.6

Table 5.2 Average chemical properties of supplementary cementitious materials

Chemical properties	**Portland cement**	**Fly Ash**	**UFFA**	**GGBS**	**UFS**	**SF**	**MK**
SiO_2 (min) %	20	50		38		85	65
Fe_2O_3 %	3.5	10.4		0.3		1.2	1
Al_2O_3 %	5	28		11		0.7	30
CaO %	65	3		40		0.2	0.5
MgO %	0.1	2		7.5		0.2	0.5
$Na_2O + K_2O$ %	0.8	3.2		1.2		1.5	1

Note: Percentages given are approximate average values. Hence, they do not add up to 100%. With actual values combined with miscellaneous items, they will add up to 100%.

Table 5.3 Variations in quality of different SCMs

SCM	Variation in chemical properties	Variation in physical properties
Fly Ash	If source of coal changes often in the thermal plant, it will have an impact on the chemical properties. Generally, it won't differ too much to have a significant impact on the concrete properties	Change in fineness of fly ash may significantly change the performance of concrete both in fresh and hardened state. Fly ash collected through air classification generally has consistent fineness. For better consistency in concrete properties, fly ash from same thermal plant, even with changing coal source, is to be preferred over fly ash from different thermal power plants (Obla, 2015)
GGBS	Generally, it won't differ too much to have a significant impact on the concrete properties	Generally physical properties of GGBS will be consistent since it is a factory-made product
Silica fume	Silica fume is generally collected from various available sources internationally and supplied. In such a situation, the silicon dioxide content can vary significantly causing a lot of variation in the hardened concrete properties. In India silica fume is generally imported from Bhutan, China and Europe.	Fineness of silica fume may vary for different sources and will have an impact on the fresh concrete properties
UFFA & UFS	Since they are produced in controlled condition, there will not be much variation in the chemical or physical properties	

5.4 Effect of Various SCMs on Concrete Properties

The use of various SCMs in concrete has an effect on fresh and hardened concrete properties. Fly Ash is spherical in nature which gives a ball bearing effect reducing the friction in concrete. It generally makes concrete cohesive and flowable. GGBS has a particle shape similar to cement, and does not offer any benefits in fresh concrete like fly ash. Silica fume, though, spherical in nature, is very small in size and increases the fines in concrete. The mix with silica fume is cohesive but needs higher dosage of admixture. It is always advisable to blend fly ash in concrete designed with silica fume.

The effect of fly ash, GGBS and silica fume on fresh and hardened concrete properties is as summarized in Table 5.4 and Table 5.5 and that of silica fume, UFFA and UFS in Table 5.6 below.

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Table 5.4 Effect of various SCMs on fresh concrete properties

Property	Fly Ash	GGBS	Silica fume
Water requirement (Water demand)	⇓ Same workability can be obtained at lower water content	⇔ Water demand of GGBS is almost similar to OPC	⇑ SF particles are very small which increase the total surface area for same weight of OPC. Water demand increases due to this for same workability
Workability	⇑ Due to spherical shape of fly ash, workability increases for same water content	⇔ Very less impact on workability though it slightly improves with same water content	⇓ Workability reduces. Can be compensated by increasing dosage of admixture
Bleeding & Segregation	⇓ Mix becomes cohesive and reduces bleeding and segregation	⇑ Concrete with GGBS has a tendency to bleed. Admixture compatibility is very important	⇓ Bleeding and segregation reduces due to high amount of fines in mix
Air content	⇓ Air content reduces with increase in fly ash content	⇒ Does not affect air content much	⇓ Air content reduces with increase in silica fume content
Heat of hydration	⇓ Dramatic reduction in heat of hydration with increase in fly ash content	⇓ Dramatic reduction in heat of hydration with increase in GGBS content	⇔ Does not affect the heat of hydration as the % replacement is very less (6% to 12%)
Setting time	⇑ Increases the setting time with increase in fly ash content	⇑ Increases the setting time with increase in GGBS content	⇓ Reduces the setting time
Finishability	⇑ Improves due to increased fines and cohesiveness	⇑ Improves due to increased fines	⇔ Varies depending upon the amount of SF used
Pumpability	⇑ Improves due to increased fines and cohesiveness	⇔ Varies. GGBS mix tends to be sticky at higher percentages. Can cause some issues	⇓ Improves pumpability due to increased fines and cohesiveness (upto 2-3% SF). Too much SF can cause stickiness and can cause issues
Plastic shrinkage cracks	⇒ Little to no effect	⇒ Little to no effect	⇑ Increases tendency of plastic shrinkage cracks
Retention Period	⇑ Increases	⇑ Increases	⇓ Reduces

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Table 5.5 Effect of various SCMs on hardened concrete properties

Property	Fly Ash	GGBS	Silica fume
Early strength gain	⇓ Higher the fly ash replacement, lower will be the early strength. Early strength gain drops considerably at higher % of fly ash even upto 7-10 days	⇓ Higher the GGBS replacement, lower will be the early strength. The drop in early strength is not as much as in fly ash	⇑ Higher the % of silica fume, higher will be the early strength. 5-7% SF in concrete made with higher volumes of Fly Ash will offset the early strength gain issue
Long term strength gain	⇑ Higher the % of fly ash, higher will be the long-term strength gain	⇑ Higher the % of GGBS, higher will be the long-term strength gain	⇑⇓ Initial strength gain is observed even upto 90 days, but eventually the strength of concrete with 100% OPC and with SF are same over long term. Sometime drop in strength is observed
Drying shrinkage	⇒ Little to no effect	⇒ Little to no effect	⇑ Increases
Permeability	⇓ Higher the percentage of fly ash, lower will be the permeability	⇓ Reduction in permeability is more than with fly ash, for equal percentage replacement	⇓ Substantial reduction in permeability compared to fly ash, GGBS
Alkali silica reactivity (ASR)	⇓ Higher the percentage of fly ash, lower will be the ASR	⇓ Higher the percentage of GGBS, lower will be the ASR	⇓ Higher the percentage of silica fume, lower will be the ASR
Chemical resistance	⇑ Higher the % of fly ash, higher will be the chemical resistance	⇑ Higher the % of GGBS, higher will be the chemical resistance	⇑ Higher the % of silica fume, higher will be the chemical resistance
Carbonation	⇒ Little to no effect	⇓ ⇒ With high percentage of GGBS, the carbonation will be more for high water binder ratio, but at low water binder ratio, it is practically same.	⇒ Little to no effect

Note: Silica fume content to be restricted to less than 12%. For higher percentages, behavior will be different including reduction in long term strength.

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Table 5.6 Effect of various ultrafine SCMs on fresh and hardened concrete properties

Property	SF	UFFA	UFS
Fresh Concrete Properties (with respect of 100% OPC mixes)			
Water demand	⇑ Increases water demand significantly.	⇒ Increase in water demand is nominal, due to spherical shape of fly ash	⇑ Increases water demand but far less than with SF
Workability	⇓ Reduces workability significantly. Usually compensated by higher admixture dosage	⇒ Slight reduction in workability. Can be compensated by nominal increase in admixture dosage	⇓ Reduces workability but not as much as SF
Stickiness	⇑ Increase in stickiness is highest	⇑ Increase in stickiness is lowest	⇑ Increase in stickiness is slightly higher than UFFA for equal % replacement
Cohesiveness	⇑ Increases	⇑ Increases	⇑ Increases
Hardened Concrete Properties			
Rate of early strength gain	High	Lower than SF/UFS	Practically same as SF
Strength gain after 28 days	⇑ Improves. It is more beneficial to have a triple blend of cement, normal fly ash and/or GGBS and ultrafine material.		
Density of Aggregate - paste interfacial zones	⇑ Improves significantly		
Impermeability of concrete	⇑ Improves significantly		
Sulphate resistance	⇑ Improves significantly		
Resistance to chloride ions	⇑ Improves significantly		
Heat of hydration	No change (Since the percentage replacement is not high)		

5.5 Codal Provisions for Using SCMs in Concrete

In the last few years almost all Indian codes have been revised to incorporate the use of SCMs in concrete. The details are as given in Table 5.7.

Explanation to IS 456 Amendment No.4

Amendment No. 4 of IS 456: Cement content prescribed in this table is irrespective of grades and types of cement and is inclusive of mineral admixtures mentioned in Cl. 5.2 of IS 456. The mineral admixtures such as fly ash or ground granulated blast furnace slag shall be taken into account in the concrete composition with respect to the cement content and water-cement ratio not exceeding the limit of fly ash and slag specified in IS 1489 (Part 1) and IS 455 respectively, beyond which these additions, though permitted, shall not be considered for these purposes.'

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It means maximum quantity of fly ash that shall be taken into account in the concrete composition for minimum OPC content computation specified shall be 35% of minimum cementitious material specified, which is in line with IS 1489 requirements.

However, 35% is not a maximum limit on fly ash content of concrete mix proportion. Thus, for a severe exposure condition concrete, the minimum cement (OPC) must be $(1 - 0.35) \times 320 = 208$ kgs. However, the concrete may have a mix design with 208 kg OPC + 208 kg Fly Ash.

Table 5.7 Codal provisions for use of SCMs in concrete

SCM	IS 456	IRC 112 / MoRTH / IRS
Fly Ash	Permissible upper limit is specified as min. OPC content to be 65% of min. cementitious content specified (IS 456: 2000, Amendment No. 4) based on environment condition, balance could be fly ash.	Max. 35%
GGBS	Permissible upper limit is specified as min. OPC content to be 30% of min. cementitious content specified (IS 456: 2000, Amendment No. 4) based on environment condition balance could be GGBS.	Max. 70%
Ultrafine SCMs	No limits specified. Usually 5-12% for SF, 3-12 for UFS & 6-20% for UFFA	No limits specified. Usually 5-12%

Authors recommendation for replacement of fly ash and GGBS for various types of concrete is as given in Table 5.8.

Table 5.8 Authors recommendations for replacement of Fly Ash & GGBS in various types of concrete

Structure	Recommended % of fly ash	Recommended % of GGBS
Bridge Projects		
Foundations, Piles	35 - 50	70 - 85
Piers & Pier Caps	35 - 50	70 - 85
Superstructure	35	50 - 70
5-7% SF / UFS / UFFA can be used to offset issue of early strength if required*		
Road Projects		
PQC	50	70
CD Works	35 - 50	50 - 70
Thermal Power Projects		
TG Foundations, Rafts	50	70 - 85
Pond Floors	50	70 - 85
Cooling Tower	25 - 35	35-50
Chimney foundations	50	70 - 85
Chimney shell	25	35
Hydro Projects		
Dam body	50 - 70	70 - 85
Tunnel lining	25	35 - 50
Power house & Caverns	35	70
Backfilling & Adit plugs	50	70 - 85

Notes (*):
If triple blending is adopted, combined percentage of fly ash and GGBS can be as much as 85%. Normally for equal strength effect, UFFA must be 2 times that of SF or UFS

5.6 Green, Durable & Economical Concrete with Fly Ash & GGBS

Traditionally, construction activities have relied on using Portland cement. With large infrastructure construction being taken up by the government, the demand and cost of cement is rising.

With the cost of cement and subsequently construction increasing, today the industry demands that the concrete used for building structures should not only have high strength but should also be economical, highly durable and the structure should have longer service life than the previously built structures.

Using ordinary portland cement alone in concrete has many problems in terms of cost, durability and environmental impact. Production of one ton of ordinary portland cement releases approximately 0.9 ton of CO_2 into the atmosphere. The current demand for sustainable construction by reducing the environmental impact and increasing the durability of the structures cannot be ignored.

The use of SCMs like, fly ash, ground granulated blast furnace slag in making concrete is the solution to the above problem. Fly ash or GGBS if not utilized have to be disposed in landfills, ponds or rejected in river systems, which presents serious environmental concerns since it is produced in large volumes. They are not to be considered as a waste product. Research & development has shown that fly ash & GGBS actually represent a highly valuable cementitious material. In order to considerably increase utilization of fly ash & GGBS that otherwise is being wasted, and to have a significant impact on greenhouse gas emissions, it is necessary to advocate the use of concrete that will incorporate these materials as a replacement of cement. A conscious use of these materials, especially the abundantly available fly ash in India, would help conserve natural resources. It would also save energy, help the cause of environment, provide superior concrete structures and benefit the users. Table 5.9 [1] gives a summary of effectiveness of some mineral admixtures on concrete.

Table 5.9 Summary of effectiveness of various mineral admixtures on concrete

Mineral admixture	% addition with respect to total cementitious material	Resistance to ASR	Resistance to carbonation	Resistance to chloride attack	Resistance to sulphate attack	Resistance to industrial wastes
Fly Ash	10 to 25% 26 to 50%	Good Excellent	Moderate Moderate	Good Excellent	Good Good	Negligible Moderate
GGBS	50% 50 to 70%	Very Good Excellent	Moderate Poor with high w/b ratio. Moderate with low w/b ratio	Very Good Excellent	Very Good Excellent	Very Good Excellent
Silica fume	5 to 12 %	Excellent	Moderate	Very Good	Moderate	Moderate

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5.7 Merits of UFFA and UFS over SF

Ultrafine fly ash is a fly ash processed through a classifier where coarser particles are removed and finer particles are collected and stored separately. Ultrafine slag (UFS) is manufactured from slag or from GGBS. It is ground to ultra-finer particles.

The specific surface area and average particle size of these products are noted in average particle size is 4µm for UFFA and 3µm for UFS.

In general, ultrafine fly ash particles are spherical but that of ultrafine slag are not as they are manufactured by grinding. Ultrafine slag and ultrafine fly ash are very effective with respect to giving better slump and retention at given water binder ratio (Fig. 5.1, [2]) and as good as silica fume (Table 5.10, [2]) with respect to early strength gain as revealed by limited study conducted at IIT, Madras.

Table 5.10 Comparision of effect of UFS (Alccofine) & Silica fume addition on compressive strength of concrete specimen with equal water/binder ratio

Compressive Strength (MPa)		
	Concrete Mix with 10% Silica Fume	**Concrete Mix with 10% Alccofine**
1 Day	20.4	20.58 (1.01)
3 Days	38.29	45.11 (1.18)
7 Days	49.83	55.72 (1.12)
28 Days	64.17	67.44 (1.05)
56 Days	68.25	70.42 (1.03)

Note: Numerals in ( ), are ration of compressive strength with 10% Alccofine and that with 10% Silica Fume

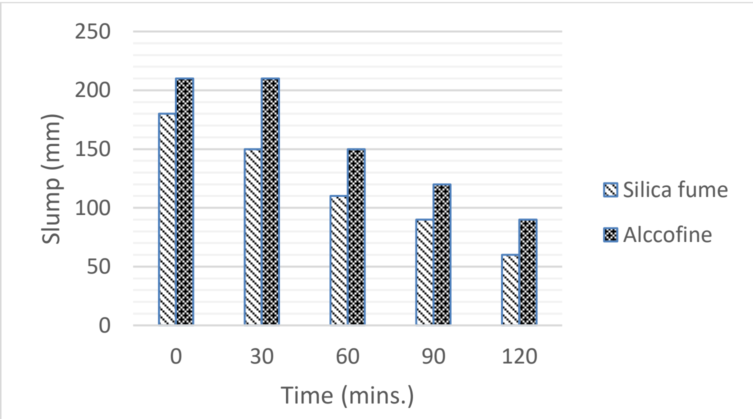

Fig. 5.1 Comparision of UFS and SF on workability of concrete designed with same proportions

Note: UFFA is similar to UFS, but quantity of UFFA has to be practically double that of UFS. Thus, if UFS is used 3%, UFFA may have to be used 6% for similar effect.

By addition of UFS pumpability of concrete improves, while with silica fume it reduces. Other benefits of UFS are that drying shrinkage at early stage gets reduced as compared to silica fume, sulphate resistance and resistance to attack from industrial wastes increases as compared to silica fume. Concrete with silica fume is highly susceptible to early shrinkage cracks, and to minimize these cracks extra care need to be taken by covering concrete surface immediately after surface finishing and curing is to be started soon after final setting of concrete. Thus, UFS and UFFA have all the advantages of silica fume without its disadvantages. Hence, it is very desirable and recommended to replace silica fume with UFS or UFFA. Further both these products are cheaper than Silica Fume.

UFFA is generally used 6 to 15% replacement of cement whereas UFS is generally used in the range of 3 to 12%. The BIS is considering publishing standards on both UFS and UFFA.

5.8 Tests for Assessing Durability

A decade ago, compressive strength was considered the sole parameter to judge the structure. But lately, compressive strength has become one of the parameters to be checked. Durability of concrete is slowly gaining popularity. When it comes to concrete durability, engineers should not rely solely on specifying a minimum compressive strength, maximum water-cement ratio, minimum cementitious content and air entrainment. It should be noted that strength alone should not be used as a surrogate test to assure durable concrete. It is true that a higher strength concrete will provide more resistance to cracking due to durability mechanisms and will generally have a lower w/cm to beneficially impact permeability. However, it should be ensured that the composition of the mixture is also optimized to resist the relevant exposure conditions that impact concrete's durability. This means that the concrete must have the following:

- appropriate cementitious materials for sulfate resistance
- adequate air void system for freezing & thawing and scaling resistance,
- adequate protection to prevent corrosion either from carbonation, chloride ingress or depth of cover,
- a low paste content to minimize drying shrinkage and thermal cracking, and
- appropriate cementitious materials to minimize the potential for expansive cracking related to alkali silica reactions.

There are better ways to quantify durability than compressive strength. Low permeability and shrinkage are two performance characteristics of concrete that can prolong the service life of a structure that is subjected to severe exposure conditions. Some of the latest quality assurance and quality control test methods used for determining the extent to which concrete can withstand corrosion, alkali silica reaction and sulfate attack are described in Table 5.11.

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Table 5.11 Durability tests of concrete

Sl. No.	Name of Test/Service	Standard Procedure
1.0	**Chloride Ingress (Critical for Coastal Areas) is Studied Through**	
1.1	Rapid Chloride Penetration Tests (RCPT)	ASTM C1202
1.2	Non- steady state chloride Migration Test	NT build 492
1.3	Chloride Diffusion Test	ISO 1920 Part 11
2.0	**Deterioration of Concrete Due to Carbonation Attack (Critical in Most of the Non-Coastal Areas Exposed to Normal Weathering) is Studied Through**	
2.1	Accelerated Carbonation Test	ISO 1920 Part 12
3.0	**Sulphate Attack is Studied By**	
3.1	Sulphate Immersion Test on Mortar Bar	ASTM C 1012
4.0	**Alkali Silica Attack on Concrete is Studied By**	
4.1	Accelerated Mortar Bar Test	ASTM C 1260
4.2	Short Term and Long-Term Mortar Bar	IS 2386 –part 7
4.3	Concrete Prism Bar Test	ASTM C 1293
5.0	**Corrosion Effect on Rebar Embedded in Concrete is Studied Through**	
5.1	Accelerated corrosion test	ASTM G1, ASTM G109
6.0	**Additional Test Methods used for Studying Durability of Concrete**	
6.1	Water Permeability Test	DIN 1048 Part 5
6.2	Sorptivity Test	ASTM C1585
6.3	Volume of Permeable Voids	ASTM 642

For assessment of chloride ingress, which is the most critical for durability against corrosion, the RCPT has been a more widely used test. Recent research has proved that the NT Build 492 test is more realistic and reliable than the RCPT for blended cement concrete. DIN test is applicable for water permeability of concrete and not chloride Ion diffusion. Till corrosion point of view, chloride Ion diffusion in concrete is more relevant.

5.9 Summary

- Use of SCMs in concrete is very essential from long term strength, durability and sustainability point of view
- Stress must be given for utilization of indigenous SCMs like fly ash, GGBS, UFS and UFFA to solve disposal issue and provide economical, durable & sustainable concrete.

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- Almost all Indian codes are now allowing use of SCMs in concrete, but many project technical specifications do not allow their use.
- Clients, Engineers and Government authorities must be educated with the benefits of using SCMs

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CHAPTER 6

AGGREGATE – IT'S EFFECT ON QUALITY AND STRENGTH OF CONCRETE

6.1 Introduction

Aggregates are one of the most important constituents in concrete. They give body to the concrete, reduce shrinkage, and effect economy. Earlier, aggregates were considered as chemically inert material but off late it has been recognized that some of the aggregates are chemically active and can cause durability issues. The mere fact that the aggregate occupies 70-80 percent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable.

The importance and contribution of aggregates towards fresh and hardened concrete properties are the most neglected part of concrete technology. Usually one may not understand the importance of investing in aggregate beneficiation. One may want to use the cheapest aggregate available with the perception of reducing cost of concrete. But quite often, it is observed that due to poor quality of aggregate, there is an increase in the total cementitious content and admixture dosage which offsets the low cost of poor quality aggregate.

6.2 Types and Properties of Aggregates

Aggregates can be classified in various ways as shown in Table 6.1. All aggregate to be used in concrete must conform to IS 383-2016. Significance of various properties of aggregate is as given in Table 6.2.

6.3 Grading of Aggregates

Grading of coarse aggregate can be defined as distribution of the particle sizes between the largest size aggregates to lowest size aggregates. Particle size is determined by sieve analysis. Generally, in reinforced cement concrete (RCC), 20 mm down aggregate are used in slabs, beams etc. 40 mm down aggregates may be used in piles, pile caps, piers, pier caps, wells and caissons etc. provided cover to the reinforcements and clear gap between reinforcement is 45-50 mm or more. In self-compacting concrete, tendency is to use 10 mm or 12 mm down aggregate. In mass concrete like dams etc. 80 mm down or 150 mm down or even bigger size aggregates may be used.

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Table 6.1 Classification based on various characteristics of aggregates

Characteristics	Description
Sources of aggregates	Natural aggregates (Sand, gravel, crushed rock such as granite, basalt, sandstone) Artificial aggregates (Broken bricks, air-cooled slag, sintered fly ash, bloated clay)
Shape	Rounded (Shaped by attrition – natural gravel, river sand, desert sand) Irregular or partly rounded (Naturally irregular or partly shaped by attrition, having rounded edges – Pit sand and gravel) Angular – Possessing well defined edges formed at the intersection of roughly planar faces (Crushed rocks of all types) Flaky – Material usually angular, of which the thickness is small relative to the width and/or length (Laminated rocks)
Size of aggregates	Coarse aggregate (Size greater than 4.75 mm) Fine aggregate (Size smaller than 4.75 mm)
Texture	Glassy (Black flint) Smooth (Chert, slate, marble) Granular (Sandstone) Honeycombed and porous (Scoria, pumice, trass) Crystalline (Basalt, dolerite, gabbro, gneiss, granite)
Strength	Aggregate impact value Aggregate crushing value Aggregate abrasion value } Lower the value, higher is the strength
Specific gravity	Light weight aggregate (Usually specific gravity less than 2.0) Normal weight aggregate (Specific gravity between 2.0 – 3.0) Heavy weight aggregate (Specific gravity higher than 3.0)

Table 6.2 Significance of various aggregate properties

Properties	Significance
Specific Gravity	Generally, aggregates with higher specific gravity have higher strength. It determines the density of concrete. Many times, lower limit is mentioned as 2.6, though aggregate with lower specific gravity can also be used subject to condition that other properties are fulfilled.
Water absorption and surface moisture	Required for maintaining the correct water cement ratio in concrete.
Bulk density	Required for estimating quantity of stockpile. Required if aggregate is purchased in volume
Particle shape and surface texture	Determines workability of concrete. Flaky and elongated aggregates increase internal friction in concrete and require higher cementitious content to achieve required workability Rounded aggregate and gravel reduce internal friction and decrease water demand of the mix.
Mechanical properties (Impact value, crushing value, Los Angeles Value)	Determines the resistance of aggregate to attrition, impact and crushing. Determines the usability of aggregate in wearing course concrete.
Alkali aggregate reactivity	Soundness of aggregate and resistance towards volume change
Grading of aggregate	Qualifies the aggregate for use in concrete. Determines the proportion of individual aggregate sizes to be blended together to achieve the desired grading

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If all aggregates are spread over a narrow particle size range, then the aggregate are known as uniformly graded. For such coarse aggregate uniformity coefficient (D_{60}/D_{10}) would be 4 or less. For uniform sand uniformity coefficient would be 6 or less. D60 and D_{10} are diameter of particle corresponding to 60% passing and 10% passing respectively. When aggregates vary gradually in size then they are called as well graded aggregate. In such cases, uniformity coefficient would be more than 4 for coarse aggregates and more than 6 for fine aggregates. If one or more intermediate sizes are missing it is known as gap graded. A uniformly graded aggregate has the highest voids while a well graded aggregate will have the least. Thus, if uniformly graded aggregate is used in concrete it will require higher cement content to fill the voids. It is always advisable to use a well graded aggregate in concrete which has least voids thus requiring minimum cement content. Well graded aggregate is rarely available directly for use in concrete. It is always a good idea to blend two or three different aggregates of varying sizes together to achieve a well graded aggregate system. The proportions of each aggregate will depend upon the individual grading. The percentage of various aggregate fractions should be such that the combined grading is within the limits specified by Road Research Note No. 4, U.K. and McIntosh and Erntroy for various maximum size of aggregate (MSA).

These combined grading curves for MSA 10, 20, 40, 80 and 150 mm are given in Fig. 6.1 to Fig. 6.5 [1]. Four curves are shown for each maximum size of aggregate except 80 mm and 150 mm. From values of percentage passing the lowest curve i.e., curve No. 1 is the coarsest grading and curve No. 4 at the top represents the finest grading. Between the curve No. 1 to 4 are three zones: A, B, C. In practice, the coarse and fine aggregate are supplied separately. Knowing their gradation, it will be possible to mix them up to get grading conforming to any one of the four grading curves. In practice, it is difficult to get the aggregate to conform to any particular standard curve exactly. The actual grading achieved will be varying from the recommended / desired value by some percentage for each sieve size. But if the grading is within the minimum and maximum limits, the combined grading should be satisfactory. It is always advisable to conduct actual lab trials to check the fresh concrete properties for the combined grading and make necessary fine tuning to the percentages as required.

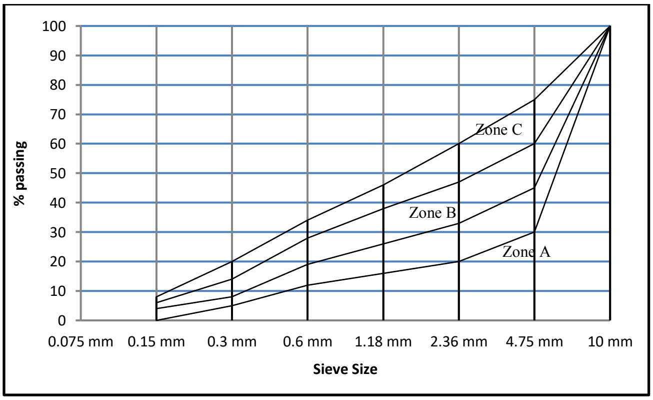

Fig. 6.1 Recommended combined grading curve for MSA 10 mm

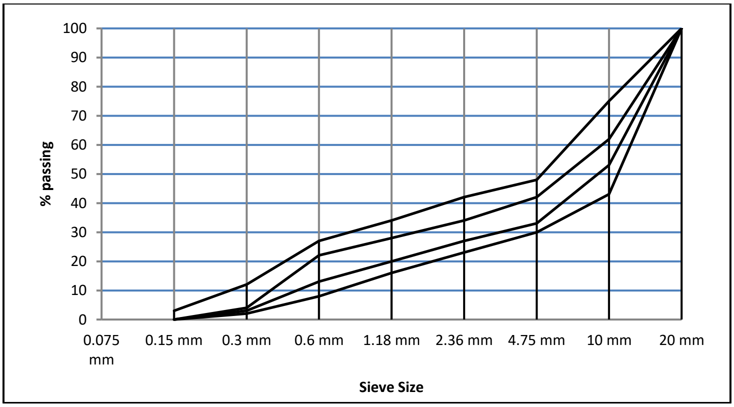

Fig. 6.2 Recommended combined grading curve for MSA 20 mm

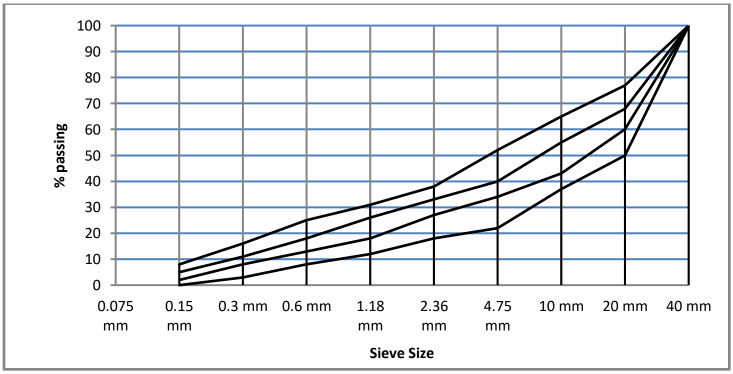

Fig. 6.3 Recommended combined grading curve for MSA 40 mm

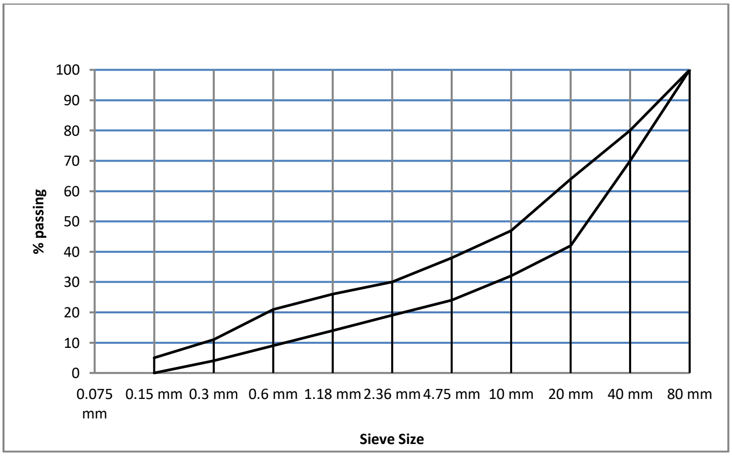

Fig. 6.4 Recommended combined grading curve for MSA 80 mm

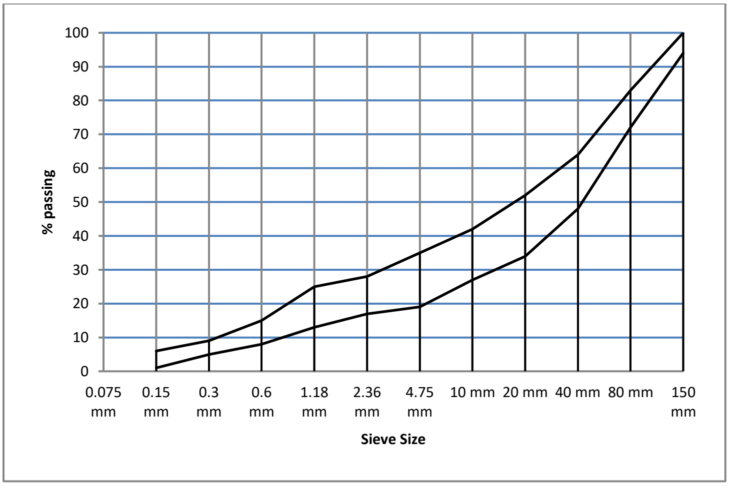

Fig. 6.5 Recommended combined grading curve for MSA 150 mm

As a guideline to achieve a satisfactory combined grading, the tentative percentages of individual fractions may be taken from Table 6.3.

Table 6.3 Tentative % of each aggregate fraction for achieving satisfactory combined grading

MSA	% of each aggregate fraction					
	150 mm	**80 mm**	**40 mm**	**20 mm**	**10 mm**	**Sand**
150 mm	18	17	16	12	8	29
80 mm		22	21	18	10	29
40 mm			27	22	14	37
20 mm				36	24	40
10 mm					60	40
10 mm (Shotcrete)					30	70

Thus, if the MSA is 80 mm in concrete, we can start with 80mm fraction of 22%, 40 mm fraction of 21%, 20 mm fraction of 17%, 10 mm fraction of 10% and sand fraction of 29%. Check the combined grading curve obtained with these percentages. If the combined grading curve obtained seems unsatisfactory change the individual percentages to obtain a satisfactory curve. Once the combined grading curve lies within the limits, conduct lab trial to check the actual performance. If required, make further fine tuning to the aggregate proportions.

A simple method to ascertain well graded packing is to put all the ingredients in different proportion in a container and vibrate it well over a vibrating table to achieve maximum possible densification. A grading combination giving highest density is the well graded desired packing with minimum voids. Some guidelines for fine tuning are as follows:

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- If the concrete mix looks too coarse, reduce the percentage of coarse aggregate and increase fine aggregate content
- If the mix is segregating or bleeding, the fines in the mix may be less. Increase the fine aggregate content in the mix
- If the mix looks too sticky or has less workability but no bleeding and segregation, the fines in the mix may be too high. Reduce the fine aggregate percent

The term fine content means any material passing 150μ sieve. It includes fines in the sand, cement and SCMs. If the sand does not contain enough fines, increasing the sand content will not serve the purpose. In such a case, we may need to blend finer sand if available, or increase the amount of SCM in the mix. If the above two options are not available, increasing cement content will be the last option.

6.4 Strength, Abrasion Resistance, Elastic Modulus and Soundness of Aggregates

Strength of concrete cannot exceed that of rock/aggregates. Abrasion resistance and elastic modules are generally indicative of strength of the rock. Invariably rock/aggregate with high strength will have better soundness. Lower aggregate crushing value, impact and abrasion value means higher strength of aggregates. These parameters are very important in qualifying aggregate for use in concrete for wearing surfaces wherein higher strength is desired.

The soundness of the aggregate indicates the resistance of aggregate to severe climatic changes such as freezing and thawing, and alternate wetting and drying. The method of testing is defined in IS:2386 (Part IV).

Elastic modulus of aggregate is generally related to the strength. Higher the strength, higher is the elastic modulus. Elastic modulus of hard rock generally varies between 200 MPa to 300 MPa. In general, for a given strength of concrete, if aggregate with higher elastic modulus is used, the modulus of elasticity of concrete is also correspondingly higher. This parameter is of high importance in prestressed concrete and tall structures.

6.5 Effects of Shape and Size of Aggregates in Concrete

Aggregate shape and surface texture influence the properties of freshly mixed concrete as well as the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Generally, flat and elongated aggregate should be avoided and the combined elongation and flakiness index limited to about 35% by weight of the aggregate. The codal limits for combined elongation and flakiness index as specified in IS 383-2016 is 40%. The water requirement of a concrete mix is the amount of water needed to produce one cubic metre of concrete, of the desired workability. The water requirement of a concrete mix is important as it has a direct effect on the economy of

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the mix (high water requirement = high binder content = high cost), and on the drying shrinkage of the concrete (high water content = high drying shrinkage).

As a general rule, coarse sands have lower water requirements than fine sands, but this is not always true. Well-graded sands tend to have lower water requirements than single-sized sands and increasing dust contents tend to increase the water requirement of sands. In general, sands with a rough surface texture (crushed sand) will have a higher water requirement than sands with smooth particle surfaces (natural sand). On the other hand, sands with a slightly rough surface texture give slightly higher concrete strengths because of improved bond.

Similar effect is observed with the shape and texture of coarse aggregate. Higher the mean size of aggregate, lower is the surface area for a given unit mass, thus requiring lesser cementitious material for effectively coating all the aggregate particles. Generally, total cementitious content can be reduced by approx. 30 kg/m^3 when MSA 40 mm is used instead of MSA 20 mm. If MSA 10 mm is used, the total cementitious content will increase by approx. 40 kg/m^3 over MSA 20 mm. Reduction in total cementitious content has a lot of benefits: cost optimization, lower heat of hydration and lower shrinkage & creep and better sustainability.

Bigger the MSA, greater will be the compressive strength of concrete. But this is valid only up to a certain limit, after which, the compressive strength of concrete starts to decrease as the MSA increases (Fig. 6.6, [1]). This is because of the following reasons:

- Larger the size of the aggregate, greater is the tendency of blocking the bleed water and thus weaker is the transition zone (higher w/b ratio in area around the aggregate). This results in concrete cracking through the transition zone since both the other phases (aggregates and cement paste) are much stronger.
- Internal bleeding can take place when water gets trapped on the underside of a large sized aggregate which results in a zone of poor bond. As the trapped water evaporates, a void is formed. All such voids formed due to internal bleeding are oriented in the same direction, and this adversely affects the strength.

It is always advisable to use the highest MSA possible in the structure, especially upto M40 grade concrete as beyond M40 using higher MSA will lead to lower strengths, which means the total cementitious material will increase thus negating the benefits of using higher size aggregate.

6.5.1 Use of crushed sand as fine aggregate

All along we, in India have been using natural sand in concrete. But of late, there is growing shortage of natural sand in many cities. In some states dredging for natural sand is banned. More states are likely to follow soon. The severity varies from market to market, and in some cases, this may not appear to be a priority topic. The quality of natural sand varies from season to season. Eventually, pressure from environmentalists and sand conservationists worldwide will continue to encourage both legislators and construction engineers to look for viable alternatives to natural sand. The best

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alternative to natural sand is to use sand produced by crushing hard stone, generally called as crushed sand. Table 6.4 gives a comparision between natural and crushed sand. Fig. 6.7 below gives typical grading of natural and crushed sand.

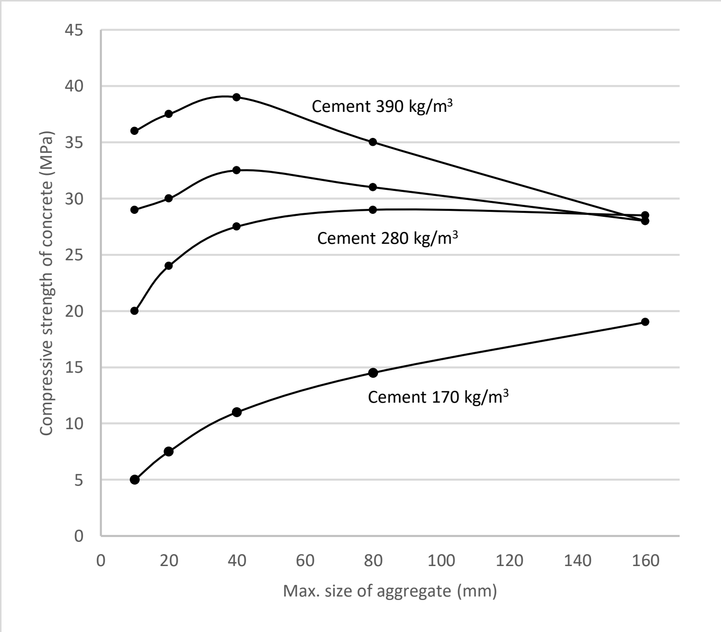

Fig. 6.6 Relationship between MSA and compressive strength of concrete designed with varying cement contents

Presently many aggregate suppliers use single staged Jaw crushers. The fine aggregate produced through this process is flaky and irregular in shape. Also, the overall process is of very small scale and primitive, with no scalping stage in the process flow. The lack of scalping in process leads feeding of all unclean materials from quarry into the main crushing flow, and thereby results in high level of inconsistency in grading, especially in the finer fines (clay & silt). This also leads to lack of control on the properties of fine particles, as the content of clay and impurities can be sometimes very high and generally inconsistent as per feed.

Table 6.4 Comparison between Natural Sand & Crushed Sand

Natural Sand	Crushed Sand
It is the result of natural weathering and abrasion of rock	A fine aggregate produced by crushing rock, gravel or slag
Mostly alluvial or weathered rock, but can be of marine origin also	Can often be flaky & elongated displaying sharper, angular edges and rough surface texture
Natural sands are rounded and smooth	Higher micro-fines content

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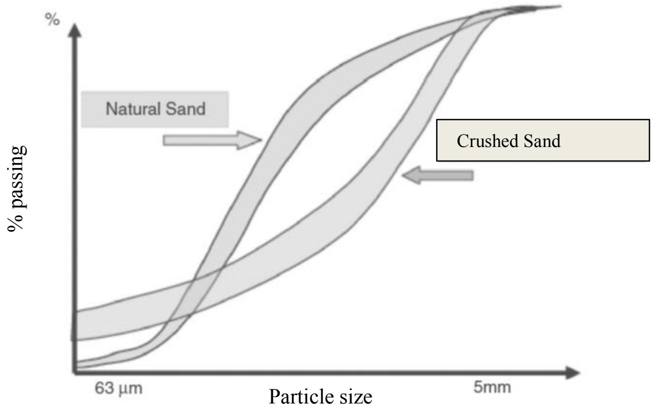

Fig. 6.7 Typical grading curves for natural and crushed sand

Optimal process

The optimal process for crushed sand could be a 3-stage crushing and screening process, which in turn can be of the following configuration

Scalping process ⟶ Primary Jaw ⟶ Secondary Cone ⟶ Tertiary Vertical Shaft Impactor

or

Scalping process ⟶ Primary Jaw ⟶ Secondary Cone ⟶ Tertiary Cone

The scalping process help in removal of deleterious material like overburden, silt & clay from entering into the primary crusher. The schematic diagram is shown in Fig. 6.8 of scalping arrangement integrated into the crushing plant system.

Both processes have their respective advantages and disadvantages. While using a VSI in the tertiary stage improves the shape of the particles as shown in Fig. 6.9, it in turn produces higher micro-fines. This can be arrested by using a cone in the tertiary stage, but care should be taken in selection of the right cone crusher for the purpose. Using a washing process (wet classification) or an air classifier can reduce the content of micro-fines in the sand, but leads to disposal hazards of the waste product which can be in conflict of inclusive and sustainable construction practices.

In order to reduce fines in VSI crushing system, the new generation VSIs are provided with by-pass system. If the fines are more, certain amount of feed is by-passed from VSI, the percentage by-pass is arrived at by trial and error method. Of course, there is a gate valve to adjust the by-pass quantity

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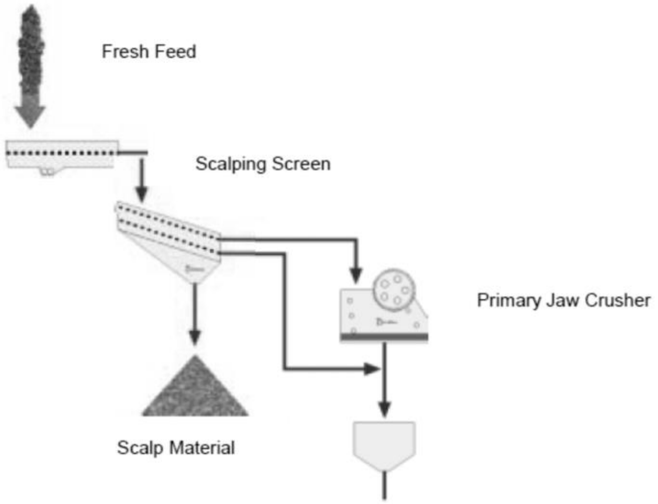

Fig. 6.8 Scalping screen integrated in crushing plant

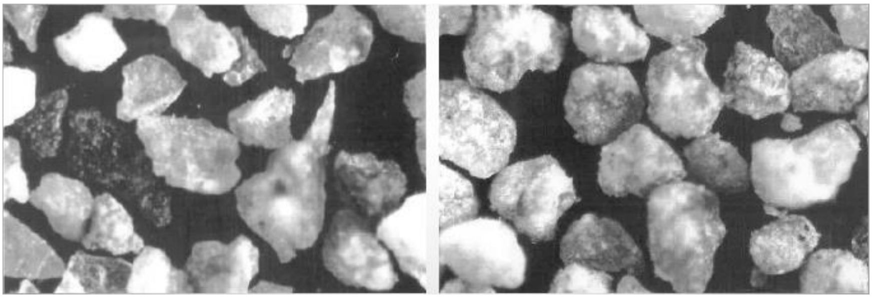

Fig. 6.9 Comparison of 2.5 mm – 1.5 mm grains before and after VSI crusher

Tests for manufactured sand

From the producer & users' perspective, the main areas of control while producing or using manufactured sand shall be:

- Particle size distribution and content of micro-fines
- Properties of aggregates associated with assessment of fines (noxiousness)
- Properties of aggregates associated with surface characteristics (shape)

Particle size distribution (PSD) and content of micro-fines

For the PSD and content of micro-fines, the grading (sieve) analysis should be used as a deterministic test. Table 6.5 [2] can be used in accordance with IS:383 for the purpose.

Table 6.5 Limits of fine aggregate grading (Zone II) as per IS 383 for manufactured sand

IS Sieve Size (mm)	*Cumulative % passing*		
	Lower Limit	*Upper Limit*	
10	100	100	
4.75	90	100	
2.36	75	100	
1.18	55	90	
600µ	35	59	
300µ	8	30	
150µ	0	20	}*
75µ	0	15	
Pan			

Note: Though these limits are as per IS 383, it is advisable as per the authors to restrict these values respectively to 15 and 10 for better quality concrete

Properties of aggregates: Assessment of fines (noxiousness)

The methylene blue value test (MBV) can be used as a deterministic test for the assessment of the characteristics of fines. The relevant international code is the British Standard BS EN 933-9:1999 or the equivalent European Standard EN 933-9:1998 and is titled as "Tests for geometrical properties of aggregates Part 9: Assessment of fines – Methylene blue test". Unfortunately, there is no equivalent Indian Standard.

Principally, the standard specifies a method for the determination of the methylene blue value (MBV) of the 0-2 mm fraction in fine aggregates or all-in aggregates. Increments of a solution of methylene blue are added successively to a suspension of the test portion in water. The adsorption of dye solution by the test portion is checked after each addition of solution by carrying out a stain test on filter paper to detect the presence of free dye. When the presence of free dye is confirmed the methylene blue value (MB or MBV) is calculated and expressed as grams of dye adsorbed per kilogram of the size fraction tested. The principle of the test is that clay minerals adsorb basic dyes from aqueous solutions, therefore the greater the quantity of dye absorbed the greater the quantity of potentially harmful fines present.

Properties of aggregates associated with surface characteristics (shape)

The flow coefficient of aggregates test can be used as a deterministic test for assessment of surface characteristics (shape) of aggregates. The relevant international code is the BS EN 933-6, titled as "Tests for geometrical properties of aggregates Part 6: Assessment of surface characteristics — Flow coefficient of aggregates". There is no equivalent Indian Standard.

This European Standard specifies methods for the determination of the flow coefficient of coarse and fine aggregates. It applies to coarse aggregate of sizes between 4 mm and 20 mm and to fine aggregate. The flow coefficient of an aggregate is the time, expressed in seconds, for a specified volume of aggregate to flow through a given opening, under specified conditions using a standard apparatus.

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6.6 Aggregate Washing

Nowadays the finished product needs to meet specifications outlined by the ever stringent and demanding world markets. Where dry screening was accepted in the past, washing and rinsing is now required to produce a silt free product.

In India screw classifiers (Fig. 6.10) are the mainstay for washing, both natural and crushed sand. These are cheap to buy, but lead to loss in excess of 20% fine sand. This resulted in a lack of finer fractions of sand between 1mm and 300µ in the grade and quality of the final washed product. When the silt and clay content is very high, single washing cycle does not give the required quality product and the washing needs to be done in 2 to 3 cycles. Another drawback is the loss of production when settling ponds need to be cleaned on a regular basis. The overall low productivity, high water usage and issue in quality of final product have led to seek alternate sophisticated methods for washing aggregate.

Fig. 6.10 Typical screw classifier for washing sand

The new washing machines function more than just washing of aggregate. They generally perform the following functions.

- Removal of clay and silt
- Removal of shale, coal, soft stone, roots, twigs and other trash
- Sizing
- Classifying or separating
- Dewatering
- Recycling the used water

The aggregate from crushing plant is directly fed into these washing units for further processing. The aggregates are washed with high water jets as they pass over the vibrating screens, thus removing the fines. The washed aggregate pass through dewatering screens for removing the excess water and are then separated as per the required size. These machines have facility to separate the fine aggregate into two fractions if required (Fig. 6.11 & Fig. 6.12).

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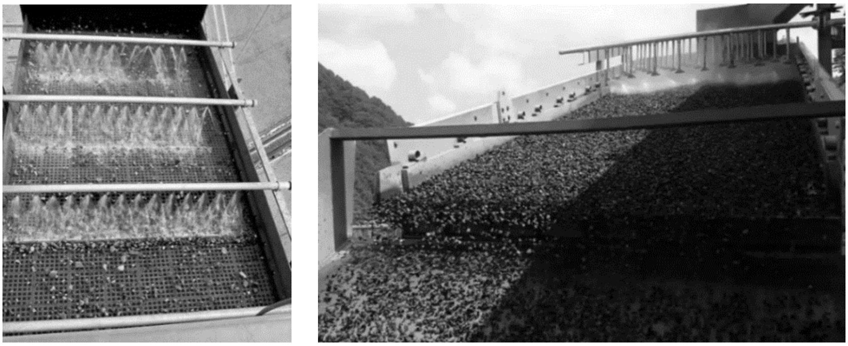

Fig. 6.11 Aggregate material being washed as it passes over a screen deck

Fig. 6.12 Typical layout of aggregate washing system integrated into crushing plant

6.7 Aggregate Moisture Correction

Rocks have pores or cavities; the extent varies from rock to rock. These pores in rock develop due to presence of air bubbles which are entrapped in rock during its formation or due to decomposition of constituent materials. Porosity can vary from close to zero to 20 percent in general and much higher in some cases.

When all the pores are dry, the condition is termed as *bone dry condition (A)*. When the pores are partly filled with water, it is termed as *air dry condition (B)*. If the aggregates are completely saturated with water but there is no water on the surface of aggregate, the condition is known as *saturated surface dry (SSD)* condition (*C*). If the aggregate is fully saturated and there is water on the surface it is termed as *wet condition (D)*. The various aggregate states are indicated in Fig. 6.13.

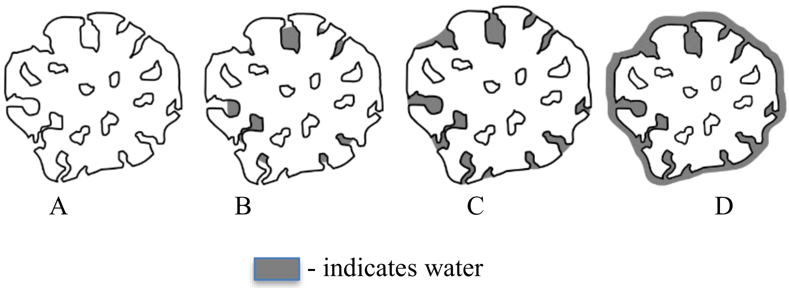

Fig. 6.13 Various aggregate states

A – Bone Dry, B – Air Dry, C – Saturated Surface Dry, D – Wet

Bone dry aggregate – Bone oven dry aggregate contains no moisture and will absorb water from the surrounding cement paste.

Air dry aggregate – The pores connected to the surface are partially full of moisture but the surface remains dry. Air dry aggregates will absorb water from the surrounding cement paste.

Saturated Surface Dry aggregate – The pores connected to the surface are completely full of moisture but the surface remains dry. Saturated surface dry aggregates are at equilibrium - they will neither absorb nor give up water to the surrounding cement paste.

Wet aggregate – All pores connected to the surface are completely full of moisture and there is a film of water on the surface. Wet aggregates will give up water to the surrounding cement paste.

Water required for effective absorption and surface moisture is known as absorbed water, knowledge of absorbed water is necessary in concrete mix proportioning.

The properties of fresh and hardened concrete are affected by the quantity of mixing water in the concrete mix. The mixing water includes all sources of water including batch water, free moisture on aggregate, ice, water in admixtures and extra water added in transit mixer (extremely undesirable). The total mixing water determines the w/b ratio of concrete. For a set of material proportion, there is a unique relationship between w/b ratio and the strength and durability characteristics of concrete. Any change in the w/b ratio will have an impact on the properties. If correct moisture correction is not done and excess water is added into concrete, the w/b ratio increases, reducing the strength and durability of concrete. If less water is added to concrete, it will lead to reduced workability and may lead to undesirable adding of water in transit mixer at pouring point. Table 6.6 gives a typical moisture correction calculation.

Table 6.6 Typical moisture correction calculation

Material	Batch Quantity, SSD condition (kg)	Water Absorption (%)	Moisture Content (%)	Moisture Adjustment		Corrected Batch quantity (kg)
				%	Wt. (kg)	
Cement	430					430.0
20mm	643	0.50	0	-0.50	3.21	646.0
10mm	522	0.60	0	-0.60	3.13	525.4
N. Sand	603	1.20	5.00	3.80	-22.90	625.5
C. Sand	241	2.00	4.00	2.00	-4.82	245.8
Water	146.20	(146.2 + 3.21 + 3.13 - 22.9 - 4.82 - 4.5/2) =				122.6
Admixture	4.5					4.5

6.8 Alkali Aggregate Reactivity (ASR)

Some aggregates containing particular varieties of silica may be susceptible to attack by alkalies (Na_2O and K_2O) originating from cement and other sources, producing an expansive reaction which can cause cracking and disruption of concrete. Damage to concrete from this reaction will normally occur only when all the following are present together:

1. A high moisture level within the concrete.
2. A cement with high alkali content, or another source of alkali.
3. Aggregate containing an alkali reactive constituent.

The alkali aggregate reactivity can be determined by one of the following methods:

1. Chemical method (does not always give accurate results and some reactive aggregate may be indicated as non-reactive)
2. Mortar bar test (Accurate but time consuming, needs 180 days of testing period)
3. Accelerated mortar bar test (Accurate and quick, needs 16 days of testing period)

If the sole source of alkalis in concrete is Portland cement, then limiting the alkali content in the cement would prevent the occurrence of deleterious alkali silica reactions. The minimum alkali content of cement at which expansive reaction can take place is 0.6% of the total alkali content. This is calculated from the actual Na_2O content plus 0.658 times the K_2O content of the clinker. The limit of the 0.6% total alkali content defines the low-alkali cement.

Total alkali content = $Na_2O + 0.658 \times K_2O$

One of the most effective mitigation methods for ASR is to use supplementary cementitious material like fly ash, GGBS or silica fume, etc. When SCM is added to concrete to protect against ASR, the level of cement replacement will depend on the SCM used. Approximate replacement levels needed to minimize ASR damage are:

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- more than 25% for fly ash (Fig. 6.14)
- more than 50% for blast furnace slag (Fig. 6.14)
- 7-10% of total binder content for silica fume (Fig. 6.14)
- 12-15% for metakaolin (Fig. 6.14)

The level of replacement needed to control ASR expansion will vary with the aggregate, the cement, the presence of other SCMs, and the chemistry, mineralogy and particle size distribution of the SCMs used, and must be determined by testing. Concrete containing SCM must be thoroughly cured to ensure that the cement is fully hydrated, the SCM is fully reacted and the desired long-term properties achieved. This may necessitate extended curing periods for SCMs that hydrate more slowly than Portland cement. Fig. 6.14 [3] shows the effect of SCMs on two-year expansion of concrete containing siliceous limestone.

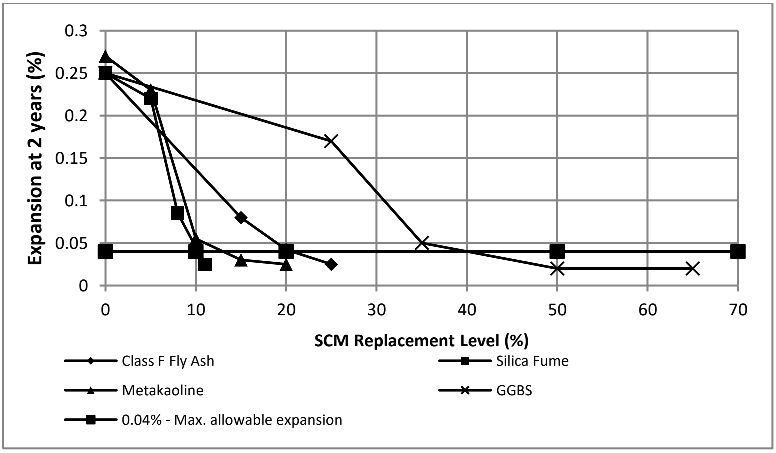

Fig. 6.14 Effect of SCMs on Two-Year Expansion of Concrete Containing Siliceous Limestone (Shehata and Thomas 2002; Ramlochan et al. 2000; Thomas and Innis 1998)

6.9 Use of Industrial Waste as Aggregate

Indian Standard for Coarse and Fine Aggregate, for Concrete – Specification IS:383-1970 permitted use of natural aggregates, coarse and fine derived from suitable rocks. Though the code permitted use of crushed stone fine aggregates in place of natural river sand but it neither helped in conserving the natural rocks nor in mitigating the adverse effect on environment.

It is now realized that industrial by-products like metallic slags and recycled concrete aggregates, should also be included in the national standard to conserve limited natural resources and to increase sustainability of concrete construction.

Fortunately, the code has been revised and the version of the code issued by BIS in January 2016 (IS:383-2016) has partially included the industrial by-products and construction and demolition (C&D) waste for use as coarse and fine aggregates. The

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revised code permits partial replacement of natural aggregates by C&D waste and industrial by-products as noted in Table 6.7 [2].

Table 6.7 Extent of Utilization (based on Table -1 of IS: 383 – 2016)

Sl. No.	Type of Aggregate	Maximum Utilization		
		Plain concrete %	**Reinforced Concrete %**	**Lean Concrete (Less than M15 Grade) %**
(1)	(2)	(3)	(4)	(5)
i)	Coarse Aggregate			
	Iron Slag aggregate	50	25	100
	Steel slag aggregate	25	Nil	100
	Recycled concrete aggregate (RCA) (see Note 1)	25	20 (Only upto M25 Grade)	100
	Recycled aggregate (RA)	Nil	Nil	100
	Bottom ash from Thermal Power Plants	Nil	Nil	25
ii)	Fine Aggregate			
	Iron slag aggregate	50	25	100
	Steel Slag aggregate	25	Nil	100
	Copper slag aggregate	40	35	50
	Recycled concrete aggregate (RCA) (see Note 1)	25	20 (only upto M25 Grade)	100

Notes
It is desirable to source the recycled aggregates from sites being redeveloped for use in the same site.
In any given structure, only one type of manufactured coarse aggregate and one type of manufactured fine aggregate shall be used.
The increase in density of concrete due to use of copper slag and steel slag aggregates need to be taken into consideration in the design of structures.

Some of the most prominent industrial wastes that can be used as aggregate are:

- Recycled concrete aggregate (RCA)
- Iron and copper slag as fine aggregate

RCA in concrete reduces the slump (in fresh stage), increases the permeability, reduces flexural strength but negligible effect on compressive strength for permissible replacement level of natural aggregate. RCA concrete, however, has better resistance to carbonation than natural aggregate. Drying shrinkage and creep of RCA concrete may be higher than natural aggregate concrete but when its use is restricted to 20% replacement as per IS 383, then results are comparable to natural aggregate concrete. Effects of RCA as fine aggregate on slump, compressive and flexural strengths, drying shrinkage etc. are similar to that of RCA as coarse aggregate. But with 20% replacement of RCA fine aggregate in reinforced cement concrete, adverse effects are negligible and behavior similar to natural fine aggregate is observed. Research on use

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of iron and copper slag as fine aggregate has proved that, when used in reasonable limits, the performance of concrete is similar to that of concrete designed with conventional aggregates.

Recycled concrete aggregates (RCA) can be used (i) as aggregates in subbase, base course and for shoulders (ii) in gravel road as surfacing (iii) for nonstructural concrete for kerbs, sidewalks and gutters (iv) in concrete paving blocks and (v) for concrete pavement (vi) drainage medium. Unfortunately, MoRTH (Ministry of Road Transport and Highway) Handbook does not permit these aggregates in any concrete, structural or non-structural. But many other countries like Canada, Australia allow use of RCA in non-structural and even in structural concrete but with limited replacement levels. MORTH specification, of course, allows these RCA in sub-base and base courses. However, the use of industrial wastes in India is not a popular practice mainly because of the codal restrictions and limited research and very limited projects executed.

6.10 Summary

- Aggregate beneficiation is one of the most neglected area in the field of concrete technology. Using better quality aggregate has a lot of benefits including cost optimization
- It is more important to have combined grading of aggregate as per requirement, rather than just the individual grading. Even if the individual grading is slightly out of the IS 383 grading requirements, but the combined grading is satisfying the requirement, it should suffice.
- It is important to estimate the silt and clay in aggregate as it has a negative impact on strength and durability of concrete apart from hampering the workability and retention
- Washing of aggregate, especially the fine aggregate has tremendous benefits in improving the concrete properties and offsets the extra cost through optimization of mix design
- Coarse aggregate moisture correction must be done before start of every concrete in order to maintain the required w/b ratio.
- Effective use of industrial wastes in concrete will lead to further the cause of sustainable construction without compromising on the performance of the concrete.

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CHAPTER 7

CHEMICAL ADMIXTURES - THEIR EFFECT ON QUALITY & PERFORMANCE OF CONCRETE

7.1 Introduction

Chemical admixtures are chemicals added to concrete, mortar or grout at the time of mixing to modify properties; either in the fresh state immediately after mixing or after mix has hardened. They can be a single chemical or a blend of several chemicals and may be supplied as powders but most are aqueous solutions because in this form they are easier to accurately dispense into, and then disperse through the concrete.

The active chemical (active solid content) is typically 35–40% in liquid admixtures but can be as high as 100% (e.g. shrinkage-reducing admixtures) and as low as 2% (e.g. synthetic air-entraining admixtures). The added water from the admixture is generally not corrected for water–cement ratio. However, authors strongly recommend this to be done, to begin with at least in case of high strength and high-performance concrete.

Admixtures are usually being added at less than 5% on the cement in the mix but the majority of admixtures are used at less than 2% and the typical range is 0.3–1.5%. This means the active chemicals are usually present at less than 0.5% on cement or 0.02% on concrete weight. The dosage may be expressed as litres or kg per 100 kg of cementitious material.

7.2 Types of Admixture and Their Advantages

Some of the major International and National standards for chemical admixtures are given below:

- IS 9103 – Specification for Concrete Admixtures
- ASTM C 494 – Standard Specification for Chemical Admixtures for Concrete
- ASTM C 1017 – Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete
- ASTM C 260 – Standard Specification for Air-Entraining Admixtures for Concrete
- ASTM C 1141 – Standard Specification for Admixtures for Shotcrete

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- BS EN 934 – Admixtures for concrete, mortar and grout. Common requirements

Classification of admixtures, based on usage is given below:

- Air-Entraining agents
- Water-reducing and High range water reducing admixtures (Plasticizers and Superplasticisers)
- Retarders
- Accelerators
- Water proofing admixtures
- Corrosion-inhibiting admixtures
- Shrinkage reducing admixtures

Classification of admixture as per various standards is as given in Table 7.1. Desired fresh and hardened concrete properties can be achieved by selecting the appropriate admixture formulation as noted in Table 7.2.

Advantages of using admixtures are given below:

In the fresh state:

- Increases workability by reducing water demand
- Reduces slump loss
- Achieves economy in high-strength concrete by reducing cement consumption due to reduced water demand
- Improves Rheology by controlling segregation and bleeding
- Accelerates or retards the setting time of concrete, as per site requirement
- Enhances freeze-thaw resistance
- Enhances facilities for achievement of high early strength/high performance concrete.

In Hardened state:

- Retards or reduces heat evolution during early hardening
- Can accelerate strength development at early ages
- Increases strength without increasing cement content mainly because of reduced water demand
- Increases durability mainly by reduced w/b ratio
- Decreases permeability mainly by reduced w/b ratio
- Controls expansion due to alkali-aggregate reaction
- Improves impact resistance and abrasion resistance
- Inhibits corrosion of steel
- Can produce coloured concrete or mortar

Desired fresh and hardened concrete properties can be achieved by selecting the appropriate admixture formulation as noted in Table 7.2.

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Table 7.1 Classification of admixture as per various standards

TYPE OF ADMIXTURE	EN	BS	ASTM	IS
Water Reducing Admixture (WRA) or Plasticizer	EN 934 (Part 2), Clause 4.2, Table 2	BS 5075 Part I	ASTM C494, Type A, ASTM C1017, Type 1	IS 9103, Table 1A
High Range Water Reducing Admixture (HRWRA) or Superplasticizer	EN 934 (Part 2), Cl. 4.2, Table 3.1 and 3.2	BS 5075 Part III	ASTM C494 Type F	IS 9103, Table 1A
Water Retaining Admixture	EN 934 (Part 2), Cl. 4.2, Table 4	-	-	-
Air Entraining Admixture (AEA)	EN 934 (Part 2), Cl. 4.2, Table 5	BS 5075 Part II	-	IS 9103, Table 1A
Accelerating Admixture	EN 934, Cl. 4.2, Table 6	BS 5075 Part I	ASTM C 494 Type C	IS 9103, Table 1A
Hardening Accelerating Admixture	EN 934 (Part 2), Cl. 4.2, Table 7	-	-	-
Set Retarding Admixture	EN 934 (Part 2), Cl. 4.2, Table 8	BS 5075 Part I	ASTM C494 Type B	IS 9103, Table 1A
Water Resisting Admixture	EN 934 (Part 2), Cl. 4.2, Table 9	-	-	-
Water Reducing and Retarding Admixture	EN 934 (Part 2), Cl. 4.2, Table 10	BS 5075 Part I	ASTM C494 Type D, ASTM C1017, Type 2	-
High Range Water Reducing and Retarding Admixture	EN 934 (Part 2), Cl. 4.2, Table 11.1 and 11.2	-	ASTM C494 Type G	IS 9103, Table 1A
Water Reducing and Accelerating Admixture	EN 934 (Part 2), Cl. 4.2, Table 12	BS 5075 Part I	ASTM C494 Type E	-

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Table 7.2 Types of admixture and the properties achieved

Type of admixture	**Their effects on concrete**
Accelerators	Accelerate setting and early-strength development
Air detrainers	Decrease air content
Air-entraining admixtures	Improve durability in freeze-thaw, deicer, sulfate, and alkali-reactive environment, improve workability
Alkali-aggregate reactivity inhibitors	Reduce alkali-aggregate reactivity expansion
Antiwashout admixtures	Cohesive concrete for underwater placements
Corrosion inhibitors	Reduce steel corrosion activity in a chloride-laden environment
Damp proofing admixtures	Retard moisture penetration into dry concrete
Foaming agents	Produce lightweight, foamed concrete with low density
Grouting admixtures	Adjust grout properties for specific applications
Hydration control admixtures	Suspend and reactivate cement hydration with stabilizer and activator
Permeability reducers	Decrease permeability
Pumping aids	Improve pumpability
Retarders	Retard setting time
Shrinkage reducers	Reduce drying shrinkage
Superplasticizers	Increase flowability and retardation of concrete. Reduce water-cement ratio
Water reducers	Reduce water content at least by 5%
Water reducers and accelerators	Reduce water content (minimum 5%) and accelerate set
Water reducers and retarders	Reduce water content (minimum 5%) and retard set
Water reducers—high range	Reduce water content (minimum 12%)
Water reducers—high range—and retarders	Reduce water content (minimum 12%) and retard set
Water reducers—mid range	Reduce water content (between 6 and 12%) without retarding

7.3 Achieving Desired Workability and Retention in Concrete

The most common use of admixtures in concrete is to achieve the desired workability and retention. The requirement differs with type and application of concrete as given in Table 7.3:

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Table 7.3 Workability and retention requirements for various types of concrete

Type of concrete	Workability (Slump)	Retention
PCC	Low (50-70 mm)	As per lead time
General structural concrete	Pumpable (100-150 mm)	As per lead time (Generally 2-3 hours)
Pile, diaphragm wall concrete	Very high (> 180 mm)	As per lead time
High rise / Long distance pumping	Very high (150-180 mm)	In laboratory, retention needs to be kept at least double the actual lead time, as there will be considerable drop in workability in long distance pumping
Pavement Quality Concrete	Low (25-40 mm)	As per lead time
Dry Lean Concrete	Very low (0 mm)	-
Roller compacted concrete	Very low (0 mm)	Very high. Generally, 36-48 hours before next layer of concrete is laid
Self-compacting concrete	Very high flow (650 – 800 mm flow on flow table)	As per lead time but special care needs to be taken to retain the self-compacting properties
Precast concrete	Medium to high (50-150 mm)	Low retention time, required for concrete to achieve early strength

The philosophy of achieving the desired workability and retention differs with each type of concrete. The first parameter which is checked during trials is the workability. If the workability is not satisfactory then the mix is rejected and revised for improvements. If cohesiveness is not considered for a moment, the workability parameters more or less depends on quantity of two ingredients: water and admixture. More the water or admixture in the mix, higher is the workability. But there is a limit to the minimum amount of water or maximum amount of admixture (saturation point) that can be added with a benefit.

If there is too much water in the mix, it will cause shrinkage and bleeding in concrete. Also for a given strength, the total cementitious material will be higher which will be uneconomical. Thus, lesser the water in the mix, beneficial it is to concrete, both in terms of durability as well as economy and sustainability.

If we go on reducing water and increasing admixture (to achieve constant workability), there will be point where the admixture will not give benefit anymore making the concrete either sticky (due to too less water in the mix) or bleed (due to too high dispersion by admixture). At this point, there is a need to increase the water content till the issue of either stickiness or bleeding is brought under control.

At high workability, cohesiveness is a very important parameter. This can be obtained only when the mix contains enough fines to hold the water. These fines can be from fine aggregate, cement or SCM. It is advisable to adjust the aggregate curve so as to achieve the desired fine content. But sometimes the fine aggregate may not have the finer fines (passing 125μ). In such case there is no option but to add SCM (if permitted) or cement to achieve the desired fine content.

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Admixture is primarily added to concrete to improve workability and retention. More the admixture dosage higher will be the workability but upto a certain point. This point is called the saturation point. Beyond this point, addition of admixture will not improve the performance. In fact, it may cause bleeding and segregation in the mix due to high dispersion. When water content is too low, certain admixtures (mainly Polycarboxylate Ether based) when added in high dosage may also cause stickiness to the mix. If bleeding or stickiness is encountered, then either there is a need to reformulate the admixture for better performance or increase the water content in the mix in order to improve the workability.

The saturation point is determined using marsh cone test (Fig. 7.1). The marsh cone test is a workability test used for specification and quality control of cement pastes. The time needed for a certain amount of material to flow out of the cone is recorded. This measured flow time is linked with the fluidity of the tested material. The longer the flow time, the lower is the fluidity.

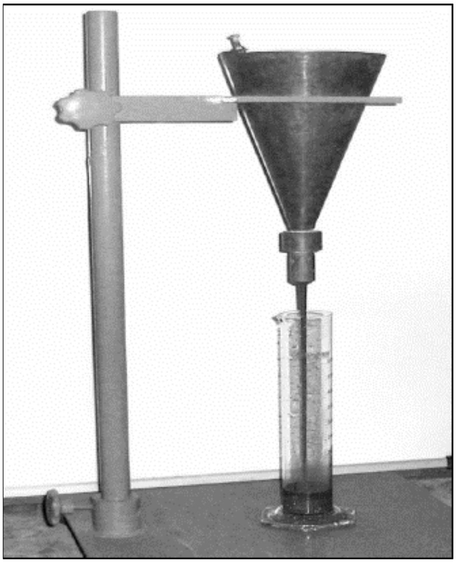

Fig. 7.1 Marsh Cone

The Marsh cone test is a simple approach to get some data about cement pastes behaviour. It is used in cement based materials mix design in order to define the saturation point, i.e. the dosage beyond which the flow time does not decrease appreciably. The cone is filled with the fluid material while the nozzle is kept closed. When the cone is filled with measured quantity of fluid, the nozzle is opened and the fluid is allowed to flow freely. The time needed for measured quantity of material to flow out is recorded as Marsh cone time.

The saturation point is defined as the chemical admixture dosage beyond which the flow time dose not decrease appreciably. The dose at which the Marsh cone time is lowest is called the saturation point (Fig. 7.2). The dose is the optimum dose for that brand of cement and admixture (plasticizer or superplasticizer) for that w/b ratio.

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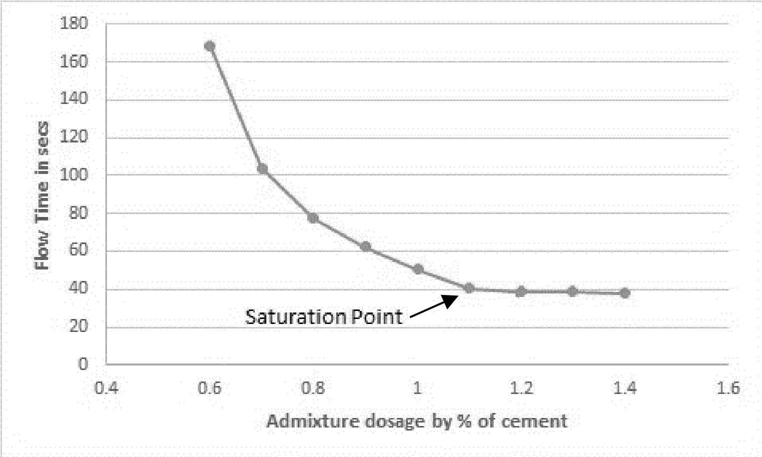

Fig. 7.2 Determining saturation point of admixture

Admixture is usually formulated with combination of one or more of the following ingredients as given in Table 7.4:

Table 7.4 Major ingredients used in admixture formulation

For workability	For retention (Retarder)	For cohesion (Viscosity Modifying Agent – VMA)
Modified Lignosulphonate (LS)	Sugar(Gluconate)	Modified Lignosulphonate
Sulphonated Naphthalene Formaldehyde (SNF)	Unrefined lignosulphonates	Acrylic - or cellulose - based water-soluble polymers
Poly-Carboxylate Ether (PCE)	Hydroxy carboxylic acids	Polysaccharides of microbial sources, such as welan gum

The admixture also contains minor other ingredients for dispersion and stability purpose but they have minimal effect on concrete properties. Table 7.5 below gives an approximate contribution of each ingredient in chemical admixtures towards various concrete properties. Usually for very low strength concrete (M10-M15), the admixture would be formulated with more of LS, with small percentage of SNF and Retarder. For medium strength concrete (M20-M30), admixture is mainly formulated with SNF and retarders. LS may be added to improve cohesiveness if required. For high grade concrete and medium strength concrete designed with crushed sand, the formulation will be primarily PCE with retarder. The percentage of retarder will vary depending upon distance and temperature. Sometimes if there is a big temperature variation between summer and winter season, there may be a need to change the percentage of retarder in the formulation. The performance of PCE based admixture depends upon the polymer used. There are different polymers imparting different performances such as: high workability & high retention, high workability and low retention, high early strength, improving cohesiveness and pumpability, etc. Different polymers can also be blended together along with retarder and VMA to get the required performance.

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Table 7.5 Approximate contribution of chemical admixtures towards various concrete properties

Properties	**LS**	**SNF**	**PCE***	**Retarder**	**VMA**
Water Reduction	Max. 10%	Max. 25%	Max. 40%	Max. 5%	-
Cohesiveness	Excellent	-	Nil to Medium	-	Excellent
Retention	-	-	Nil to Excellent	-	-
Retardation	Excellent	-	-	Excellent	Slight
Air Entrainment	Good	-	-	-	-
Early Strength	Low	Medium	High	Reduces	-

** The properties imparted by PCE admixture depend on the polymers used.*

Based on the observations in the first trial, the mix must be fine-tuned to achieve desired results. The fine tuning of various properties can be done as per flow charts given in Fig. 7.3, Fig. 7.4, Fig. 7.5 & Fig. 7.6.

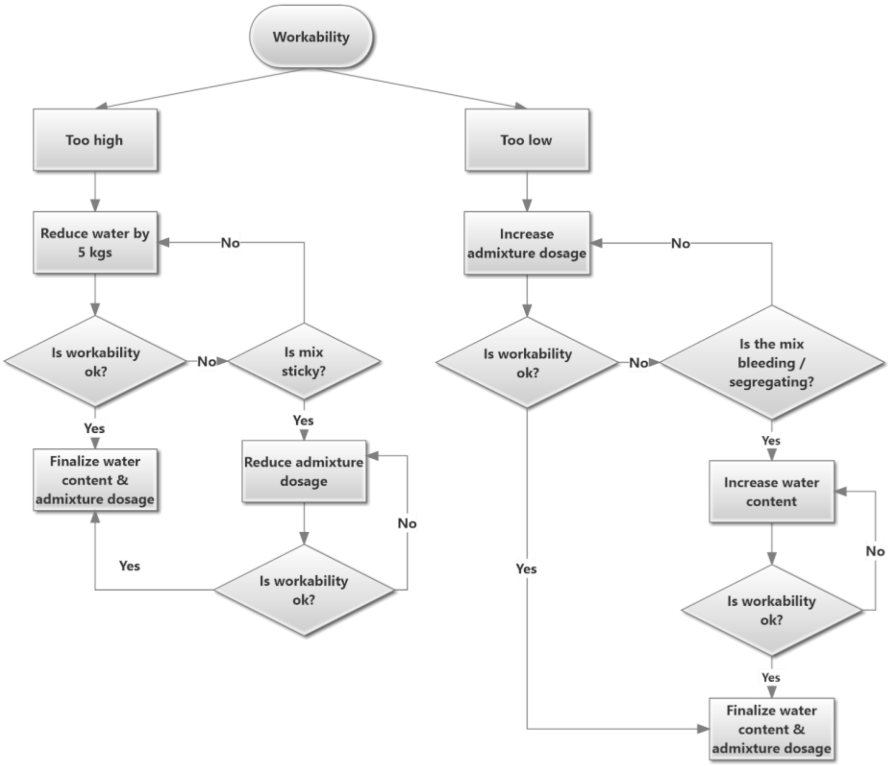

Fig. 7.3 Flow chart for fine tuning mix to achieve desired workability

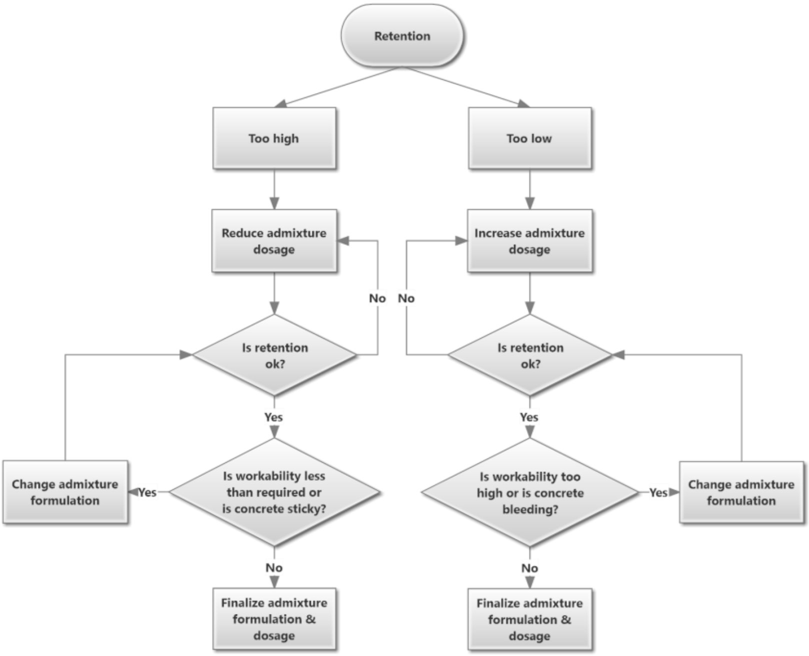

Fig. 7.4 Flow chart to achieve desired retention

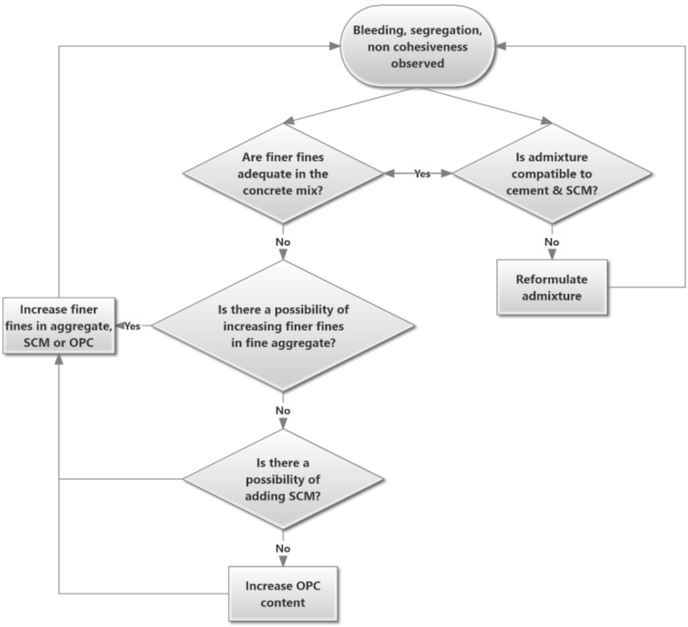

Fig. 7.5 Flow chart to control bleeding, segregation and non-cohesiveness

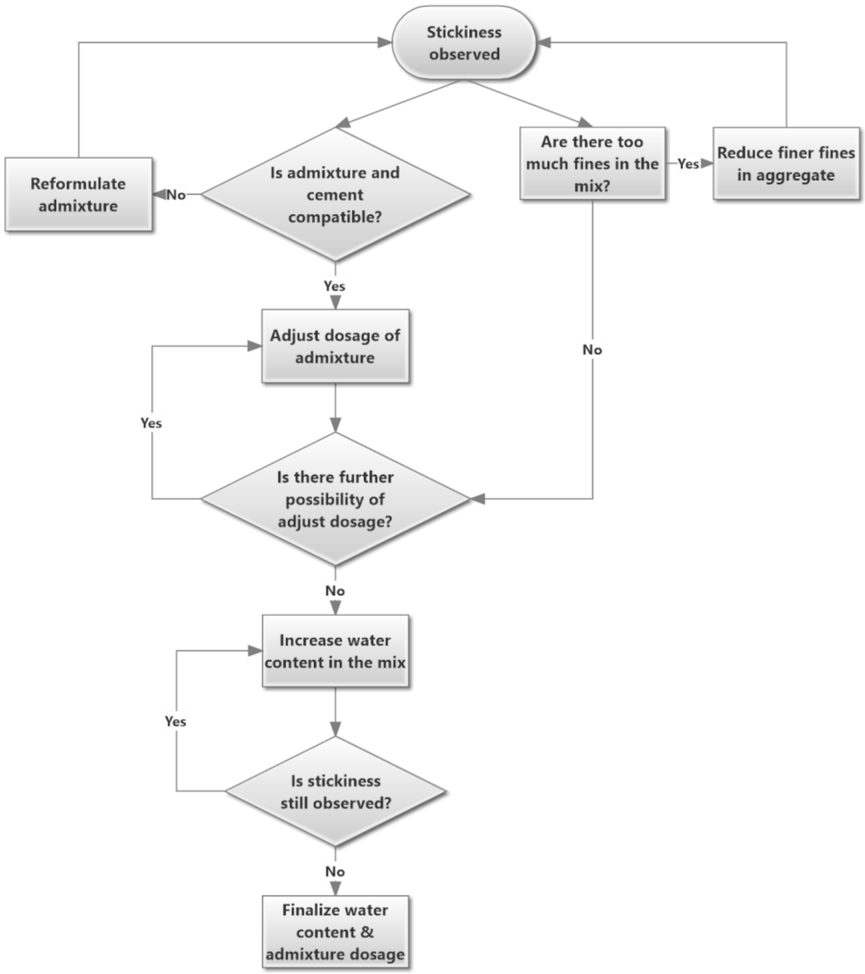

Fig. 7.6 Flow chart to control stickiness in concrete

7.4 Robustness of Admixture and Its Compatibility with Cement

The term compatibility refers to the desired effect on performance when a specific combination of cement and chemical admixtures is used. Here cement means cement plus SCMs. The complex interaction between cement and chemical admixtures in concrete mixtures sometimes leads to unpredictable performance of concrete in the field which is generally defined as incompatibility.

The problems that may be encountered during concreting operations maybe bleeding, loss of cohesiveness, flash setting, delayed setting, rapid slump loss, stickiness, improper strength gain, inordinate cracking etc. arise due to incompatibility between cement and chemical admixtures. These issues in turn affect the hardened properties of concrete, primarily strength and durability. The complexity is further aggravated with use of double blends (OPC + Fly Ash/GGBS), triple blends (OPC + Fly Ash/GGBS + SF/UFFA/UFS) or quadruple blends (OPC + Fly Ash + GGBS + SF/UFFA/UFS). Variation in silt and clay content of sands adds to further issues to compatibility. Further in large projects, there is always a possibility of change in source of cement.

It is very difficult to ensure that an admixture formulation that produces all the desired effects with cement A would do the same with cement B. Some admixture formulation may show higher fluidizing effect on some brand of cement than other cement brands. There is nothing wrong with either the admixture or the cement brand. It is just that the admixture formulation is not compatible to the chemical properties of a particular cement and hence it does not give the desired performance. All that needs to be done is to understand the chemistry of the cement to be used and formulate the right admixture.

Users, who are unaware of compatibility issues, often suffer when the supply of cement and/or admixture is changed midway through a project. Problems arising out of compatibility issues are often mistaken for problems with concrete mix design, because of the lack of information about the subject amongst practicing engineers.

It is always advisable to formulate an admixture which is compatible to various combinations of materials in a project, though it may not always be feasible. If not feasible, one should at least have alternate admixture formulation ready for different combinations so that the change can be quickly done in case there is a change in the cement or any other raw material. It is observed that PCE based admixtures are more robust in terms of compatibility with varying ingredients than the conventional SNF based admixtures. A concrete mix is considered to have a robust behavior when a little variation in the composition of one of the ingredients of the mix does not lead to big variation in the properties of concrete (Fig. 7.7, [1]). The robustness of concrete is mainly due to the robustness of chemical admixture used.

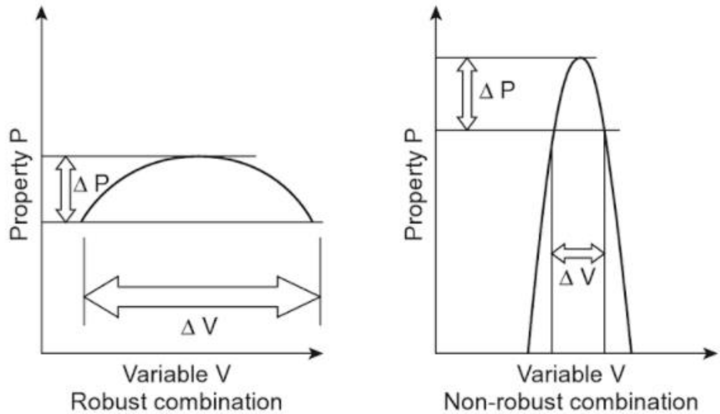

Fig. 7.7 Robustness of concrete to variation in material properties

It must be noted that a good compatibility of cement admixture and a well optimized mix need not necessarily be a robust mix. It has been encountered sometimes by the authors that a well-designed mix satisfying all parameters at a particular admixture dosage goes out of control when there is a variation in admixture dosage. A variation may lead to detrimental side effects such as bleeding, segregation, rapid loss of slump, excessive set retardation, or excess of air in concrete. This happens because the cement admixture compatibility lies only in a very narrow range of admixture dosage. If the dosage remains within that narrow range the performance is satisfactory, but even if the dosage goes a little out of that narrow range, the concrete parameters go out of the acceptable range. Such a behavior or combination is called as non-robust combination.

The robustness of the chemical admixture can be controlled by using the right formulation. The following points need to be addressed for better robustness:

- Formulate the admixture such that it is compatible and robust with at least 2 to 3 different cement brands likely to be used in the project. PCE based admixtures have a better compatibility and robustness capabilities as compared to conventional SNF based admixtures.
- Do not design the formulation such that the dosage is very low (applies more for PCE based admixtures). Low admixture dosage means the solid contents in the admixtures are high. A little increase or decrease in the admixture dosage means the reactive solids may either be too much or too little. PCE based admixtures have a very high water reducing and dispersing capacity and a little increase or decrease in dosage (with high reactive solids) can lead to a high variation in the fresh concrete properties. It is advisable to formulate an admixture with lower reactive solids and a slightly higher dosage so that even if there is a slight variation in the actual dosage during production the impact is minimal.
- If it is expected that there will be variation in the 150 μ passing in sand, the same can be accounted for in the formulation of the admixture right at the beginning.

7.5 Split Dosing of Admixture

Due to various reasons listed below, it may happen that the workability of concrete is insufficient at the pouring point:

- Delay in reaching the pouring point due to traffic or breakdown of transit mixer
- Breakdown of concrete pump or other activity delaying the pumping process
- Increase in ambient / concrete temperature

During such situations, redosing of admixture is the right approach in restoring the desired workability of concrete. Never add water to the concrete in transit mixer for increasing the workability as it will lead to increase in the water binder ratio causing reduction in strength and durability of concrete.

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Re-dosing Procedure [2]

It must be noted that the period within which re-dosing is effected, shall not be more than the duration stipulated for concrete consumption, as determined and agreed earlier. Hydration can commence as soon as retarding effect of admixture is withdrawn and re-working of concrete beyond this period shall not be practiced. Concrete mixes with high OPC content and high ambient temperature can influence second main peak of hydration. However, mixes containing fly ash and GBBS will have delayed and slow hydration process.

Only trained personnel shall carryout the re-dosing at site. Re-dosing amount, process shall be coordinated by the competent and authorised personnel of the concrete manufacturer. Re-dosing amount shall be in percentage to total binder content / cum (example for mix having 400 kg binder per cum, amount of super-plasticizer to be re-dosed for a dosage of 0.10% will be 400 × 0.10/100 = 0.40 kg/cum).

It is advisable to perform the re-dosing before workability of concrete becomes too low that mixing and dispersing of re-dosed super-plasticizer in the entire volume of concrete available in the truck mixer drum becomes difficult. Normally re-dosing is preferred to be carried out when slump value of the concrete mix is about 80 to 100mm. However, it has been reported that when PCE based admixtures are used workability can be enhanced from low slump value of about 50 mm, provided thorough mixing is done @ appropriate speed and duration. Mixing of concrete after re-dosing shall be done for at least 3 minutes @ 12 RPM (TM drum's). This is to ensure that the admixture is mixed with the entire drum load and the mix is homogeneous.

The amount of re-dosing shall be determined by the Quality Control personnel of the concrete manufacturer based on the type of mix, volume of concrete in the transit mixer and climatic condition.

Total amount of admixture added to concrete, including re-dosed quantity, shall not exceed the maximum percentage limit prescribed by the admixture manufacturer. The details like reason for re-dosing, approximate amount of concrete required re-dosing, amount of admixture re-dosed, time, TM/batch number, etc. shall be recorded. Whenever redosing is expected due to delay in pouring concrete, it is advisable to cast cube specimen to verify the strength of concrete re-dosed with superplasticizer to ensure that the strength is not affected by re-dosing.

Non-retarding super-plasticizer is found to be more suitable to avoid delay setting of concrete when re-dosing is done, especially in mixes having fly ash or GGBS. However, consumption of concrete after re-dosing shall be done as early as possible as workability would drop drastically with time for redosed concrete mixes.

7.6 Corrosion Inhibiting Admixtures

Chloride attack is one of the most important aspect for consideration when we deal with the durability of concrete. Chloride attack is particularly of concern because it primarily causes corrosion of reinforcement. Statistics have indicated that over 40 per cent of failure of structures is due to corrosion of reinforcement.

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Due to high alkalinity of concrete a protective passivity layer is formed around the reinforcement bars. The protective passivity layer can be lost due to reduction in pH value due to carbonation or due to the presence of chloride present in the pore water and oxygen.

Corrosion of steel in concrete is an electrochemical process. When there is a difference in electrical potential along the steel reinforcement in concrete, an electrochemical cell is set up. In the steel, one part becomes anode and other part becomes cathode connected by electrolyte in the form of pore water in the hardened cement paste. The positively charged ferrous ions Fe++ at the anode pass into solution while the negatively charged free electrons pass through the steel into cathode where they are absorbed by the constituents of the electrolyte and combine with water and oxygen to form hydroxyl ions (OH)-. These travel through the electrolyte and combine with the ferrous ions to form ferric hydroxide, which is converted by further oxidation to rust. This process is called as corrosion.

It may be noted that no corrosion takes place if the concrete is dry or probably below relative humidity of 60 percent because enough water is not there to promote corrosion. It may also be noted that corrosion does not take place if concrete is fully immersed in water because diffusion of oxygen does not take place into the concrete. Probably the optimum relative humidity for corrosion is 70 to 80 percent. The products of corrosion occupy a volume as many as seven times the original volume of steel when fully corroded. The increased volume of rust exerts thrust on cover concrete resulting in cracks, spalling or delamination of concrete.

Corrosion inhibitors, which come in powder, gel and liquid form, retard the rate of the corrosion reaction. There are three main types of inhibitors:

Anodic inhibitors, which retard the corrosion reaction at the anode: Corrosion can be prevented or delayed by chemical method by using certain corrosion inhibiting chemicals such as nitrites, phosphates, benzoates etc. It is added to the concrete during mixing of concrete. The typical dosage is of the order of 10-30 litres per m3 of concrete depending on chloride levels in concrete.

When the pH value of the concrete is high, the steel is protected by a passivating layer of ferric oxide on the surface of steel. However, the passivating layer also contains some ferrous oxide, which can initiate corrosion when the chloride ions reach the steel. The nitrite ions present in the corrosion-inhibiting admixture will oxidize the ferrous oxide to ferric oxide, thus stabilizing the passivating layer even in the presence of chlorides. The concentration of nitrite must be sufficient to cope up with the continuing ingress of chloride ions. [3]

Cathodic inhibitors: They retard the reaction at the cathode and seek to prevent oxygen reaching the reinforcing steel. At low dosages, they are effective at reducing corrosion rates but are generally less efficient than the anodic type. [3]

Bipolar inhibitors: They retard the corrosion process both at the anode and the cathode. These combine the benefits of both anodic and cathodic inhibitors at relatively low dosages. In this category, organic migratory bipolar corrosion inhibitors are the most widely used.

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Migratory bipolar corrosion inhibitors are organic inhibitors. They protect the steel at both the anodic and the cathodic sites. The bipolar corrosion inhibitor chemistry involves migration of its molecules by electron density distribution to both the anodic and cathodic sites of the steel. By virtue of its high vapour pressure, very high affinity and virtue of diffusion these inhibitors migrate towards the steel in concrete and get deposited in a monomolecular layer. This is true even in dense concrete. This barrier coating then raises the chloride threshold concentration for corrosion.

Furthermore, the inhibitor within the concrete matrix reduces the rate of chloride ion migration towards steel. It also dislodges previously absorbed chloride ions and water molecules on the steel surface. Concrete penetrating corrosion inhibiting admixture upon addition into the concrete matrix plays a major role in inhibiting the corrosion process. Two codes available internationally for testing these types of inhibitors are ASTM G 109 & JIS A 6205.

They are available, both as surface applied inhibitors and as admixture inhibitors. Surface applied inhibitors are used by spraying on the complete surface of the structure being repaired so that protection to the unexposed reinforcement is taken care of. Admixture inhibitors are used in the fresh mortar/concrete being placed for strengthening the structure. [3]

Specification for surface applied corrosion inhibitor and admixture corrosion inhibitor are given in Table 7.6 [3].

7.7 Shrinkage Reducing Admixture

The loss of moisture from the concrete as it dries results in a volume contraction which is termed as drying shrinkage. Drying shrinkage is undesirable as it leads to cracking due to either internal or external restraint, curling of floor slabs, and excessive loss of prestress in pre-stressed concrete applications. Drying shrinkage can be reduced significantly by using shrinkage-reducing admixtures. These are organic-based formulations that reduce the surface tension of water in the capillary pores of concrete, thereby reducing the tensile forces within the concrete matrix which cause drying shrinkage.

This type of admixture should not be confused with shrinkage-compensating materials which are normally added at above 5% on cement and function by creating an expansive reaction within the cement paste to treat the ‘effects’ of drying shrinkage.

Shrinkage reducing admixtures are normally 100% active liquids and are water soluble. They have a characteristic odour and a specific gravity of less than 1.00. The dosage is largely independent of the cement content of the concrete and is typically in the range 5–7 litres/m^3.

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Table 7.6 Specification for surface applied corrosion inhibitor and corrosion inhibitor admixture

Applied Corrosion Inhibitor	
Base	Bipolar water based organic inhibitor. Concrete penetrating type.
Colour	Colorless hazy liquid
Specific Gravity	1.01 – 1.02 at 25°C
Viscosity at 25°C	11-12 sec by Ford B4 Cup
pH	Minimum 9.5
Dosage	To be sprayed at the rate of 1 litre per $4m^2$
Toxicity	Non-toxic, eco-friendly
Evaluation	Should pass JIS - 6205 standard
Admixture Corrosion Inhibitor	
Base	Bipolar Organic inhibitor. Concrete penetrating type
Colour	Brownish
Specific Gravity	1.05 – 1.08 at 25°C
Viscosity at 25°C	11-12 sec by Ford B4 Cup
pH	Minimum 9.0
Dosage	3 kgs per cubic meter of concrete
Toxicity	Non-toxic, eco-friendly
Effect on concrete properties	No adverse effect on physical properties in fresh & hardened concrete in the absence of any other admixtures. However, it is essential to carry out trial mix with desired admixtures along with migratory corrosion inhibitor.
Compatibility for Higher Thermal Cycles	Compatible for higher thermal cycles No deleterious effects even at high temperature. Effective even at higher temperatures.
Evaluation	Should pass ASTM-G-109 standard & JIS - 6205 Should pass tropical climate test (thermal cycles).

7.8 Recommended Practice for Storage of Admixture

- All admixtures, including the approved sample, should be stored in covered shed (Fig. 7.8)
- If the admixture is to be used within very short duration, the same may be covered with tarpaulin
- Admixture drums should not be stored in cement godown as there is a possibility of cement dust getting mixed with admixture whenever the container is opened for usage
- The lid of opened container should always be kept in a closed condition when not in use
- When stored in open and high ambient temperatures, admixtures may foam and generate gas aerobic bacteria. In such situations, the drums get swollen (Fig. 7.9). The pressure should be released by opening the lid and stirring

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well. In any case, it is a good practice to stir the admixture in the drum before use.

- Even at batching plant, admixture drum should be properly covered, even when pumping the admixture (Fig. 7.10)

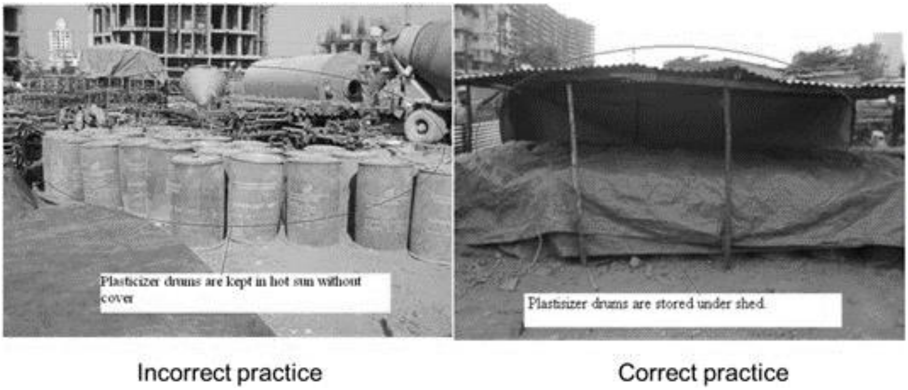

Fig. 7.8 Correct and incorrect method of storing admixture drums

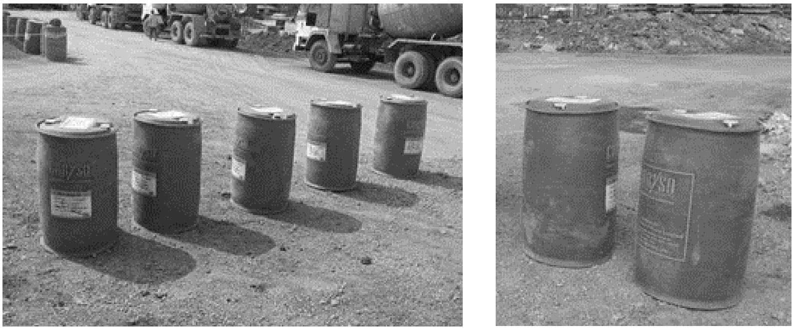

Fig. 7.9 Bulging of sealed admixture drums kept exposed to direct sunlight

Other Guidelines for use of Admixtures

- If the drums are stored for a long period, the admixtures should be stirred well before use
- If the admixture dispenser is used, calibrate the systems and weighing system regularly at least once in a month
- Clean the dispenser motor and hose regularly (once a week)
- Do not cut the admixture drum to insert hose for pumping admixture. Instead open the drum lid and insert the hose into the drum and cover the lid with a rubber lap or other means so that dust will not enter into the drum (Fig. 7.10)
- Retain a sample of 5 kg of the approved admixture at site along with manufacturer's chemical analysis certificate
- Any batch of admixture shall have the same physical state and composition, as that of the admixture tested for acceptance

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Highly incorrect method of pumping admixture with drum lid cut open | Incorrect method - Cap to be provided to arrest dust into chemical | Proper arrangement for covering the lid of drum to avoid contamination

Fig. 7.10 Correct and incorrect method of pumping arrangement for admixture at batching plant

Guidelines for ensuring consistency in admixture performance

In large projects which extend for 2 to 3 years, it is an enormous task to ensure the consistency of concrete because of variations due to the ingredients, climatic conditions, etc. In order to ensure the consistent supply of admixtures the following guideline is recommended.

- Finalize lab sample after conducting series of trials to achieve concrete properties meeting specification requirements
- Once the chemical admixture is finalized, keep a 25 litre sample in laboratory as reference sample.
- Whenever a new lot is procured, conduct the trials again and if satisfactory, replace the old reference sample with new one, so that the reference sample always is fresh
- Always keep the reference sample sealed and store securely
- Trials to be conducted for slump, retention and if possible strength against each batch comparing with reference sample

7.9 Summary

- Chemical admixtures are one of the greatest innovations that has happened in the concrete technology.
- Many properties of concrete (fresh and hardened) can be controlled using right formulation and dosage of admixture
- It is important to check the compatibility of admixture with cement to achieve the desired results in concrete
- Redosing of admixture can be done in order to increase the workability, but it must be done only by authorised personnel having complete knowledge of the subject and after taking due precautions as noted in this chapter.
- Proper storage of admixture is important to maintain the properties of admixture

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CHAPTER 8

CONCRETE TEMPERATURE – ITS EFFECT ON QUALITY AND STRENGTH OF CONCRETE

8.1 Introduction

Concrete temperature affects the fresh and hardened concrete properties. The effect of temperature on concrete needs to be studied with respect to:

- Effect of temperature on fresh concrete
- Effect of temperature on hardened concrete
- Effect of concrete temperature in mass concrete

In fresh concrete, the main property that gets affected by the temperature is workability and retention. At higher workability, the reduction in slump is faster with increasing temperature. At higher curing temperatures, the early strength is high but the ultimate strength drops. In mass concrete, the issue is related to high peak temperature and temperature differential between core and surface of concrete.

All these aspects are discussed in detail in this chapter.

8.2 Effect of Temperature on Fresh Concrete

Temperature basically affects the workability of concrete. At higher concrete temperature, the effects are as follows:

- Water demand to achieve same workability increases with increase in concrete temperature
- Concrete loses its workability (retention) faster at high concrete temperatures
- Setting of concrete is accelerated at higher concrete temperature

Higher the concrete temperature, higher is the amount of water content required (with chemical admixture content unchanged) to produce the same slump. Fig. 8.1 [1] gives the relation between amount of water and temperature to obtain a constant slump of 75 mm. Thus, to achieve the same slump either higher water content is required or increased dosage of admixture is added to concrete. For a given grade of concrete, the required water binder ratio must be maintained from strength and durability considerations. Thus, if we increase the water content in the mix to maintain the same slump, we also need to increase the cement content to maintain the water binder ratio.

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This not only changes the mix design but also will not be economical. The better solution is to add the required amount of admixture to maintain the slump. As a thumb rule, for a given concrete mix design, the dosage of admixture increases during summer and reduces in winter for the same slump.

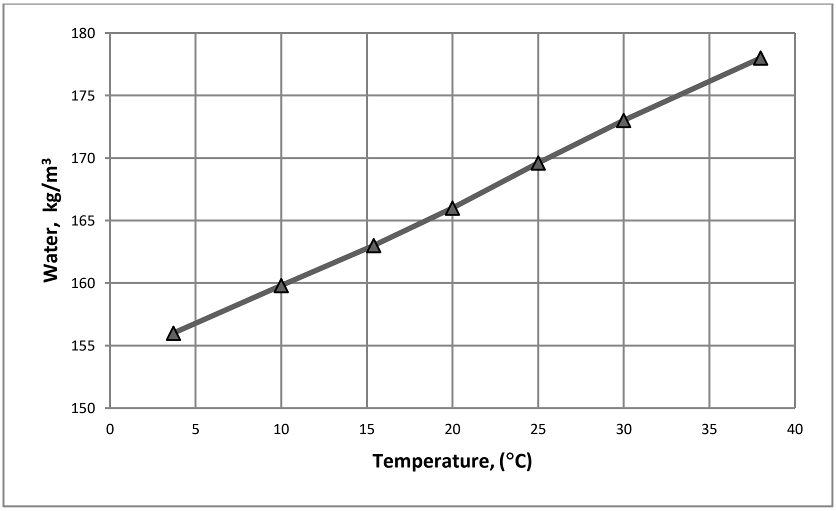

Fig. 8.1 Effect of temperature on workability

Higher concrete temperature accelerates the rate of hydration of cement thereby increasing the rate of slump loss as shown in Fig. 8.2 [1]. In order to achieve the desired slump at placing point either there is a need to have a higher slump at the starting point or to add retarder to the concrete. There is also a tendency of adding water in concrete at the placing point in case required slump is not observed. This increases the water binder ratio of the concrete thereby reducing strength and durability. It is not advisable to add water at the placing point and such practices must be stopped. In order to achieve the desired slump, either sufficient retarder should be added at the batching plant or split dosing of admixture is to be done, part dosing at batching plant and balance dosing at the placing point.

Higher concrete temperature also increases the rate of setting time. This results in greater difficulty in handling, compacting, and finishing, and poses a greater risk of cold joints. Setting time of concrete can be controlled by adding suitable amounts of retarders along with plasticizer / superplasticizers. It may be noted that the amounts of retarders required during peak summer will vary against that required during winter time to achieve a certain setting time. Because of such effect of concrete temperature, suitable adjustment must be made in the dosage of plasticizer and retarder. Fig. 8.3 [1] gives the relation between temperature and setting time of concrete.

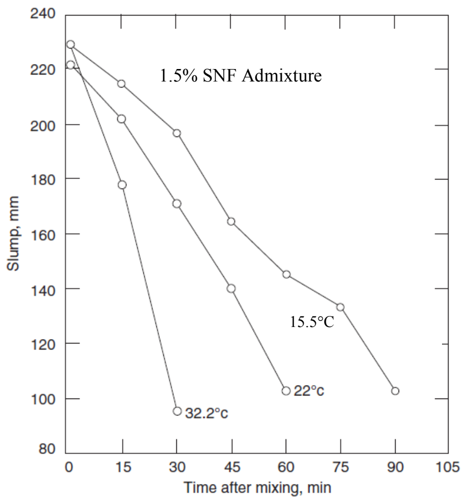

Fig. 8.2 Effect of temperature on slump loss

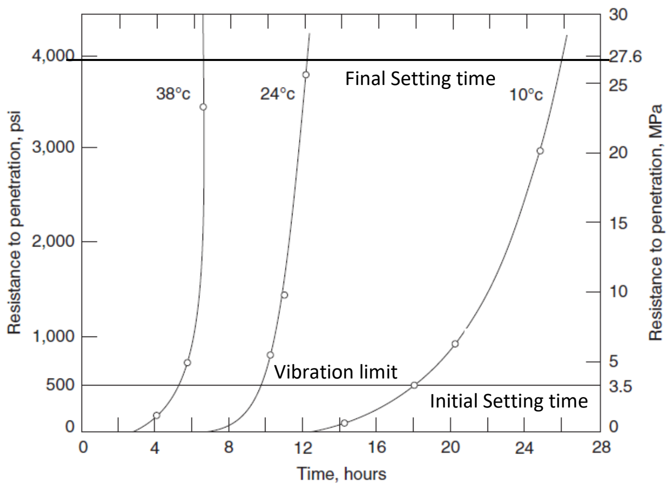

Fig. 8.3 Effect of temperature on setting time of concrete

8.2.1 Role of admixture to control workability at varying concrete temperatures

The temperature of concrete is directly affected by the ambient temperature. The temperature of fresh concrete varies – higher during the day, lower during the night; higher in summer, lower in winter. During seasonal changes, especially in the northern India, the changes in fresh concrete temperature can be very high.

When continuous large pours spanning more than 12-hour period are done, there is a change in the temperature of concrete. The best time to start the concrete is early evening, around 4.00 pm and try to complete by 12.00 pm the next day. But this may not always be possible. Table 8.1 below gives an idea for controlling the workability of concrete with admixture.

Table 8.1 Indicative guidelines for controlling workability of concrete with admixture

Ambient temperature	Concrete temperature	Effects	Remedy & indicative admixture dosage
7.00 am - 20°C	24°C	Desired workability & retention achieved with 1% admixture	
10.00 am - 23°C	25°C	Desired workability & retention achieved with 1% admixture	
01.00 pm - 29°C	32°C	At 1% admixture dosage, the workability will be lower and retention will be less	Increase the dosage of admixture by 0.1-0.2% to improve the workability (Dosage 1.2%)
03.00 pm - 34°C	37°C	Even at 1.2% dosage, the desired workability and retention may not be achieved	Increase the dosage of admixture by 0.1% (Dosage 1.3%)
07.00 pm - 27°C	30°C	Earlier increase dosage will be very high and bleeding and segregation may be observed	Reduce the dosage of admixture by 0.1-0.2% (Dosage 1.1%)
12.00 am - 20°C	24°C	May observe bleeding because of high dosage.	Use 1% admixture
3.00 am - 17°C	21°C		Reduce admixture dosage to 0.8%

It will be observed that the workability of concrete can be controlled in a 24-hour concreting period just by varying the dosage of admixture.

The same concept may not be true in case of seasonal changes. In a place like Mumbai where the summer and winter temperature difference is not very high, the same admixture with the above concept will work. Thus, throughout the year, concreting can be done with the same admixture.

But in northern India, where the summer temperature goes upto 45°C and winter temperature drops to 10°C or lower, the above concept may not work. If the admixture has been designed during the summer, the amount of retarder in the admixture will be high enough to maintain the retention for the desired time. During the winter, even if the admixture dosage is reduced by 0.2-0.3%, still the amount of retarder in the admixture will be considerably high and can cause delayed setting or very low early strength gain. In some cases, the concrete may not set for a very long time.

In case we further try to reduce the admixture dosage, we may not get the required workability. In such cases, it is advisable to change the formulation of the admixture as required. The formulation for winter will have lower retarder percent in the admixture formulation. SNF based admixtures are more prone to above issues than PCE based admixtures. The formulation of PCE based admixture is more robust to take care of the workability and retention issues with the same formulation and in most cases, may not require a separate formulation.

8.3 Effect of Temperature on Hardened Concrete

In hardened concrete, the effects of temperature are as follows:

- Higher early strength at high concrete temperature
- Lower ultimate strength at high concrete temperature
- Lower durability due to high porosity at high concrete temperature

Note: Here temperature refers to concrete temperature during curing period.

Researches indicate that the concrete cured at lower temperature has lower early strength gain and higher ultimate strength. It may be noted that ultimate strength is not the strength achieved at 28 days as the hydration in concrete continues even after 28 days, more so for concrete designed with SCMs. Concrete designed with SCMs tend to be more sensitive to strength gains at varying curing temperatures.

During severe winters, it is extremely important to maintain the temperature of water in the curing tank, else the results can be completely misleading. As per Indian Standard the concrete cubes must be cured at a temperature of 27±2°C. During severe winter, the temperature of water if not controlled may go very low and this will affect the strength gain of the cubes cured at low temperature and the cubes may not gain the required strength. This may even result in concrete cubes not achieving the target strength and hence may be deemed as failed for not achieving the desired strength in 28 days.

The best solution is to use immersion rods attached to a thermostat which control the heating of water as required (Fig. 8.4). The curing tank can be covered during the night when not in use to prevent loss of heat and partially opened when placing and taking out of cubes. The temperature of concrete in the actual structure depends on:

- Initial placement temperature of concrete
- Rise in temperature of concrete due to heat of hydration (applies more for mass concrete)

As a general rule, the placement temperature of various types of concrete are as given in Table 8.2. The actual requirement specified in the technical specification may be different from that specified above.

Table 8.2 General placement temperatures for various concretes

Type of concrete	Max. Placement temperature
General structural concrete	40°C
Pavement Quality Concrete	30°C
Mass Concrete (Raft, Footing, etc.)	25-30°C
Barrage Concrete	20-25°C
Dam Concrete	10-12°C

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Fig. 8.4 Controlling temperature of water in curing tank by immersion rods connected to thermostat

8.3.1 Mass concrete

Mass concrete is defined in ACI 116R as "any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking." The design of mass concrete structures is generally based on durability, economy, and thermal action, with strength often being a secondary, rather than a primary, concern. The one characteristic that distinguishes mass concrete from other concrete works is thermal behavior.

Major applications of mass concrete and probable grades of concrete used are:

- Dams (M10 to M20) – Low strength mass concrete
- Barrages (M15 to M25) – Low strength mass concrete
- Tunnel linings (M25 to M35) – Medium strength mass concrete
- Rafts and footings (M25 to M40) – Medium strength mass concrete
- Thick core walls (M30 to M80) – Medium to high strength mass concrete
- Mega columns (M40 to M100) – High strength mass concrete

The hydration process is an exothermic reaction and liberates lot of heat. In case the concrete element is thick enough, usually thickness more than 0.9 m, the heat remains trapped in the core of the structure and the temperature rise is substantial. The amount of heat generated is proportional to the amount of cementitious material, especially the OPC content in the concrete.

8.3.1.1 Effect on concrete strength

The reaction between cement and water is similar to any other chemical reaction, proceeding at a faster rate with increasing temperature. At high temperatures, there is insufficient time available for the diffusion of the products of hydration away from the cement particles due to the low solubility and diffusivity of the products of hydration.

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This results in a non-uniform precipitation of the products of hydration within the hardened cement paste.

Although a higher temperature during placing and setting increases the early strength, it adversely affects the ultimate strength. This is because the rapid initial hydration according to Verbeck and Helmuth (1968) appears to form products of a poorer physical structure, probably more porous, and a proportion of the pores will always remain unfilled resulting in voids which do not contribute to the strength of concrete. At low temperature, slow hydration will result in a uniform distribution of hydration products within the interstitial space and high strengths at latter ages.

Generally, for mass concrete, the maximum temperature allowed in the core is restricted to 65-70°C. It is observed that the effect of reduced ultimate strength is less when SCMs are used (Table 8.3) Hence when SCMs are used the maximum core temperature can be allowed upto 75-80°C.

8.3.1.2 Effect due to temperature differential

The heat generated from the hydration of cement causes a rise in temperature of concrete. If this rise occurs uniformly throughout a given concrete element without any external restraint, the element would expand until the maximum temperature has been reached. If concrete cools down uniformly, as it loses heat by lower ambient temperature, the concrete will experience uniform contraction. This uniform expansion and contraction will result in no thermal stresses within the concrete element. According to Neville (1997), restraint exists in all but the smallest of concrete members. These thermal restraints result in external and internal cracking of the concrete. Fig. 8.5 [2] shows an example of temperature change, which causes external cracking of large concrete mass. The critical 20°C temperature difference occurs during cooling.

In massive concrete structures, internal restraint occurs from the inability of the heat to dissipate quickly from the core of the member due to the low thermal diffusivity of the concrete. Concrete is basically a bad conductor of heat. In massive members, the surface cools quickly to ambient temperature but the core remains at high temperature for a long time depending on the thickness of the concrete section. A typical temperature distribution in thick concrete section is as shown in Fig. 8.6.

A temperature differential is set up between the core of the concrete and the surface due to the accumulation of the heat from the hydration process. The unequal thermal expansion in the various parts of the concrete member results in stresses, compressive in one part and tensile in the other (Fig. 8.7). Cracking of the surface results when the tensile stresses at the surface of the element due to the expansion of the core exceed the tensile strength of the concrete. According to Fitz Gibbon (1976), the cracking strain of concrete is reached when an internal thermal differential of 20°C is exceeded. Research indicates that the initial crack in concrete develops on the tension face when the tensile strain is between 100×10^{-6} and 200×10^{-6}. For a temperature difference of 20°C, taking the coefficient of thermal expansion of concrete as 10×10^{-6} per °C, the differential strain is 200×10^{-6}. Thus, when the temperature difference exceeds 20°C, the cracking in concrete is initiated. [3]

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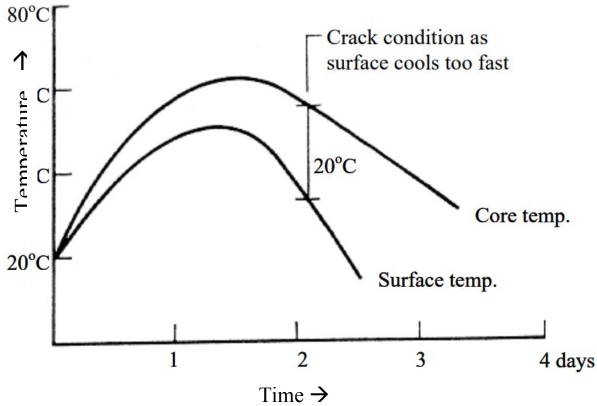
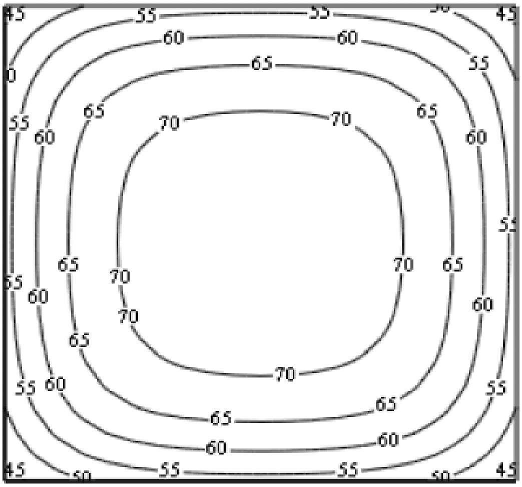


Fig. 8.5 External thermal cracking



Note: Numerals in the figure are in "°C"

Fig. 8.6 Typical temperature distribution in thick concrete section

It must be appreciated here that the coefficient of thermal expansion of concrete largely depends on the coefficient of thermal expansion of aggregate as it occupies 70 to 80% of the volume. Thus, for varying coefficient of thermal expansion of aggregate, the differential strain developed in concrete will also vary proportionally. In case of aggregate made of basalt, granite and dolerite where the coefficient of thermal expansion is much lower than quartzite and sandstone, the allowable temperature differential can be higher than 20°C. Most codes and technical specifications restrict the temperature differential to 20°C without considering these effects and that leads to an unnecessary unrealistic and uneconomical requirement.

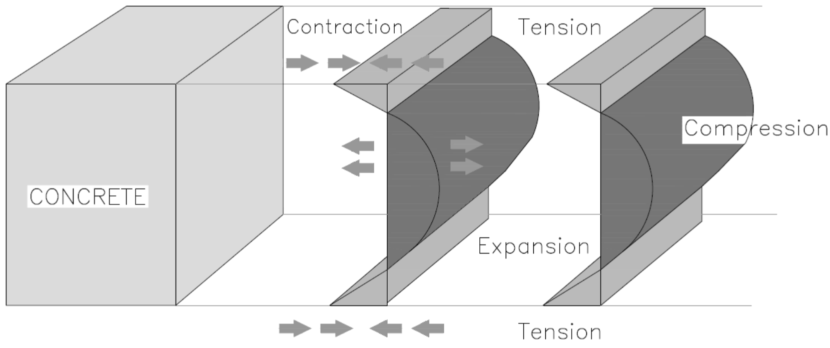


Fig. 8.7 Development of tensile stresses due to temperature differential in thick concrete section

Fig. 8.8 [2] shows a pattern of temperature change, which causes internal cracking of a large concrete mass. The critical 20°C temperature is reached during heating but cracks open only when the interior has cooled through a greater temperature range than the exterior.

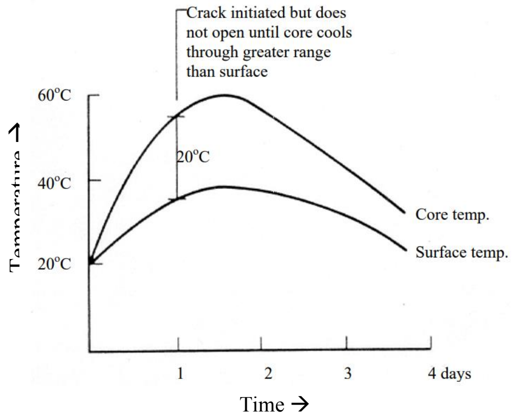


Fig. 8.8 Internal thermal cracking

Cracking due to thermal behavior may cause loss of structural integrity and monolithic action or may cause extreme seepage and shorten the service life of the concrete structure.

8.3.1.3 Measures to be taken for mass concrete

In mass concrete two parameters: maximum rise in temperature of concrete in core and maximum temperature differential between core and surface of concrete are important. Effective measures that can be taken to control the above-mentioned parameters are mentioned below:

1. **Design concrete for 56 or 90 days –** Usually mass concrete elements like raft, footings, columns are never loaded to their full capacity within 28 days. These elements can be designed for 56 or 90 days. Structures like dams and barrages can be designed for 180 or 365 days. Concrete designed with supplementary cementitious material like fly ash or/and GGBS gain 10-15% strength above 28 days in 90 days. This advantage can be taken and concrete can be designed for at least 56 or 90 days rather than for 28 days strength. This will facilitate concrete to be designed at lesser cementitious material content. Lower the cementitious material in concrete, lesser will be the heat of hydration.

2. **Use of supplementary cementitious material –** Supplementary cementitious material like fly ash and GGBS have much lower heat of hydration as compared to cement. When replaced in substantial quantities it helps in reducing the total heat of hydration apart from improving long term strength and durability of concrete. Fly ash and GGBS also help to counter the ill effect of high temperature on compressive strength of concrete. Table 8.3 [4] below gives effect of different curing temperatures on concrete made with 100% OPC, 18% Fly Ash and 50% GGBS. It can be seen that concrete made with fly ash and GGBS exhibit lesser reduction in strength. For example, concrete with 100% OPC exhibit 78% strength at 91 days when cured at 82°C instead of 23°C, whereas concrete with fly ash and GGBS exhibit 86% strength. If higher percentage of cement is replaced by FA and/or GGBS, the effect of strength reduction will be still lower.

Table 8.3 Effect of different curing temperatures on strength of concrete

Days	Concrete Mixes	100% OPC, w/b = 0.41			18% Fly Ash, w/b = 0.41			50% Slag, w/b = 0.40		
	Curing Temp. (°C)	23	71	82	23	71	82	23	71	82
7 d	Comp. Strength, MPa	40.84	39.85	38.21	44.57	46.85	44.50	38.14	48.60	42.82
		1.00	0.98	0.94	1.00	1.05	1.00	1.00	1.27	1.12
28 d	Comp. Strength, MPa	45.67	40.21	38.42	51.52	47.30	47.27	53.32	49.46	45.35
		1.00	0.88	0.84	1.00	0.92	0.92	1.00	0.93	0.85
91 d	Comp. Strength, MPa	49.99	42.19	39.23	57.70	51.68	50.41	58.63	48.43	50.16
		1.00	0.84	0.78	1.00	0.90	0.87	1.00	0.83	0.86

Note: Values in Sub-rows under 7d, 28d and 91d are ratios with respect to strength @ 23°C.

3. **Place the concrete at lower temperature –** The maximum temperature of concrete attained in the core depends on the placement temperature plus the rise in temperature due to heat of hydration. If the placement temperature is lowered the maximum temperature attained is also lowered accordingly. The concrete temperature can be lowered by: cooling aggregate by keeping under shade and sprinkling water (Fig. 8.9), use of chilled water, use of ice as replacement of water in production of concrete. Since aggregate is the maximum part of concrete, reducing the temperature of aggregate has a very big impact on the temperature of concrete. The process of cooling of concrete is discussed in detail in para 8.3.1.4.

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4. **Insulating the surface to control temperature differential –** The temperature differential between the core and surface of concrete can be very effectively controlled by covering the surface with insulating material like thermocol, thick plastic sheets or keeping the wooden shutter in place. Placing insulating material on the surface does not allow the heat to escape quickly thus maintaining the temperature differential. The insulation must be kept in place till the differential is within permissible limits. Once the differential is within limits, the insulating material can be removed. If the wooden shuttering is removed the insulating material must be quickly placed on the surface without much delay. If the insulating material is kept in place for more than 7 days, the need for curing gets reduced. Fig. 8.10 and Fig. 8.11 shows some of the methods of insulating concrete.

Fig. 8.9 Keeping aggregate under shade and sprinkling of water for cooling of aggregate

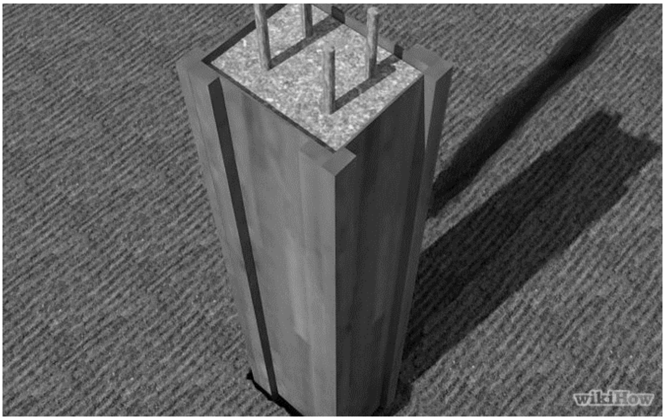

Fig. 8.10 Wooden shutter kept in place for insulating

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Fig. 8.11 High density thermocol used for covering the concrete raft pour to control temperature differential

8.3.1.4 Cooling of concrete

The temperature of freshly mixed concrete depends on the temperature and weights of each ingredient in concrete. The temperature of concrete can be calculated as follows:

Grade of Concrete:	M60 A20 (M60, MSA 20 mm)	
Production per day	400	cum.
No. of working hours	20	hrs.
Production per hour	20	cum.
Ambient temperature	35	°C
Desired placement temperature	25	°C

Concrete mix design

Ingredients	Weight / cum	Water absorption %	Moisture content %	Corrected batch	Initial temp.	Temp. after sprinkling water
Cement	300			300	45	
Total SCMs	350			350	35	
20 mm agg.	480	0.7	1	480	35	30
10 mm agg.	480	0.7	0.7	480	35	30
Sand	773	2	4	773	30	

Excess moisture in aggregate $= (1-0.7) \times 480 + (0.7-0.7) \times 480 + (4-2) \times 773$

$= 16.9$ kgs

Actual water added after moisture correction = $150 - 16.9 = 133.1$ kgs

Water required for sprinkling on coarse aggregate

Quantity of aggregate to be sprinkled per hour =	(480 + 480)/1000 × 20 =	19.2 tons
Specific heat of aggregate =		0.2 kcals/kg °C
Specific heat of water =		1 kcals/kg °C
Quantity of heat to be extracted from aggregate =	(480 + 480) × 20 × 0.2 × (35 - 30) =	19200 kcals
Quantity of water required for sprinkling on aggregate =	19200/(35 – 27) =	2400 lit/hr.

Heat balance calculations

Material	Wt/cu.m (kgs)	Sp. Heat (kJ/kg°C)	Temp. at time of mixing (°C)	Wt. x Sp. Heat	Wt. x Sp. Heat x Temp.
	(1)	(2)	(3)	(1) × (2) = (4)	(3) × (4) = (5)
Cement	300	0.92	45	276	12420
Total SCMs	350	0.92	35	322	11270
Coarse aggregates (20 mm)	480	0.84	30	403.2	12096
Coarse aggregates (10 mm)	480	0.84	30	403.2	12096
Sand	773	0.84	30	649.32	19479.6
Water added to B.P.	103	4.18	4	430.96	1723.83
Ice (A" x T - W x 334)	30	2.09	-2	62.7	10145.4
Water in C.A. (20 mm)	1	4.18	30	6.02	180.58
Water in C.A. (10 mm)	0	4.18	30	0	0
Water in Sand	15.5	4.18	30	64.62	1938.68
Total	2533			2618.02	61059.29

Note: 334 kJ is the heat of fusion of ice.

Chilling Plant Calculation for concrete & ice production			
Temp of feed water		27	°C
Quantity of water required for concrete	133.1 × 20	2662	ltr/hr
Temperature of chilled water in batching plant		4	°C
Temperature of chilled water in chilling plant	4 – 2	2	°C
Quantity of Chilling Required (Ton Refrigeration – TR)	2662 × (27 - 2) / 3024	22	TR
Assuming 10% extra	1.1 × 22	24	TR

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Ice Plant Calculation			
Quantity of ice required per cum of concrete		30	kg
Quantity of ice required per day	400 × 30/1000	12	tons
Assuming 10% wastage	1.1 × 12	13	tons

8.4 Summary

- Temperature has an effect on the fresh and hardened concrete properties
- During high ambient temperature, the dosage of admixture will increase in order to achieve the same workability
- In case of extreme climate, it is advisable to plan for different formulations for chemical admixtures during summer and winter
- For all concrete, it is advisable to use SCMs. Further in mass concrete SCMs like fly ash and GGBS greatly help in reducing the heat of hydration.
- One of the most effective methods of cooling aggregate is to keep it under shade and sprinkle water.
- Use of chilled water and ice can effectively cool concrete produced in batching plant.
- For mass concrete, it is advisable to use SCMs as they not only reduce the total heat of hydration but also offset the effect of reduced ultimate strength.

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CHAPTER 9

FACTORS AFFECTING QUALITY AND PRODUCTIVITY OF CONCRETE AT BATCHING PLANT

9.1 Introduction

The quality of concrete depends on the controls exercised in four phases:

1. Phase 1 – Selection of right quality of materials.
2. Phase 2 – Accepting the material of right quality at the batching plant
3. Phase 3 – Producing the right quality of concrete in the batching plant
4. Phase 4 – Placing, compacting and curing the concrete correctly in the actual structure

If the controls during any of these phases are not up to the mark, the final product produced will not be of the desired quality. Producing concrete of consistently good quality is one of the requirements for successfully completing the project. It is also very important to ensure that the adequate quantity of concrete is produced as per the planning schedule. For this batching plant of adequate capacity needs to be selected. The production, transportation and placement capacities must be determined at the start of the project.

This chapter discusses the various factors that affect the quality and productivity of concrete at the batching plant and how to improve them (quality and productivity).

9.2 Selection of Quality Materials

The following measures need to be exercised for selection of right quality of materials:

1. Identify the type of cement to be used – OPC, PPC, PSC, etc.
2. Identify various sources of cement available and check history of consistent supply of quality and quantity.
3. Identify sources of SCMs to be used in concrete, if blended cement concrete is to be produced in batching plant.
4. Identify sources of water, fine and coarse aggregates and collect samples for checking suitability for use in concrete
5. Once the selection of cement, SCMs, water, fine and coarse aggregates is done, collect samples for conducting trials.
6. Depending upon the concrete requirement, select right type of admixture formulation by conducting trials with different chemical admixtures.

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7. Based on the trial results, fine tune the formulation of chemical admixture to achieve the desired fresh and hardened concrete properties.
8. It is advisable to identify and approve at least two sources of cement & SCMs and three sources of admixtures for successful completion of project without any quality and supply issues.

9.3 Accepting the Materials of Right Quality at the Batching Plant

Once selection of materials and concrete mix designs are done, it is important to ensure consistent supply of materials. Inspection and test plan (ITP) may be devised for each incoming material and the relevant properties checked before accepting the material. Sample ITP for various materials is as given Table 9.1 below:

Table 9.1 Sample inspection and test plan

Sr. No.	Material	Test required	Relevant I.S. code	Acceptance criteria	Recommended frequency	Whether In-house or 3rd party testing (Recommended)
1	Cement	Normal consistency	IS 269 for OPC 43 & 53 grade IS 1489 Part 1 for PPC IS 455 for PSC	As specified in relevant IS Code	250 t	In - house
		Compressive strength			250 t	In - house
		Initial and final setting			250 t	In - house
		Specific gravity			2000 t	In - house
		Soundness by Le-Chateliers Method			2000 t	In - house
		Soundness by Autoclave method			2000 t	3rd Party Testing
		Specific surface			2000 t	3rd Party Testing
		All chemical properties			2000 t or at every 6 months whichever is Earlier	3rd Party Testing
		Chloride content			2000 t or at every 6 months whichever is Earlier	3rd Party Testing
2	Fly Ash	Physical and chemical properties	IS 3812 Part 1	IS 3812 Part 1	3 samples for source approval Every 2000 t or at every 1 - month interval, whichever is earlier	3rd Party Testing
		Moisture content		IS 3812 Part 1	Each batch of 100 t	In - House
		Loss on ignition		Maximum 2%	Each batch of 100 t	In - House

		Particles retained on 45 μ sieve		Maximum 34%	Each batch of 100 t	In House
3	Micro Silica	SiO_2, (%)	IS 15388	Minimum 85 %	Every 2000 t	3rd Party Testing
		Moisture Content (%)		Maximum 3%	Every 100 t	In - house
		Loss of Ignition		Maximum 4%	Every 100 t	In - house
		Alkalies as Na_2O (%)		Maximum 1.5%	Every 2000 t	3rd Party Testing
		Oversize % retained on 45 μ IS Sieve		Maximum 10%	Every 100 t	In - house
		Compressive strength at 7 days as % of control sample		85%	Every 100 t	In - house
		Specific surface (m²/g)		Minimum 15	Every 2000 t	3rd Party Testing
		Specific gravity		For batch qualification value shall not deviate by ± 0.2 from values obtained during mix qualification	Every 2000 t	3rd Party Testing
4	Ground Granulated Blast Furnace Slag (GGBS)	Fineness (m²/kg)	BS EN 15167	Minimum 275	Every 500 t or at every 6 months interval	3rd Party Testing
		Loss of Ignition (%)		Maximum 3.0%		
		Insoluble residue (%)		Maximum 1.5%		
		Initial setting time		Not more than twice that of OPC when tested (50% OPC + 50% GGBS)		
		Magnesium oxide (%)		Maximum 18%		
		Sulphide (%)		Maximum 2%		
		Sulphate (%)		Maximum 2.5%		
		Chloride content (%)		Maximum 0.10 %		

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		Moisture content (%)		Maximum 1.0%		
		Activity Index After 7 days After 28 days		Minimum 45% Minimum 70%		
5	Aggregate	Specific Gravity (SSD Condition)		2.6 for C.A. 2.55 for F.A.	One Sample for every 5000 t for new source or change in source	In house
		Deleterious material for fine aggregate (% by weight)	IS 383		One Sample for every 5000 t for new source or change in source	In house
		a) Material passing 75 µ		Max. 3% for natural Sand Max 15% for crushed sand		In house
		b) Shale		Max. 1.0 %		3rd Party Testing
		c) Coal and lignite		Max. 1.0 %		
		d) Clay lumps		Max. 1.0 %		
		e) total of other deleterious substances such as alkali, Mica coated grains, soft and flaky particles and loam		Max 5.0 %		
		f) total of all above substances		Max. 5% for natural Sand Max 2% for crushed sand		
		Deleterious material for crushed coarse aggregate (% by weight)			One Sample for every 5000 t for new source or change in source	3rd Party Testing
		Coal and lignite		Max 1.0%		
		Shale		Nil		
		Clay lumps		Max 1.0%		
		Soft fragments		Nil		
		Material finer than 75 µ		Max 1.0%		
		Sum of % of all deleterious materials		Max 2.0 %		

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		Size and gradation		IS 383	Once Sample for every 1000 m^3 of concrete	In house
		Absorption/ Moisture		Maximum 3.0 %	One sample daily	In house
		Silt Content (for Natural Sand)		Maximum 8%	Once in a week	In house
		Organic impurity (for natural sand only)		No impurity	Once in Six months	3rd Party Testing
		Flakiness and elongation index (For coarse aggregate only)		Max. combined EI & FI 40%	Once in a Month	In house
		Crushing Value (for CA only)		Max 45 %	Once in six months	In house
		Abrasion Value (for CA only)		Max 45 %	Once in six months	In house/ 3rd Party Testing
		Impact Value (for CA only)		Max 45 %	Once in six months	In house
		Alkali silica reactivity		Innoccous	Once for a source	3rd Party Testing
6	Water (mixing of concrete and Curing)	pH	IS 456	More than 6	Every 3 months	In house/ 3rd Party Testing
		Organic solids		Max. 200 mg/l	Every 3 months	3rd Party Testing
		Inorganic solids		Max. 3000 mg/l	Every 3 months	3rd Party Testing
		Sulphates (as SO3)		Max. 400 mg/l	Every 3 months	3rd Party Testing
		Chlorides (as Cl)		Max. 2000 mg/l for concrete not containing embedded steel and 500 mg/l for reinforced concrete	Every 3 months	3rd Party Testing
		Suspended matter		Max. 2000 mg/l	Every 3 months	3rd Party Testing
		Average 28-day compressive strength		Not be less than 90 % of the concrete prepared with distilled water	In case of doubt regarding development strength	In - House

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		Initial setting time (IST) of test block		IST of test block shall not differ by more than +30 minutes from initial setting time of control test block	In case of doubt regarding development strength	In - House
7	Chemical Admixture	Water reduction as % of control	As per IS 9103	Minimum 18%	Composite sample of minimum 4 individual samples representing 100 t of admixture	In - House
		Air entrainment	As per IS 9103	± 1% of control mix		In - House
		Initial setting time deviation from control	As per IS 9103	At least - 1 hour later but not more than - 3 hours later		In - House
		Final setting time deviation from control	As per IS 9103	At least - Nil Not more than 3.30 hours later		In - House
		Compressive strength as % of control mix	As per IS 9103	1 day: Min. 125% 3 day: Min. 125% 7 days: Min. 115% 28 days: Min. 110 %		In - House
		Flexural strength as % of control mix	As per IS 9103	3 days: Min. 110% 7 days: Min. 100% 28 days: Min. 100%		In - House
		Specific Gravity at 25°C	As per IS 9103	Within ± 0.02 of value stated by manufacturer		In - House
		Solid content	As per IS 9103	With ± 3% of value stated by the manufacturer		MTC / Third party for Source approval
		pH	As per IS 9103	7 - 8		In - House
		Chloride content (%)	As per IS 9103	0.2 % Max		MTC / Third party for Source approval

Note: The above limiting values are taken from relevant IS standards. In case the technical specification demands a different limiting value for any particular parameter for any material the same needs to be followed for that particular project.

9.4 Producing Quality Concrete from Batching Plant

1. Cover aggregate bins to protect from heat, rain and dust. Fig. 9.1 [1] shows protection system for star bin as well as inline bin system. In spite of protection, as shown in Fig. 9.1 aggregates in star bin system get wet in rains hence it is preferable to adopt inline bin system.
2. Check the grading of aggregate before start of any major pour. Adjust the proportion of aggregate to get the required combined grading.
3. Ensure proper moisture correction is done before start of concrete works.
4. Ensure that moisture sensors in the batching plant are in working condition so that the moisture correction for fine aggregate is automatically done for each batch of concrete.
5. Check the first batch of concrete produced and make necessary changes if required.
6. For big concrete pours which go on throughout the day, there will be changes in the fresh concrete properties as the ambient temperature changes. Necessary correction to the dosage of chemical admixture must be done accordingly.
7. Continuous feedback from the pouring point must be taken by batching plant operator to understand that the concrete reaching site is as per requirement.
8. In case of any need for adjusting the workability of concrete, it must be done by adjusting admixture dosage by authorised personnel only.
9. Provide PCC layer about 100 mm below star bin aggregate storage area.
10. Provide RCC wall 15 cm high at the end of star bin area boundary. This will prevent aggregate from spilling outside the bin and getting intermixed with soil/ dust etc. (refer Fig. 9.1 & Fig. 9.2 [1]).

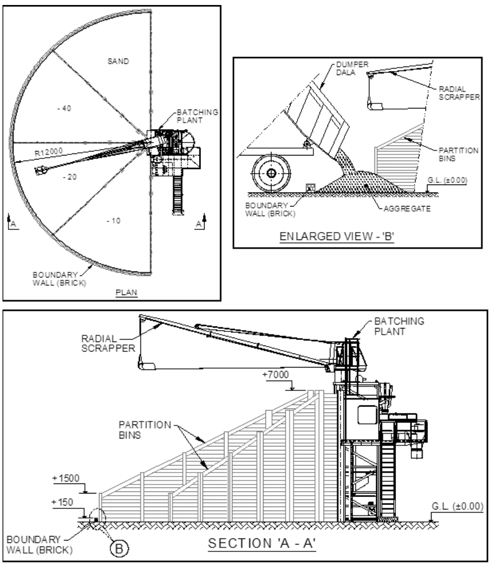

Fig. 9.1 Protection on aggregate in star bins system

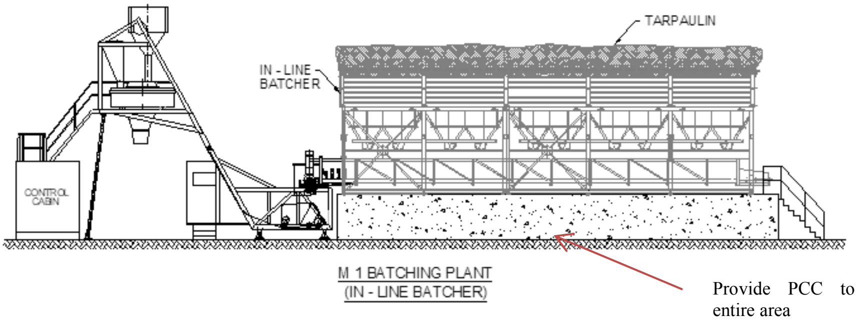

Fig. 9.2 Protection on aggregate in inline bins system

9.5 Selection of Batching Plant for a Project

Main factors in selecting a batching plant for any project are:

1. Capacity of batching plant

In order to meet the requirement of project specific parameters as mentioned above, a concrete plant of adequate capacity should be installed. It should take into account the amount of various ingredients proposed for use in the mix like, quantity of cement, fly ash, admixtures like plasticizer, retarder, air entraining agent etc.

The manufacturer gives the rated production capacity of the batching plant along with the assumptions. In case of deviations from the assumptions, the capacity may get altered. Some of the assumptions are:

a. Cement content
b. Size of aggregate
c. Type of aggregate
d. Workability

A standard cycle diagram for a Schwing Stettar 60 cum/hr. batching plant is shown below in Fig. 9.3.

The above cycle time holds good for general concrete having cement content 300 kg/cum and water cement ratio 0.5. The mixing time for such a concrete mix design is 30 secs and a 1 m^3 batch is discharged in 64 secs.

Rated capacity of batching plants is based on cement content of 300 kg or less per cum of concrete for which cement screw conveyor of 168 mm diameter is provided. If cement content per cum of concrete increases over 300 kg per cum say to 450 kg/cum, then feeding time increases by 50%, thereby reducing the output of concrete from the batching plant. To overcome this problem, it is advisable to provide bigger size screw conveyors with higher motor capacity. The bigger size screw conveyor is 219 mm diameter. The feeding capacity of this bigger size conveyor is 60 t/hr. against standard conveyor of 168mm dia. whose feeding capacity is 40 t/hr. (Fig. 9.4). Hence, even if cement content per cum of concrete is 450 kg, time taken to feed cement remains unchanged and as a result actual production is unaffected.

Another important point to be considered is the chemical admixture used. The conventional naphthalene based admixtures have a much lower viscosity as compared to the new PCE based admixtures. If the dispenser pump of adequate capacity is not provided in the batching plant, it will not be able to pump the high viscosity PCE based admixtures properly.

It is extremely important to understand the impact on the loading, mixing and discharge time of concrete when there is a change in the mix design. The time cycle shown below in Fig. 9.5 achieved for M80 grade concrete having quadruple blend cementitious system with OPC, Fly Ash, GGBS and Alccofines in the mix. The mix was designed with 100% crushed sand and having a workability of 150 mm after 3 hours.

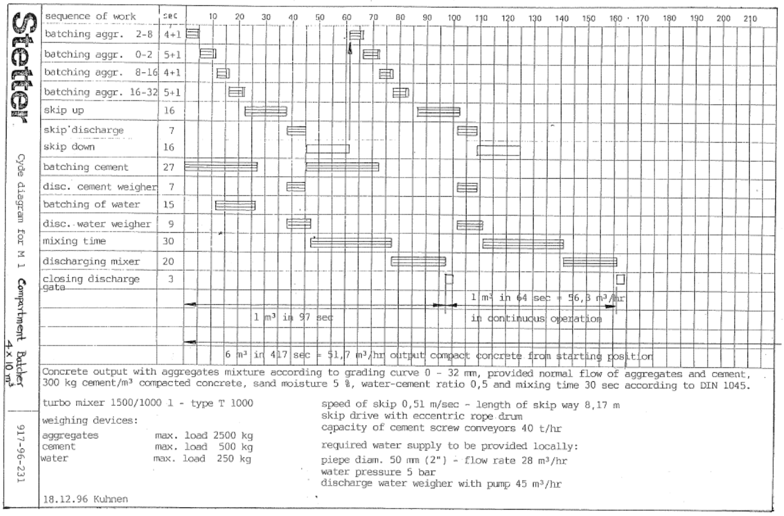

Fig. 9.3 Typical cycle time for Schwing Stetter plant of 60 cu.m./ hour capacity

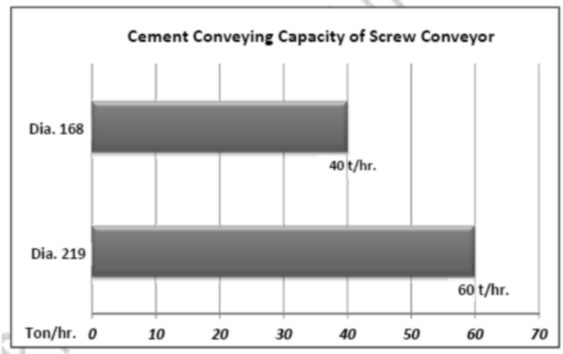

Fig. 9.4 Cement conveying capacity of screw conveyor

Note: Diameter is in mm

Activities	5	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360	375
Charge aggregates	5s																									
Charge cement		15s																								
Premix time							2m																			
Charge water, ice & admix.											30s															
Final mixing time																			3m							
Discharge & door close time																									30s	
Total Cycle Time	375 secs (6.25 mins for 1.5 cum. Concrete)																									

For 1 batch of 1.5 cum.	6.3	mins.
For 1 Transit Mixer of 6 cum.	25	mins.
Per hour BP capacity (Theoretical)	14	cum.
Per hour BP capacity (Actual)	12	cum.

Fig. 9.5 Typical cycle time for M80 grade concrete

In order to achieve a consistent quality concrete, it can be observed that initial dry mixing of 60 secs was required and with further 90 secs of final mixing. Since the mix was sticky it took almost 30 secs for discharge from the hopper instead of the normal 20 secs. All this added up to reduce the production capacity of a 90 cum/hr. batching plant to just 12 cum/hr.

When mix design is with blended cement, high cementitious content or crushed sand are to be used, the mixing times usually need to be higher than those recommended by the manufacturer. Also, when ice is used as a part replacement of water, the mixing time increases slightly for producing a uniform mix. Right formulation of admixture can be of some help in slightly reducing the overall mixing time, but the final mixing time required must be determined by conducting trials with varying mixing times and checking the quality of concrete produced.

If the effect of the actual mix design to be produced from the batching plant is not taken into consideration, the production achieved will not be as per the project requirement.

2. Types of mixers

Suggested criteria for the selection of mixer are as under:

- Size of aggregate
- Easy to clean
- Ease of replacing the blades or parts
- Sensitivity of the blades to wear and tear
- Mixer Capacity (Size of drum)
- Mixing energy required
- Efficiency of a mixer
- Mixing time
- Mixing method
- Location of the construction site (distance from the batching plant)
- Amount of concrete needed

Pan mixer and twin shaft mixers are the most common mixers used in batching plant.

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- Pan mixers give the best quality product, with minimum cement usage, for all types of mix and batches of up to 3 cubic metre
- Above 3 cubic metres, consider multiple batches from a pan type, due to its high speed and superior mixing action
- If this is not possible, the twin-shaft is the mixer of choice, especially for high slump concrete and SCC

9.6 Layout of Batching Plant

A good layout of batching plant is extremely important to ensure that the transit mixers as well as other vehicles entering the batching plant can move without hindering each other's movement. The first and primary important parameter is that at the batching plant the transit mixers should arrive and leave in the same direction (Fig. 9.6 [2]). Reversing the transit mixer to come under the hopper can lead to a situation where the mix is ready to be discharged but the transit mixer is still not under the hopper in correct position. This will lead to loss of productivity.

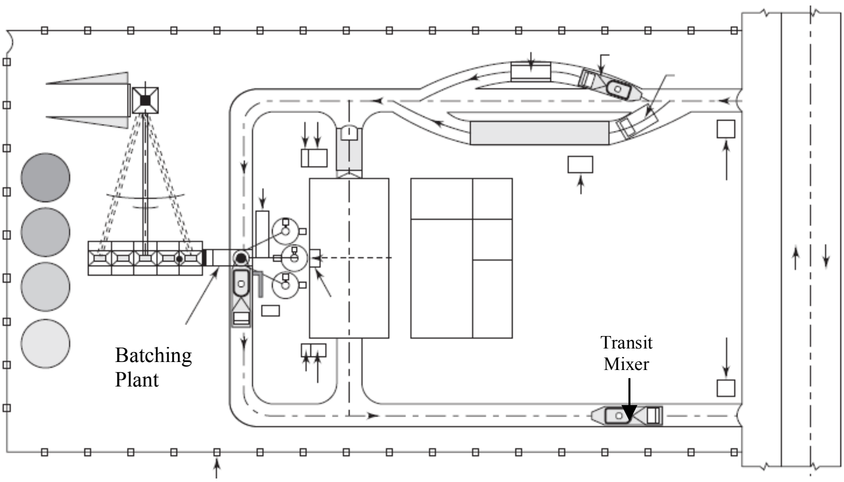

Fig. 9.6 Proper layout of batching plant for easy movement of transit mixer

Secondly for exact positioning of transit mixer (TM) just below the discharge chute at very first attempt by the driver of TM so that concrete is discharged in TM without spillage, it is essential to provide markers as shown in Fig. 9.7. Even with provision of such markers, it is very difficult for TM to stand at exact location at the very first attempt, so that concrete from discharge chute of batching plant can fall exactly into entry hopper of TM without spillage. This is particularly so because diameter of the discharge chute is practically same as diameter of the entry hopper of TM. To avoid such spillage problem, it is recommended to have enlarged diameter of entry hopper of TM. With such arrangement, it is very convenient for TM to stand below discharge chute at very first attempt so that concrete falls properly in the inlet hopper of TM without any spillage. Fig. 9.8 indicates extended inlet hopper of TM w.r.t. to discharge chute.

Fig. 9.7 Providing indicators for proper positioning of TM under chute

Fig. 9.8 Enlarged entry hopper of TM

Note: In this case diameter of the inlet hopper of TM was increased by 75% over its original size.

9.7 Other Issues Improving the Quality of Concrete at the Batching Plant

- Ensure proper calibration of the batching plant as per norms. For batching plant which is continuously utilized close to rated capacity, the frequency may be reduced for better control.
- Check the batching plant print out regularly to check the consistency of batch weights.
- The cabin of operator should also be at the hopper level, so that he can continuously monitor the discharge of concrete and take immediate corrective actions if required.
- Maintain a small can of admixture in the TM so that in case any adjustment to workability is required, the same can be done at site by the authorised personnel.
- Keep the mixer and mixer blades clean all the time and check the clearance of blades with the mixer body. If the clearance is more than the permissible, then mixing of concrete materials will not be very effective. Hence the same must be rectified immediately when brought to the notice.

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- Ensure that the wash water from the batching plant mixer and TM is discharged completely before start of work. Washing need not be done after every trip of TM. Frequency can be decided based on actual observations, generally, washing can be done after 3-4 trips, unless the lead is long.
- Ensure that the TM is covered with hessian cloth and kept wet all the time.

9.8 Summary

- Selecting right materials for designing concrete is extremely important.
- Ensure that the incoming raw materials are regularly checked as per the ITP so that the consistent quality is maintained.
- Understand the effect of mix proportion of concrete on the productivity before installing a batching plant for the project.
- Regular calibration and maintenance of batching plant mixer and transit mixer must be done.

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CHAPTER 10

TRANSPORTATION & PLACEMENT FACTORS AFFECTING QUALITY OF CONCRETE

10.1 Introduction

The main objective while transporting concrete is to pour it into the structure in the shortest possible time and achieving the desired properties in fresh and hardened conditions. Once the concrete is effectively transported to the placement point, the next important step is to ensure that the concrete is placed properly in the forms without segregation and compacted to form a homogenous mass without honeycombing and minimum entrapped air.

The right selection of transportation and placement means are extremely important to achieve the required purpose.

10.2 Selection of Transportation and Placement Methods

Concrete can be transported and placed by a variety of methods and equipment, such as transit mixers, belt conveyors, dumpers, pipelines with concrete pump, buckets, tremies, cranes and hoists, chutes, etc. The method of transportation should efficiently deliver the concrete to the point of placement without losing mortar or significantly altering the concrete's desired properties including w/b ratio, slump, air content and homogeneity.

Various conditions should be considered when selecting a method of transportation, such as: mixture ingredients and proportions; type and accessibility of placement; required delivery capacity; location of batch plant; and weather conditions. These conditions can dictate the type of transportation best suited for economically obtaining quality in-place concrete.

Various types of transportation and placement methods and their application are given in Table 10.1 [1] below. Various quality control issues encountered with the various transportation and placement methods are discussed in Table 10.2.

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Table 10.1 Various types of transportation and placement methods and their application

Method	Advantages	Remarks
Transit mixers	Slump ranging from very low (25 mm) to flowable mixes with can be transported effectively. Changes to the workability of concrete can be done in case it is not as per the requirements. Mix can be transported to any distance and time if the mix is designed for the same.	Most commonly used and extremely versatile method of transporting concrete.
Dumpers or Trucks	Mixes with very low slump (0-50 mm) can be effectively transported in large quantities over long distances.	Very useful for Roller Compacted Concrete, Pavement Quality Concrete or Dry Lean Concrete.
Conveyor Belts	Can place large volumes of concrete quickly when access is limited. Belt conveyors have adjustable reach, traveling diverter, and variable speed both forward and reverse.	End-discharge arrangements needed to prevent segregation and leave no mortar on return. In adverse weather (hot, windy and rainy) belt needs protective cover.
Buckets	Convey concrete directly from batching plant to formwork or to secondary discharge point. Used with cranes, cableways, and dumpers for construction of buildings and dams	Discharge control can be difficult. Select bucket capacity to conform to size of the concrete batch and capacity of placing equipment.
Pipelines	Used to transport concrete directly from batching plant (in case of short distance) or from transit mixer at jobsite to formwork. Pipelines take up little space and can be readily extended. Delivers concrete in continuous stream. Pump can move concrete both vertically and horizontally. Truck-mounted pumps can deliver concrete directly to the location. Tower-crane mounted pump booms provide continuous concrete for tall building construction.	A combination of transit mixer and pipelines is the most common method used for transportation and placement of concrete. Constant supply of concrete is needed with right consistency and without any tendency to segregate.
Tremies	Used for placing concrete under water without contaminating the concrete with water. Provides a uniform concrete placement under water. This is a common method adopted in concreting bored cast-in-situ piles, diaphragm walls, etc.	Precautions are needed to ensure that the tremie discharge end is always buried in fresh concrete, so that a seal is preserved between water and concrete mass. Concrete mixes need greater slump, more than 150 mm, so that it is self levelling and can be easily compacted by movement of tremie up and down.
Chutes	For conveying concrete to a lower level, usually below ground level, on all types of concrete construction. Chute may be attached to Transit Mixer if length is short like for piles or independently if length is long.	Low cost and easy to maneuver. No power required; gravity does most of the work. Slopes should range between 1 to 2 and 1 to 3 and chutes must be adequately supported.
Pneumatic guns (shotcrete)	Used where concrete is to be placed in difficult locations and where thin sections and large areas are needed. Ideal for placing concrete in tunnel supports (shotcrete), freeform shapes, for repairing structures, for protective coatings, thin linings, and building walls with one-sided forms.	Requires higher cementitious content and high workability. Quality of work depends on skill of those using equipment. Only experienced nozzlemen should be employed.

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Table 10.2 Important quality control issues for various transportation and placement methods

Methods	Attributes	Issues
Transit Mixers	Actual slump less than required	Need to add correct dosage of admixture and the TM rotated at full speed to allow the admixture to be mixed uniformly in the concrete. If the admixture is not mixed uniformly and only gets mixed with the upper quantity, there will be bleeding or segregation due to excess admixture in that concrete. Many times, the pump operator adds water instead of admixture to increase the slump, which will lead to increase in w/b ratio and loss of strength and durability. Hence, this practice should not be permitted.
	Temperature of concrete at pouring point	Temperature of concrete may rise by 2-5°C depending upon the initial concrete temperature, ambient temperature and lead time. Strict control must be exercised at the pouring point by authorized personnel to monitor the workability and make necessary changes if required. It is advisable to cover the TM with hessian cloth which must be kept wet all the time. If the lead time is very high, the driver can sprinkle water during transit to wet the hessian cloth if it dries.
Dumpers	Higher slump	If the slump of concrete is more than 75 mm and the distance of travel is long with bad road conditions, the concrete tends to get compacted in the dumper leading to formation of slurry at the top. It becomes difficult to unload the compacted concrete and the slurry gets discharged earlier than the main concrete on the pouring area leading to inhomogeneous concrete. It is advisable to control the slump of concrete to less than 75 mm for transporting in dumpers.
	Evaporation of moisture from surface	If the dumper is not covered, the water from the top surface evaporates due to ambient temperature and wind causing the top concrete to false set. This leads to inhomogeneous concrete. It is essential to cover the dumper at least during high ambient temperature and wind conditions to avoid evaporation of water from top concrete. Covering the dumper all the time is an ideal condition.
Conveyor belts	Segregation of concrete	If the conveyor belt is long and the mix is not cohesive, there is a possibility of segregation, especially if the drop height is more. It is advisable to have a long flexible hose reaching up to the discharge point to avoid segregation.
Buckets	Control on discharge of concrete	Discharge gate can be manually or pneumatically controlled. It is important to control the discharge of the gate to avoid too much concrete accumulated at one place. This would lead to using a vibrator for spreading the concrete over the area which is a bad practice. Pneumatic control gates are preferred over manual operations as there is a better control. It is advisable to have a good operator for controlling the discharge.
Tremie	Accidental removal of tremie end out of concrete	The end of tremie must always be at least 2 to 3 metres inside the concrete in order to allow the contaminated concrete to come up to the top and not get intermixed with fresh concrete. Tremie pipe should be moved up and down for compaction of concrete. Care must be taken while lifting the tremie pipe for removing the upper pipes. Generally, a 3 m tremie pipe section is removed when the concrete is at least 6 m filled above the bottom of the tremie pipe. Tremie pipe joints should be leak proof.

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Pipelines	Choking of concrete in pipelines	Refer 10.3 for complete details on pumpable concrete
Chutes	Segregation of concrete	There is a possibility of segregation of concrete if the discharge is not properly maintained. It is advisable to maintain the slopes between 1 to 2 and 1 to 3 and chutes must be adequately supported. Concrete discharge should be as close to the pouring point as possible.
Pneumatic guns (shotcrete)	Choking of pipeline. Rebound of shotcrete	If the shotcrete is having low slump, there is a possibility of pipe choking. Rebound can be as high as 50% if the operator is not having knowledge of the operations. Slump of shotcrete must be maintained high. Amount of accelerator dosage will vary based on the actual workability, cementitious material content, temperature of shotcrete, type of accelerator, etc. Skilled operator must be deployed for shotcrete operations to minimize rebound. Correct pump pressure and angle of shotcrete gun are extremely important to reduce the rebound percentage. The nozzle must be at 90° to the surface and the distance between nozzle and the surface must be 0.5 – 1.5 m for best performance in terms of compaction and rebound.

10.3 Pumpable Concrete

A concrete which can be pushed through a pipeline is called a pumpable concrete. Pumping is one of the quickest and best methods of placing concrete. With pumping, we automatically ensure good quality homogeneous concrete free from segregation, as any concrete which is not properly proportioned and is segregating will result in choking of the pipeline / pump.

Advantages of pumping of concrete:

- Concrete can be moved horizontally and vertically in one go.
- Concrete pump acts as silent quality control inspector since, it refuses to handle any concrete which is unduly harsh, inadequately mixed, non–cohesive and not correct in consistency.
- Saving of large gang of labour for large concrete pours.
- Pumped concrete gives better finish and strength to concrete structure since it has good cohesion and high workability.
- Concrete can be placed in inaccessible places very easily.
- Mass concreting can be carried out in a limited time at high speed and without or with minimum cold joints.
- Concrete pumps help in speedier completion of contract thus helping in increased cash flow, reduction in project overheads.
- Pipeline for delivery of concrete occupies very little space and can be extended or removed easily.
- If mobile boom pump is used both horizontal and vertical movements of the boom pumps are possible. This eliminates the need for chutes and avoids segregation of the concrete mix.

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10.3.1 Design considerations for pumpable concrete

In order to pump concrete, the pressure exerted by the pump on the concrete has to overcome the pipeline wall friction, the resistance created at bends and tapers, the concrete pressure head when placing at a level higher than the pump and the inertia of the concrete in the pump. Pumpable concrete emerging from pipeline flows in the form of a plug (Fig. 10.1 [2]) which is separated from the pipe wall by a thin lubricating layer consisting of cement paste. The mix must be able not only to bind all the constituent materials together under pressure, but must also facilitate the movement of sufficient grout to maintain the lubricating film initially placed on the pipeline wall. The mix should also be able to deform (alter its cross-sectional area) while flowing without causing segregation. The mix deforms in the valve assembly, at bends and taper sections. To achieve this, the proportion of fines, i.e. cement, SCM and fine sand passing 0.25 mm size is of prime importance. A quantity of fines between 350 to 400 kg/m^3 is considered necessary for pumpable concrete. This is required not only for maintaining the lubricating film but also for having enough paste to cover all the individual aggregate grains.

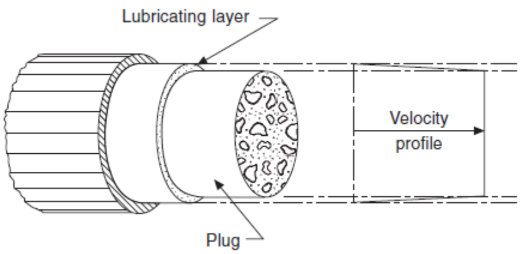

Fig. 10.1 Plug Flow

If the concrete pump is mechanically sound there are two main reasons for pipeline blockage. The plug of concrete will not move because either:

a. Water is being forced out of the mix creating bleeding and blockage by jamming, or
b. There is too much frictional resistance due to the nature of the ingredients of the mix

Both conditions are caused by poor grading at opposite extremes. Condition (a) where high voids are involved, increases flow resistance locally, and condition (b) where there is a high proportion of very fine materials, increases the flow resistance generally. The above issues can be countered by:

a. Excessive frictional resistance by: decreasing the cement content; adjusting the aggregate coarse/fine ratio to increase voids; increasing water content and using suitable admixture.
b. Excessive segregation and bleeding by: increasing cementitious content; adjusting aggregate coarse/fine ratio to reduce voids; using suitable admixture.

As a general guideline, the recommended fines content for various maximum sizes of aggregates are as given below in Table 10.3 [3].

Table 10.3 Recommended fines content for various size of aggregates

Max. size of aggregate (mm)	Recommended fines content per cubic metre of concrete, kg
8	525
16	450
20	435
32	400
40	380
63	325

Notes: Fines are defined as cement + SCM + aggregate passing 0.125 mm sieve

Effect of cement and cementitious materials

In general, finer materials reduce bleed and this is true for cements. Fly ash is slightly finer than cement; its spherical particle shape and glassy texture are acknowledged factors in reducing the water demand and increasing the cohesion of concrete. Accordingly, fly ash makes a significant contribution to the pumpability of concrete with low cohesion, particularly when combined with a low cementitious content. Micro silica (2-3%), Ultrafine Fly Ash and Ultrafine Slag (Alccofines) can make a considerable increase in the cohesion of concrete and is especially beneficial in concrete with low cohesion. Ground granulated blast furnace slag has little effect on pumpability as the particle shape and size resemble those of most Portland cements. Metakaolin has little effect on the pumpability of concrete but it has been beneficial in the case of concretes with low cohesion.

However, it should be remembered that total cementitious contents tend to be higher for a given strength class when using fly ash or GGBS and this could give rise to excessive cohesion. Conversely, if the total cementitious content is low, some bleeding can occur when high proportions of GGBS are used in combination with difficult aggregates and specific admixtures.

A suitable aggregate for pumping will have a continuous grading that allows controlled migration of water and fine material towards the pipe/concrete interface. Excessive bleeding is caused by gap-graded aggregates or by coarse sands that present discontinuity between the coarser cement grains and the finest aggregate particles. Well-graded coarse aggregates combined with sand that contains an adequate proportion of ‘finer fines’ will produce a continuous and smooth grading curve that goes some way to meet the requirements of particle packing theory and pumpable concrete.

It is difficult to make a pumpable concrete with excessively coarse sand unless a finer sand or SCM such as Fly Ash is included; merely increasing the sand content in an attempt to improve pumpability can make matters worse because of the absence of ‘finer fines’ between the gradings of the sand and cement.

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Most shapes of aggregate can make pumpable concrete provided the volume of voids is kept to a minimum. High indices of flakiness and elongation can create difficulties in pumping due to aggregate interlock and bridging at bends in the pipeline. The sand properties and proportions need extra consideration when using any badly shaped coarse aggregate.

The voids that occupy the interstices between aggregate particles demand a large proportion of grout to fill them. If they are not filled, uncontrolled bleeding, segregation and aggregate interlock are promoted by the presence of voids. When voids are in concrete are minimum, the segregation resistance of concrete is high. This can be achieved by optimizing the sand content as shown in Fig. 10.2 [2].

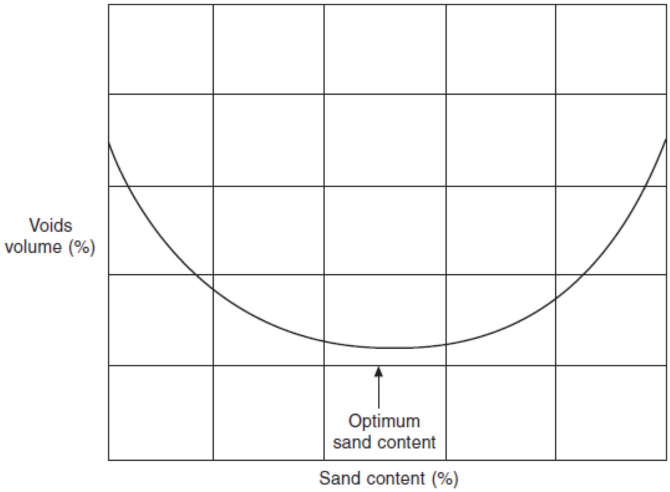

Fig. 10.2 Relationship between voids content and sand content for determining optimum aggregate grading

Overfilling of voids with an excessive quantity of cementitious material can produce the high friction condition referred to earlier, which can be unfavourable to pumping (Fig. 10.3) [2].

For optimized pumpable mix, voids in all-in-aggregates (coarse and fine) have to be minimum and the optimum cement content shall be adequate to fill the voids. For e.g., if voids of all in-aggregates, is 20% and density (bulk) of all-in-aggregate is 1500 kg per cum, then minimum cement content for pumpable concrete is $0.2 \times 1500 = 300$ kg/cum.

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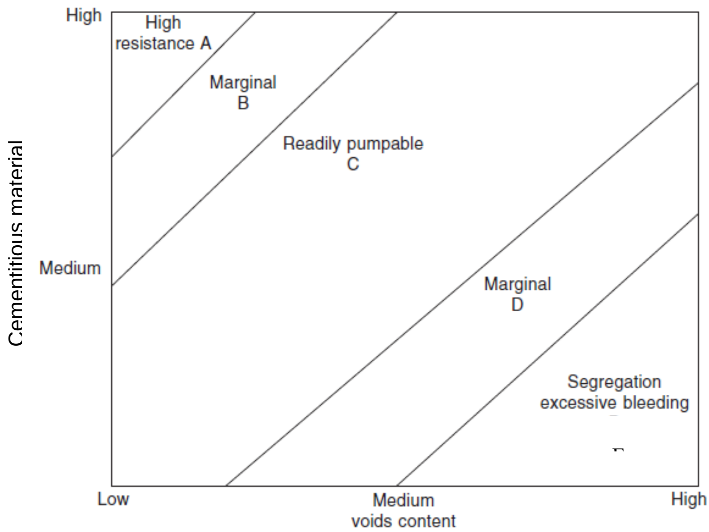

Voids content in aggregate

Fig. 10.3 Relationship of voids to pumpability

Notes:
Zone A – High frictional resistance
Zone B – Pumps at high pressure, if health of pump is not good it will be difficult to pump and may lead to choking of pipeline
Zone C – Pumpable mixes
Zone D – Tends to segregate, can lead to choking of pipeline
Zone E – Excessive segregation and bleeding, mixes not pumpable

10.3.1.2 Essential execution parameters for concrete pumping

1 Laying of pipeline

It is very important to understand the right method of lying of pipeline. A lot of time, money and annoyance will be saved if laying of pipelines is properly planned and carried out with care. The following points are important:

a. Dimensions of pipeline: Generally, concrete pipelines are available with varying diameters – 100 mm, 125 mm and 150 mm being the most commonly used in India. Nominal bore (NB) of pipeline shall be at least two and a half times the highest size of the coarse aggregates to be used in pumpable concrete. Friction i.e. flow resistance and consequently pumping pressure being inversely proportional to the pipeline diameter, higher diameter pipes are to be preferred to reduce pumping pressure. But large diameter pipes being heavier and difficult to be handled manually, a compromise shall be made for selection of pipeline diameter. Pipeline of 125 mm nominal bore is a good compromise. Pipeline of 100 mm nominal bore is more suitable for short lengths where concrete distribution is done through end hose by manual labor. Pipeline of 150 mm nominal bore is preferred for tunnel concreting where large size aggregates (MSA 60 mm) are used and concrete distribution is mechanized.

It is always advisable to use a 125 mm diameter pipeline as it generally caters to all aggregate sizes used in pumpable concrete. Concrete designed with 40 mm aggregate can be easily pumped through a 125 mm pipeline (Min. dia. required for 40 mm aggregate is $40 \times 2.5 = 100$ mm). It may be noted that there is no need use 150 mm dia. pipeline for pumping concrete with MSA 40. Authors have successfully used 125 mm dia. pipeline for pumping concrete with 40 mm aggregate in many projects.

b. Layout of pipeline: While planning the layout of the concrete pipeline, it is essential to ensure that it is the shortest route from the pump to the pouring point. While doing so, ensure that the route has minimum nos. of bends. The correlation for over 100 mm dia. of pipeline is as follows:

1 m vertical rise	=	2 m to 3 m horizontal length
One 90 Deg. Bend	=	3 m horizontal length
One 45 Deg. Bend	=	2 m horizontal length
One 30 Deg. Bend	=	1 m horizontal length
1 m rubber pipe	=	2 m steel pipe

It is strongly advised to avoid 90° bend to pipeline, both in horizontal and vertical direction, and provide smooth curves.

c) Starting distance for vertical pumping: Always provide a horizontal starting distance between the concrete pump and the vertical line. This depends upon the maximum pumping height and pipe diameter. The horizontal starting distance should be approximate 10 to 15% of vertical distance. In any case, it should not be less than 5m.

d) Anchoring and Fixtures: Pipeline should be well anchored so that it does not get displaced due to the motion of the concrete flowing through the pipes. Where bends are installed in pipeline high forces are released due to change of direction which result in a considerable movement of the pipeline. Supports must be provided at either side of the bend. (Fig. 10.4 & Fig. 10.5)

The practice adopted by some of providing supports by stones, bricks, wooden purlins (without fastening the pipeline to purlins) below pipeline should be stopped.

e) Leak proof coupling: A leaking coupling is equal to 1m of horizontal pipeline. Ensure that there are no leaking pipes and coupling joints (Fig. 10.6) because concrete bleeding results in plug formation in the pipeline and it hampers the pushing of concrete out of the pipe. There is also a possibility of air getting entrapped in the pipeline which can cause choking of pipeline.

f) High Ambient Temperatures: Shading, covering or even cooling the pipeline is advisable when using long pipelines. The pipeline is to be painted in light or white colour and the concrete in the hopper is to be covered with the wet sacks. With outputs of 20 cum/hr. the concrete needs approx. 15 minutes to flow through a pipeline of 125 mm dia., 400 m long. Within this time the concrete absorbs considerable heat and if pumping gets delayed the concrete can easily start setting causing choking of pipeline.

Fig. 10.4 Proper anchoring of horizontal pipeline with anchors at both ends of coupling (if couplings are 3m apart, one more support is desirable)

Fig. 10.5 Proper anchoring of vertical pipeline with anchors at both ends of coupling (if couplings are 3m apart, one more support is desirable)

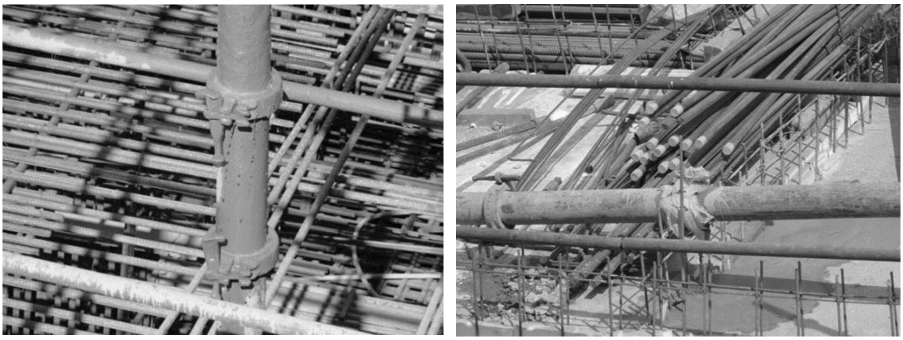

Fig. 10.6 Leaking pipelines and coupling joints can cause serious quality & pumping issues

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2 Priming of concrete pipeline / pump

a) Priming (lubricating): Pipeline must be primed before placing concrete in the pipeline. This sliding layer regenerates itself automatically when concrete is pumped continuously by the fine mortar in the mix. This priming is must for newly laid or cleaned pipeline of longer distances (the pipeline of the placing boom is relatively short and it is often possible to start pump without any special priming).

b) Lubricating mix: The lubricating mix can be prepared with 1:1 ratio of cement & water. Fly ash or GGBS if available should be used replacing 50% cement as they are better lubricators than cement and economical. Where pipeline is more than 100m long we can use 2 parts of cementitious material, 1 part of sand and water. Approximately 250 litres of mix is required for 100 m pipeline.

Nowadays there are readymade chemicals available with admixture suppliers which can be directly mixed in water and pumped into the pipeline for providing lubrication. Such chemicals save not only in terms of cement consumption but also save the operating cost of batching plant and transit mixer involved in production and transportation of cement slurry. The admixture suppliers suggest recommended dosages for per metre length of pipeline.

3 Consistency of concrete mix and pump pressure

The correct consistency of concrete mix is very essential for smooth pumping of concrete. Normally, the concrete consistency is measured by slump and flow parameters. As a general rule, a concrete having slump of more than 100 mm or a flow more than 425 mm can be pumped easily. Flow of concrete is a better parameter for judging the pumpability of concrete mix. With the complexity of concrete mix design increasing with use of SCMs and chemical admixtures, it is also very important to check the viscosity of the concrete mix.

A concrete mix which has higher viscosity will tend to exert higher pressure on the pump, thus reducing the output and increasing the wear and tear of pipeline and breakdown of the concrete pump. Concrete must always be designed keeping this point into consideration, especially when long distance pumping is to be done. During long distance pumping, the concrete tends to loose its consistency and it can be observed that a highly flowable concrete will have lost a considerable amount of flow when discharged out of a long distance pipeline. This must be kept in mind while designing the concrete mix in the lab.

In planning of concrete pumping, a very first step is to calculate the capacity and pressure required to transport concrete with required slump. In general, greater the diameter of pipe line, lesser will be the pressure requirement. The line pressure required for concrete pumping depends on many factors such as vertical rise, pipeline layout, no of bends, concrete slump etc. Following thumb rules may be adopted to calculate rough estimation for pipeline pressure required for concrete pumping.

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Start up pressure required by pump 20.0 kg/cm^2
Every 20m horizontal pipeline 1.0 kg/cm^2
Every 4m vertical pipeline 1.0 kg/cm^2
Every 90° elbow 1.0 kg/cm^2
Every 45° elbow 0.5 kg/cm^2
Every pipe coupling 0.1 kg/cm^2
Every 5m of end hose (flexible) 2.0 kg/cm^2
Safety factor 10 % of total

Following example shows how to calculate pressure required for concrete pumping.

A trailer pump is installed 40m away from the building and is required to pump concrete 80 m vertically, the calculations of pressure is as per the following:

Start up pressure	=	20 kg/cm^2
Vertical delivery line (80m) / (4)	=	20 kg/cm^2
Horizontal delivery line (40m) / (20)	=	2 kg/cm^2
Couplings (40 Nos) / (0. 1)	=	4 kg/cm^2
Elbow 90 degree (2 Nos) × (1)	=	2 kg/cm^2
End hose 5m (1 No) × (2)	=	2 kg/cm^2
Total	=	50 kg/cm^2
Add 10 % for safety factor	=	5 kg/cm^2

Total Pressure required for concrete pumping = 55 kg/cm^2
Note: 1 bar ≈ 1 kg/sq.cm.

10.4 Compaction of concrete

The purpose of compaction of concrete is to achieve the highest possible density. Vibration is the most common and effective method of compaction. When concrete is placed in the forms, air bubbles can occupy between 5 percent (in highly workable mix) to 20 percent (in low slump mix) of the total volume. The mortar component of the mix if fluidified will reduce the internal friction thus facilitating dense packing of coarse aggregate particles. Continuous vibration expels most of the entrapped air, but it is not usually possible to remove the entire entrapped air from the concrete. Generally, 1% entrapped air remains even in well compacted concrete.

Compaction of concrete, which is achieved by imparting vibration to concrete, is a two-stage process as shown in Fig. 10.7 [4]. First, the aggregate particles are set in motion and the concrete consolidates to fill the form and give a level top surface (liquefaction). In the second stage, entrapped air is expelled. The first stage is achieved quickly and the surface levels, giving the impression that the concrete is compacted. Entrapped air takes a little more time to rise to the surface. Compaction should therefore be prolonged until this is accomplished, i.e. until air bubbles no longer appear on the surface.

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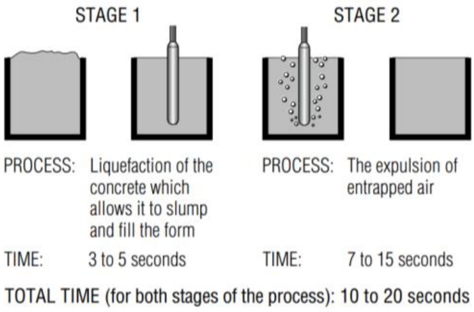

Fig. 10.7 Stages of compaction of concrete

10.4.1 Effect of compaction on fresh concrete

The effect of compaction on the properties of fresh concrete needs to be understood to ensure that the type and amount of vibration applied to the concrete are appropriate. Otherwise, defects such as excessive mortar loss and other forms of segregation can occur.

Concretes lacking fines can be difficult to compact and, even when fully compacted, can have a high porosity. On the other hand, those with too high a fines content, particularly if they also have a high slump, may be prone to segregation and excessive bleeding.

Concretes with lower workability, i.e. stiffer mixes, will require a greater energy input to compact them fully. This may be achieved by using a high-energy vibrator or by vibrating the concrete for a longer time. In the latter case, the vibrator must have at least sufficient capacity to liquefy the concrete. Conversely, more workable mixes will require less energy input. The size and angularity of the coarse aggregate will also affect the effort required to fully compact concrete. The larger the aggregate, the greater the effort required, while angular aggregates will require greater effort than smooth or rounded aggregates.

10.4.2 Effect of compaction on hardened concrete

Since compaction of concrete is designed to expel entrapped air and optimize the density of the concrete, it benefits most of the properties of hardened concrete. As may be seen from Fig. 4.1, its effect on compressive strength is dramatic. For every 1% air entrained/entrapped in concrete, there is a drop in compressive strength by approximately 5%.

Permeability of concrete is also affected since compaction, in addition to expelling entrapped air, promotes a more even distribution of pores within the concrete, causing them to become discontinuous. This reduces the permeability of the concrete and hence improves its durability. The abrasion resistance of concrete surfaces is normally improved by adequate compaction. However, excessive vibration, or excessive

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working of the surface, can cause an excessive amount of mortar (and moisture) to collect at the surface, thereby reducing its potential abrasion resistance.

10.4.3 Internal vibrators

Internal or immersion-type vibrators are commonly used to consolidate concrete in walls, columns, beams, and slabs. Flexible-shaft vibrators consist of a vibrating head connected to a driving motor by a flexible shaft. Inside the head, an unbalanced weight connected to the shaft rotates at high speed, causing the head to revolve in a circular orbit. The vibrating head is usually cylindrical with a diameter ranging from 20 to 150 mm (Refer Table 10.4 [5]). The dimensions of the vibrator head as well as its frequency and amplitude in conjunction with the workability of the mixture affect the performance of a vibrator.

Table 10.4 shows the range of characteristics and applications for internal vibrators for various applications. As a general rule, the radius of action of a given vibrator not only increases with the workability of the concrete (higher slump), but also with the diameter of the head. A good general rule is to use as large a diameter head as practicable, bearing in mind that vibrators with diameters more than 100 mm will probably require two men to handle them. Below this diameter, the appropriate head size will be dependent on the width of the formwork, the spacing of the reinforcement and the cover to it.

Immersion vibrators should be inserted vertically into concrete, as quickly as possible, and then held stationary until air bubbles cease to rise to the surface, usually in about 15–20 seconds, Fig. 10.8 [6]. The vibrator should then be slowly withdrawn and reinserted vertically in a fresh position adjacent to the first. These movements should be repeated in a regular pattern until all the concrete has been compacted (Fig. 10.9, [6]).

Fig. 10.8 Use of an immersion vibrator

Table 10.4 Range of characteristics and applications for internal vibrators for various applications

Dia. of head, mm	Recommended frequency, vibrations per minute	Suggested values of			Approximate values of		Application
		Eccentric moment, kg.mm (10^{-3})	Average Amplitude, mm	Centrifugal force, kg	Radius of action, mm	Rate of concrete placement, m^3/hr	
20-40	9000-15,000	3.5-12	0.4-0.8	45-180	80-150	0.8-4	Plastic and flowing concrete in very thin members and confined places. May be used to supplement larger vibrators, especially in prestressed work where cables and ducts cause congestion in forms. Also used for fabricating laboratory test specimens.
30-60	8500-12,500	9-29	0.5-1.0	140-400	130-250	2.3-8	Plastic concrete in thin walls, columns, beams, precast piles, thin slabs, and along construction joints. May be used to supplement larger vibrators in confined areas.
50-90	8000-12,000	23-81	0.6-1.3	320-900	180-360	4.6-15	Stiff plastic concrete (less than 80-mm slump) in general construction such as walls, columns, beams, and heavy slabs.
80-150	7000-10,500	81-290	0.8-1.5	680-1800	300-510	11-31	Mass and structural concrete of 0-50 mm slump deposited in quantities up to 3 m^3 (deposited at one go) in relatively open forms of heavy construction (powerhouses, heavy bridge piers, and foundations)
130-150	5500-8500	260-400	1.0-2.0	1100-2700	400-610	19-38	Mass concrete in gravity dams, large piers, massive walls, etc. Two or more vibrators will be required to operate simultaneously to mix and consolidate quantities of concrete of 3 m^3 or more deposited at one time into the form.

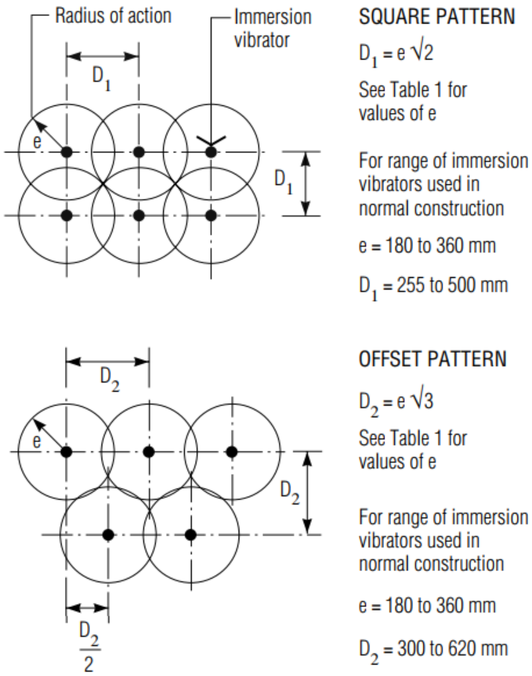

Fig. 10.9 Alternative patterns for use of immersion vibrators

The following procedure should be followed for effective use of internal vibrators:

1) Concrete surface must always be visible. Adequate lighting must be provided for deep and thin sections.
2) When inserting a poker, allow it to penetrate to the bottom of the layer plus about 100 mm into previous layer (Fig. 10.10, [7]) as quickly as possible under its own weight (Fig. 10.11, [7]). If done slowly, the top of layer will get compacted first, making it difficult to the entrapped air in the lower part to escape to surface.

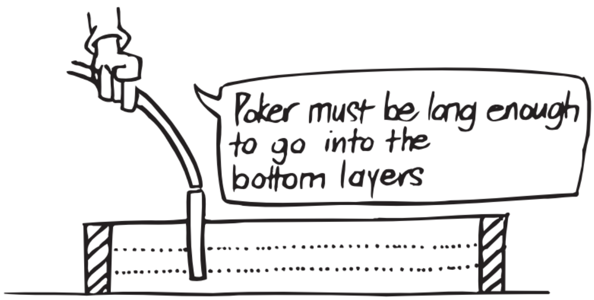

Fig. 10.10 Vibrator must penetrate about 100 mm into previous layer during compaction

3) Hold the Poker in concrete for about 20 to 30 seconds. Withdraw slowly (Fig. 10.11). Ensure that the hole made by the poker gets closed up. In case of very stiff concrete, this may not happen. In such case, put the poker back near to the hole and vibrate.

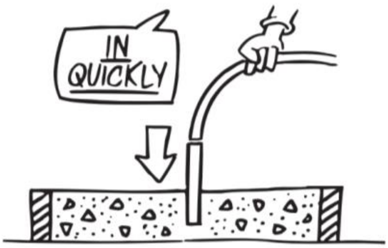

Fig. 10.11 Method of inserting & withdrawal of vibrator in concrete

4) Depending upon type of concrete, size of structure etc., put the poker at next location which may be about 500 mm away from the previous location (Fig. 10.12, [8]). With small diameter pokers, this distance may be suitably reduced.

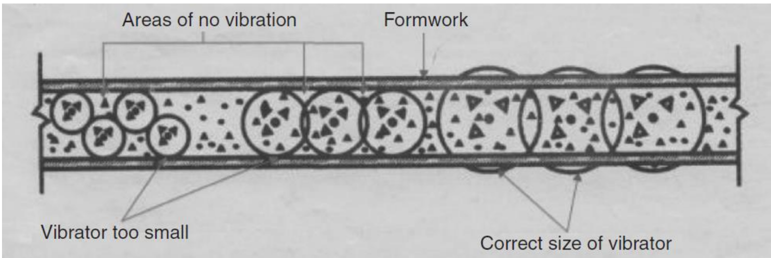

Fig. 10.12 Circles indicate area of vibrator influence

5) Avoid touching Rebars and formwork face (Fig. 10.13, [7]) as it can disturb the locations and also damage the vibrator poker.

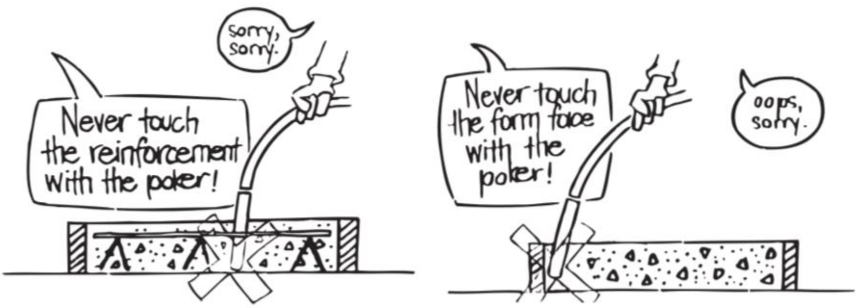

Fig. 10.13 Do not touch reinforcement or formwork with vibrator

6) Avoid using poker to shift or to flow the concrete as it will cause segregation (Fig. 10.14, [7]).

Fig. 10.14 Avoid spreading concrete with vibrator

7) Avoid putting poker into top of heap of concrete (Fig. 10.15, [8]).

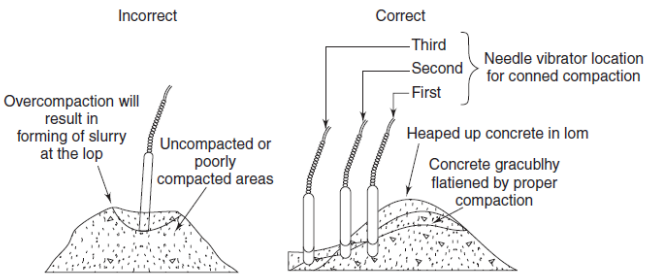

Fig. 10.15 Incorrect and correct method of compaction in a heaped concrete

8) To attain good durability & finish, concrete must be placed directly in corners and ends of walls. Then flow of concrete, if any, should be from the corners and ends rather than towards them (Fig. 10.16, [8]). If cut-outs, openings, void-formers are introduced within the formwork and concrete is required to be placed around them, then correct methods as illustrated in Fig. 10.16 need to be followed.

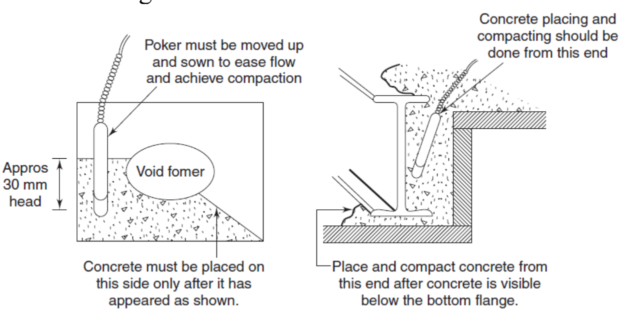

Fig. 10.16 Correct method of placing concrete below a circular or structural Void former

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9) Full length of poker head (metallic part) should be immersed in concrete, vertically in case of deep structures, inclined in case of flat structures.
10) Avoid running the vibrator when not in concrete, so that the bearings do not get overheated.
11) Avoid sharp bends in the flexible shaft.
12) Avoid wasteful operation of vibrators such as wrong positioning, out of concrete & vibrating already compacted concrete.
13) Avoid excess / over vibration to prevent segregation. Normally the appearance of concrete surface just vibrated gives indication that compaction has been done. A thin film of mortar on surface is a sign. Also, air bubbles stop coming to top when compaction is achieved. Experienced operators can recognize the typical pitch (whine) of poker indicating completion of compaction.
14) Special precautions will be required where rebars are congested and lot of embedded parts / inserts exist.
15) Normally, poker should be inserted vertically into concrete. However, for slabs, it may be placed in inclined manner without flexible shaft getting sharply bent.
16) After concreting, clean the vibrator and maintain for next operation. When not in use, store the vibrator horizontally on suitable racks.
17) In case of columns, and walls, it is advisable to tamp the outside face of shutters simultaneously along with vibrator by wooden mallets. This will remove air bubble marks on the surface.
18) The flexible shafts of vibrator get damaged frequently. Keep enough spare needles with shaft readily available during concreting.

10.4.4 External vibration

External vibrators can be form vibrators, vibrating tables, or surface vibrators such as vibratory screeds, plate vibrators, vibratory roller screeds, or vibratory hand floats or trowels. Form vibrators, designed to be securely attached to the outside of the forms, are especially useful:

(1) for consolidating concrete in members that are very thin or congested with reinforcement, (2) to supplement internal vibration.

Form vibrators can be either electrically or pneumatically operated. The spacing should be such that the intensity of vibration is uniformly distributed over the form; optimum spacing is best found by experimentation. Sometimes it may be necessary to operate some of the form vibrators at a different frequency for better results; therefore, it is recommended that form vibrators be equipped with controls to regulate their frequency and amplitude. Duration of external vibration is considerably longer than for internal vibration—generally between 1 and 2 minutes.

The following procedure should be followed for effective use of external vibrators: [5]

1. As a general rule, when the thickness of the concrete in the form exceeds 150 mm, use vibrators (staggered) on both sides of the form. In columns, the reinforcement steel will aid in vibration transfer to the center of the column.

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2. The sinusoidal vibration waves are strongest at the vibrator and they move away in a circular pattern (like the waves when a stone is thrown into water) and reach a 100-150 cm radius. Generally, a 100 cm radius from the vibrator can be considered as an effective vibration area. Some of the vibration will travel upto 150 cm radius. At the 150 cm radius, the vibration from the next vibrator should overlap the first.
3. For determining the number of form vibrators required for a particular case, the following formula is used (ACI 309R-96)
   a. For plastic mixtures in beam and wall forms

   $$CF = 0.5(MF + 0.2MC)$$

   where CF = centrifugal force (kgf); MF = mass of form (kg); and MC = mass of concrete (kg)
   b. For stiff mixtures in pipe and other rigid forms

   $$CF = 1.5(MF + 0.2MC)$$

   The centrifugal force generated by form vibrator is specified in the data sheet. Knowing CF (force) and centrifugal force produced by each vibrator, number of vibrators needed can be decided.
4. **Placing of vibrators:** If the thickness of wall is 150 mm, vibrators need to be fixed as shown in Fig. 10.17 [8]. If thickness of wall is more than 150 mm, vibrators have to be fixed on both side and staggered for effective vibration as per Fig. 10.18 [8].

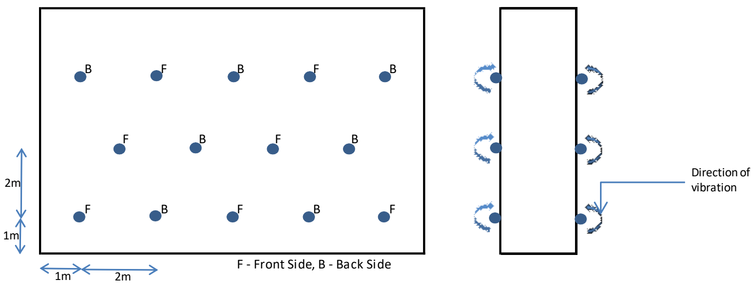

Fig. 10.17 Placement of external vibrators for wall thickness less than 150 mm

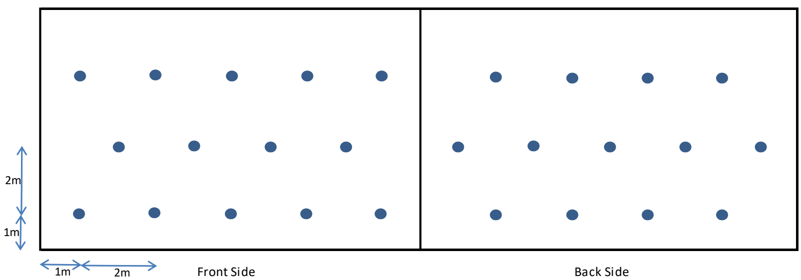

Fig. 10.18 Placement of external vibrators for wall thickness more than 150 mm

5. **Vibration procedure:** Placement of vibrators should be as per the guidelines stated in previous paragraphs. Do not start vibrators until the concrete reaches them and is about 15 cm above them. The time required to vibrate varies depending on concrete slump, additives, stiffness of form, vibrator force, etc. When no more air bubbles are breaking on the surface, and a glistening surface appears on top of the concrete, it can be considered that proper compaction is achieved. Once the vibration of one layer is completed, the vibrators can be taken out and fixed on the second layer as shown in Fig. 10.19 [8].

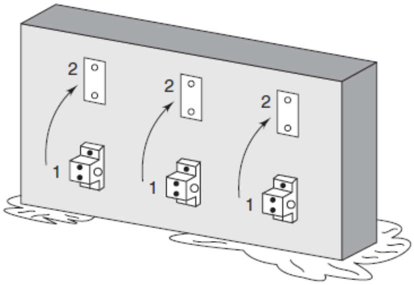

Fig. 10.19 Sequence of external vibrator compaction

Attaching a form vibrator directly to the form generally is unsatisfactory. Rather, the vibrator should be attached to a steel plate that in turn is attached to steel I-beams or channels passing through the form stiffeners. Loose attachments can result in significant vibration energy losses and inadequate consolidation.

10.5 Troubleshooting of concrete quality issues

Various quality issues related to fresh and hardened concrete, potential causes and mitigation methods are discussed in Table 10.5 below.

Table 10.5 Troubleshooting of concrete quality issues

Sr. No.	Potential causes	Actions to consider	Explanation
1. Slump out of specification			
1.1.a	Change in water content or aggregate grading	Check aggregate moisture content	If moisture correction is not correctly calculated, the difference in water content in the mix will cause change in slump. For large pours, moisture correction should be done more than once a day, especially during monsoon season.
1.1.b		Check aggregate water absorption	For projects with longer duration, the properties of aggregate may change even if the raw material comes from the same quarry. It is advisable to check water absorption atleast every 6 months to check any change in properties.

1.1.c		Check for segregation in the stockpile	If the stockpiling of aggregate is not done properly, it is possible that the aggregate will segregate. This will lead to different grading than the actual considered in the mix design and the water demand of the combined grading may change causing change in slump from batch to batch.
1.1.d		Check whether water was added at the site	If the slump is insufficient, sometimes the operator adds additional water arbitrarily. In case slump is found less, only admixture should be used for improving the slump.
1.2.a	Change in mix proportions	Check batch equipment for calibration	If the calibration of batching plant is not proper, there will be variation in the batching of ingredients and will cause change in slump
1.3.a	Admixture	Check delivery ticket for correct admixture dosage	If the calibration of batching plant is not proper, there will be variation in the batching of admixture and will cause change in slump
1.3.b		Check solid contents of admixture used	If the reactive solid content of the admixture is reduced, the workability achieved at a particular dosage will be less. In such situation increase the dosage of admixture and refer the issue to admixture manufacturer
1.4.a	Concrete temperature too high or too low	Check the concrete placement temperature	Change in temperature will cause change in slump. In such cases, either control the temperature of concrete to the temperature at which trials were taken or change the dosage of admixture and/or retarder to control the slump
1.5.a	Haul time	Check the batch time on the concrete delivery ticket. Haul times should not change substantially.	If the haul time changes substantially than that it is designed for, the change in slump will be observed. In case the haul time is much less, the slump will be more and vice versa. In such cases adjust the dosage of admixture if the change in haul time is consistent. If haul time is very high, consider split dosing of admixture or redesign the mix.
2. Loss of Workability/Slump Loss/Early Stiffening			
2.1.a	Ambient temperature increases	Check concrete temperature	Increase in concrete temperature will cause quicker loss of slump. Cool the concrete to acceptable levels by sprinkling water on aggregate stockpiles, use chilled water or ice in concrete production

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2.1.b		Improve retention of concrete	Increase the dosage of admixture and/or retarder to improve the retention of concrete. Never add additional water to increase workability as this will increase the water binder ratio beyond permissible limits and cause reduction in strength and durability
2.1.c		Use a mix design that includes slag or fly ash	Use of fly ash or slag in substantial amounts reduce the effect of temperature change on slump
2.2.a	Transport time too long	Use retarder in the mix	In case the transport time is increasing much beyond the design time, increase the dosage of admixture or retarder to get the required retention time or consider split dosing.
2.3.a	Mix proportions have changed	Check/monitor the moisture contents and grading of the aggregate stockpiles	See 1.1.a, 1.1.b and 1.1.c
2.3.b		Check the batch weigh scales	See 1.2.a
2.4.a	Compatibility issues between cement and admixture	Check chemical & physical properties of cement	If there is a major change in any of the chemical or physical parameter of cement, it can affect the setting time of cement and consequently concrete. Always check compatibility of cement and admixture whenever there is a change of cement and/or admixture source.
2.4.b		Check properties of admixture	Sometimes change in raw material of admixture may cause incompatibility with certain cements. In such cases, change the admixture to suit the requirements. Whenever a new lot of admixture is received at site, check the slump and retention of concrete mix in lab to ascertain compatibility
2.4.c		Check temperature of concrete	Sometimes change in temperature of concrete may result in incompatibility of cement and admixture. In such cases, bring the temperature of concrete within acceptable limits
2.4.d		Variation in air content	In case the air content is more than the design limits, it causes change in the workability levels. Change the air entrainer dosage to bring the air content within acceptable limits
3. Mix is sticky			
3.1.a	Sand too fine	Change the sand grading	If the fines in sand are too high, the mix tends to become sticky. Try to procure sand within the grading limits. If this is not possible, reduce the percentage of sand.

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3.2.a	Mix too sandy	Check the sand and combined aggregate grading	If the mix has too much sand the concrete tends to be sticky. Reduce sand content and check the combined grading. It is important to have a consistent combined grading rather than individual grading. If required make changes to the individual percentages of aggregate to achieve consistent combined grading
3.3.a	Cementitious materials	Check the cementitious materials contents. Mixtures containing GGBS and fly ash appear sticky but finish well and respond well to vibration energy.	If the total cementitious content is too high, especially with silica fume, the mix will be sticky. In such cases adjust the dosage of admixture and sand proportion to achieve desired results
3.4.a	Admixture	Check formulation of admixture	Certain admixtures, especially Polycarboxylate ether based admixture tend to make the concrete sticky. Change the formulation to get desired results
4. Mix segregation			
4.1.a	Inconsistent concrete material—batching, mixing, placing	Check aggregate gradation	If the fines in the mix are less or there is poor grading, the mix tends to segregate.
4.2.a		Verify batching/mixing procedures so that the mixture is adequately mixed.	If the concrete is not properly mixed, the mix tends to segregate. Check mixing efficiency of batching plant mixer. Check if the mixer blades are clean.
4.3.a		Check aggregate stockpile, storage, and loading procedures to prevent aggregate segregation.	If the aggregates segregate in the stockpile, the grading will not be consistent and there are chances that the concrete may segregate. In such cases, improve the stockpiling, storage and loading procedures to have consistent grading throughout the stockpile.
4.4.a		Place concrete as close to final position as possible to minimize secondary handling	Use of vibrators to move concrete leads to segregation. Try to place concrete as close to its final position as possible and not use vibration as means to move concrete.
4.5.a		Check for over vibration	Reduce the vibration energy if consolidation efforts cause segregation. (Vibration at 5,000–8,000 vpm is sufficient for most well-graded mixtures.)

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5. Excessive fresh concrete temperature			
5.1.a	Hot ingredients	Check temperature of each ingredient going into concrete	In warm climate environment, keep aggregate under shade. Sprinkle water on coarse aggregate to reduce temperature. Sprinkling water on fine aggregate is not recommended. Use chilled water and/or ice as mixing water. If the cement directly comes from factory in bulker the temperature will be high. Plan number of silos and their capacities such that the fresh cement received from bulkers will be used only after 5 days of receipt within which time the temperature of cement is reduced.
5.2.a	Long haul times	Check the rise in concrete temperature during haul time	The temperature of concrete rises during transit. It may happen that due to long haul time the temperature of concrete rises beyond acceptable limits. In such cases reduce the production temperature accordingly. Cover transit mixer with wet hessian cloth to reduce rise in concrete temperature
5.3.a	Hot weather	Check the ambient temperature	If possible do the concreting works during the coolest period of the day, i.e., in the night Also may follow practices given in Sl. No. 5.1.a
6. Mix sets early			
6.1.a	Cementitious materials	Check for changes in the cementitious materials	Changes in the cementitious material source or properties; particularly cement, may result in incompatibility; changes in proportions may also affect setting times.
6.2.a	Admixture	Check for dosage of admixture, particularly accelerator	If the dosage of admixture is batched less than the design, the mix may set early. Also, if accelerators are used, check if higher amount of accelerator is batched. The performance of accelerators is temperature sensitive.
6.3.a	Hot weather	Check the ambient and concrete temperature	The hydration reaction is faster at higher temperature. Use retarders and try to incorporate fly ash or GGBS. See Sl. No. 5.1.a, 5.2.a and 5.3.a

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7. Delayed setting			
7.1.a	Cementitious materials	Check for changes in the cementitious materials	Changes in the cementitious material source or properties; particularly cement, may result in incompatibility; changes in proportions may also affect setting times.
7.2.a	Excessive retarder / admixture dosage	Verify the proper batch proportions.	If the dosage of admixture is batched more than the design the setting may get delayed. Also, if retarders are used, check if higher amount of retarder is batched. The performance of retarder is temperature sensitive.
7.3.a	Cold weather	Check the ambient and concrete temperature	The hydration reaction is slower at low temperature. Reduce the retarder / admixture dosage if temperature is low
7.4.a	Organic contamination	Check aggregate and water for any organic contamination	Organic contamination can cause delay in setting of concrete. Check sand and water at regular intervals for any such contamination
8. Plastic shrinkage crack			
1.a	High evaporation rate (excessive loss of moisture from surface of fresh concrete; i.e., evaporation rate > bleed rate)	Check for adequate curing, ambient temperature, wind velocity and humidity	If the rate of evaporation of moisture from concrete surface is more than 1 $kg/m^2/hr$, then there is a possibility of getting plastic shrinkage cracks. Rate of evaporation can be high because of: high concrete temperature, high ambient temperature, high wind velocity, low humidity. Apply curing compound immediately to avoid loss of moisture. If surface texture is not an issue, spread wet hessian cloth on the surface or, cover concrete surface with plastic sheets to protect against wind. Consider use of fibres in concrete. Cool concrete temperature using chilled water and sprinkling water on aggregate. Try to plan concrete works during cool periods of the day, i.e. in the night.
9. Strength gain is slow			
9.1.a	Cold temperature during / after placement	Heat the mix water	The rate of gain of strength is slow when the concrete temperature is low. Increase the temperature of concrete by using hot water
		Use burlap/insulating blankets for protection from freezing	Maintain the temperature of concrete by using blankets to avoid loss of heat
		Use an accelerating admixture	Accelerating admixture can facilitate higher rate of strength gain even when the concrete temperature is low

		Use of steam	Steam can be sprayed into the enclosure to increase the temperature of the concrete
9.2.a	Mix proportions or materials have changed	Check for any change in material properties	If the material properties have changed, it can affect the strength gain
		Verify that batch weights are consistent with the mix design	In case the cement quantity is batched less or supplementary cementitious material like fly ash or GGBS have been batched more there is a possibility that the strength gain is slow. Also if the dosage of admixture is batched more, there can be excessive retardation and the strength gain will be slow, though in this case the 28 days strength may not be affected. This is very unlikely when properly maintained and calibrated computerized batching plant is utilized.
10. Strength gain is low			
10.1.a	Cementitious material	Check for changes in the cementitious materials	If the material properties have changed, it can affect the ultimate strength of concrete
		Check that the correct materials have been loaded into the cement/fly ash/slag silos.	If cementitious material is loaded in wrong silo, the batching of material will be wrong leading to incorrect results. Authors are aware of such incidents.
		Use ultrafine SCM for early strength	Use of silica fume, ultrafine slag (Alccofine), ultrafine fly ash helps in getting early strength.
	Aggregate contamination	Check for any contamination of aggregate	If the aggregates are contaminated with organic impurities this can lead to lower strength. Aggregate containing clay or silt will also reduce the strength of concrete as they will hinder proper bonding between cement paste and aggregate
	Water	Check water content batched	If the water content is not correctly batched during production the effective water binder ratio will differ from the design value and the strength achieved will be less if w/b ratio is more and vice versa. Moisture determined for aggregate may be incorrect, particularly during monsoon season. This may lead to having either more or less water in the mix than the actual value. This will increase or decrease the water cement ratio leading to lower or higher strength.

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		Check if additional water added to the transit mixer	If additional water is added to transit mixer during transportation or before placement location, the effective water binder ratio will increase leading to lower strengths. The need for such addition must be analyzed and if required chemical admixture may be added. Under no circumstances water should be added.
	Inadequate or variable mixing	Check for all probable cause of inadequate or variable mixing. Examine the mixer and mixing procedures. Check for worn out mixer blades. Check for mixer overloading. Batch smaller loads. Check the sequencing of batching. Check for mixing time consistency. Conduct batch plant uniformity testing	If the mixing of concrete in the batching plant is inadequate or variable, there is a possibility that the strength achieved may be low or the result may vary in wide range.
	Testing procedures	Check for any discrepancy in testing procedures. Verify proper making, curing, handling, and testing of strength specimens. (Flexural strength specimens are particularly vulnerable to poor handling and testing procedures). Verify the machine calibration. Check the cube moulds for conformance to specifications.	If the specimen is not properly compacted, cured, handled the results achieved will be lower. If the testing machine is not properly calibrated the results achieved will not be true. If the cube dimensions are incorrect, the loading on the specimen will not be uniform resulting in lower strength. If the specimen is cured at lower temperature than specified the resultant strength will be low.
11. Honeycombing			
11.1.a	Inadequate compaction	Check if sufficient vibration is imparted to concrete	If sufficient vibration is not imparted to concrete, proper compaction will not be achieved
	Poor workability	Check if the workability at the pouring point is enough to achieve desired compaction or self-compacting concrete need to be specified	If the workability is less than required for achieving proper compaction, it might result in honeycombing. It may be noted that the amount of workability and vibration required will vary from case to case and has to be judged depending upon the dimensions of the element, congestion of reinforcement and shape of the element

	Hot weather may cause premature stiffening of concrete	Check for ambient and concrete temperature	Higher ambient and concrete temperature may cause the concrete to stiffen quickly, just not allowing adequate time for proper compaction of concrete.
12. Early cracking of concrete pavements			
12.1.a	Concrete mix	Check if cement / cementitious content is high	If cement content is high, the shrinkage will also be higher. This may cause cracking in early age
12.1.b		Check fines in fine aggregate	If the fines in sand, especially crushed sand is very high, the water demand is high and the surface may tend to dry faster causing shrinkage cracks
12.2.a	Saw cutting	Check if the saw cutting was done as per procedure	If the saw cutting is delayed, the concrete shrinkage will cause cracking in haphazard manner. When timely saw cutting is done the shrinkage will happen along the cut. As far as possible the saw cutting must be done along the direction of the wind. Check that the diamond saw blade is appropriate for concrete aggregate hardness, fines, etc.
12.3.a	Curing	Check if adequate curing is done	If the curing is inadequate and the moisture from the surface of concrete evaporates, shrinkage cracks will start developing. Check that the curing compound is sprayed as soon as the finishing is complete. Follow the guidelines given in the next chapter (Chapter 11) on curing of concrete.
12.4.a	Insufficient joint depth	Check if the joint depth provided is sufficient	If the joint depth provided is insufficient to cater for the shrinkage, cracks will develop
12.4.b		Check if the actual depth cut is as per design	
12.4.c		Check that saw operators are not pushing saws too fast, causing them to ride up.	
12.4.d		Check the condition of saw blades	
12.5.a	Excessive joint spacing	Check if the joint spacing provided is adequate	If the joint spacing is too high, the joint cut may not provide enough shrinkage compensation and slab may crack. Reduce spacing between the joints. Slabs may be too wide in relation to thickness and length; add intermediate joints. Maintain a reasonable length-width ratio.

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12.6.a	Warping (slab curvature due to moisture gradient; the term "curling," however, is commonly used in the industry to cover both moisture and temperature related slab distortion)	Check the moisture state of base.	If the base on which the concrete is laid is dry, it will tend to absorb the water from fresh concrete causing the concrete to curl. Ensure that the surface on which concrete is laid is not dry. Improve or extend curing.
12.6.b		Check if the temperature variation throughout the day is not very high	Cover the slab, particularly when night/day temperatures vary widely
12.7.a	High temperature	Check if the temperature during concreting is very high	Higher ambient or concrete temperature will cause faster evaporation of moisture from the concrete surface. Avoid concreting during the period when temp. is high.
12.8.a	Dowel bars	Check if the cracks are developing near the dowel bars.	If the dowel bars are not exactly perpendicular to the joint surface, they will not allow for movement of the concrete panel during expansion and contraction. This will cause the panel to crack near the dowel bars
12.8.b			If one end of the dowel bar is not free (either by use of plastic sleeve or some other debonding agent) then it will not allow free movement of the panels causing the panels to crack.
13. Thermal cracking in mass concrete			
13.1.a	Temperature differential between core and surface of concrete	Check the temperature differential between core and surface of concrete	Concrete being a bad conductor of heat does not dissipate heat from the core quickly. On the other hand the surface of the concrete cools quickly to the ambient temperature. If the temperature difference between the core and surface is more than 20-25°C, tensile stresses will develop beyond the permissible limits and thermal cracks will develop.
13.1.b		Check the placement temperature of concrete	Higher the placement temperature, higher will be the temperature attained at the core of the concrete. It is important to control the placement temperature of concrete to control the temperature differential
13.1.c		Avoid removing the side formwork quickly	The side formwork should be just loosened and left in place with a small gap between concrete surface and the formwork for few hours. This will allow the heat to dissipate slowly from the surface rather than a quick cooling which would happen if the formwork is removed completely.

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13.1.d		Cover the concrete surface with insulating material	Covering the surface with some insulating material (saw dust, plastic sheets, etc.) will not allow the surface to cool quickly, thus helping to reduce the temperature difference. But care must be taken to calculate this effect on the maximum temperature attained at the core, as covering the surface with insulating material will not allow the concrete to cool as fast and thus the maximum temperature attained will be higher than it would without any insulation on the surface. The placement temperature should be calculated accordingly. Under no circumstances the maximum temperature attained in the core of concrete should be more than 70°C for concrete with 100% OPC. For concrete design with SCMs, the temperature upto 75- 80°C may be allowed, depending upon the quantum of SCMs used.
14. High rebound losses in shotcrete			
14.1.a	Shotcrete mix design	Check the aggregate grading	If the aggregate grading is not as per the desired grading curve, the rebound will be more. If the coarse aggregate is higher than desired, the rebound will be more.
14.1.b		Check the amount of cementitious fines	If the cementitious fines are less, the rebound will be more. It may be desirable to have some amount of super fines like silica fume, UFS, UFFA or metakaolin in the mix as it makes the mix more cohesive
14.1.c		Check the workability of the mix	If the workability is too high, higher dosage of accelerator will be required to control the rebound. It is desirable to have the minimum possible workability to the mix that is required for pumping of shotcrete
14.1.d		Check the dosage of accelerator going in the nozzle	If the accelerator dosage going in the nozzle is incorrect or inconsistent, the rebound will be high. Check the accelerator pump if any inconsistency is observed.
14.1.e		Check the temperature of shotcrete	Lower the temperature of shotcrete, higher will be the dosage of accelerator required to control the rebound. But too high dosage of accelerator will reduce the ultimate strength of shotcrete. It is desirable to increase the temperature of shotcrete rather than increasing the dosage of accelerator.

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14.2.a	Surface condition	Check for any seepage	If the seepage is very high, it will not allow the shotcrete to stick to the walls. It may be desirable to reduce the seepage of water using suitable techniques, if possible, before start of shotcreting activities
14.2.b		Check for nature of substrata	In hard rock tunnel, the amount of rebound will be higher than in soft ground tunnel. This is due to the contact surface being both hard and of various incidental angles to the spray direction due to the blocky nature of the rock. In such cases an initial non-structural shotcrete layer of lower strength is advisable to act as a cushion to receive the structural shotcrete lining.
14.2.c		Check the fixity of mesh reinforcement	If the mesh reinforcement is loose, the vibrating condition will cause higher rebound. Ensure proper fixity of the mesh. Wherever possible, opt for fibre reinforced shotcrete as it improves productivity, has less rebound and may reduce overall costs.
14.3	Nozzleman	Check the spraying technique	The nozzleman must be trained for the shotcrete spraying process. The most significant influence on rebound is the angle of nozzle to the substrata. The nozzle should always be held at right angles to the substrata to optimize compaction and steel fibre orientation, except when full encapsulation of lattice girder or steel reinforcement is required. The distance between the nozzle and the substrata should be between 1 to 2 m. If the nozzle is closer than this, the projected shotcrete will tend to tear-off the freshly placed material. If the nozzle distance is more than 3 m, then the energy to compact the concrete is severely reduced resulting in excessive rebound, poor compaction and low strengths.
14.4	Equipment	Check for operating parameters	The air volume and pressure should be as proposed by the manufacturer. Nozzles should be checked for wear as this affects the output velocity of shotcrete

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15. Low core strength of shotcrete			
15.1.a	Shotcrete	Check for compliance to actual mix design	Check if the water binder ratio is correct. If the moisture correction is not correctly calculated or if extra water is added to transit mixer the effective water cement ratio shall be more than the design water binder ratio and the strength of the cores will be less. If the accelerator dosage has gone very high the ultimate strength shall be lower.
		Check the quality of shotcrete	If the shotcrete is not properly sprayed, the compaction will not be adequate. This will lead to lower strengths. If the rebound has been very high, majority of the coarse aggregate will not be present in the shotcrete layer. This will lead to reduced strengths.
5.2.a	Cores	Check the process of core extraction, handling, storing and testing	If the core bit is worn out or the core extraction machine is loose and vibrating during extraction, there is a likelihood of micro cracks developing in the core extracted. After extraction, the cores must be safely transported to the lab without too much vibration as this can cause micro cracks. The cores must be immediately stored in water till the time of testing to ensure proper curing. The horizontal surfaces of the cores must be exactly parallel to each other. The cutting and surface preparation must be done precisely. If the horizontal surfaces are not parallel to each other, during testing the load gets applied eccentrically on the core and the test results may vary by even more than 25%. Check the calibration and rate of loading of the compression testing machine.

10.6 Summary

- Right type of transportation and placement methods must be planned right at the beginning of the project depending upon the type of concrete. The capacity of these equipment must be properly planned and deployed for timely completion of project.
- Concrete pumping is the most commonly used method of placement. Strict quality control must be exercised to produce good pumpable concrete which

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can be placed without any issues related to segregation, bleeding and choking of pipeline.

- Use of good quality aggregate, sand and use of SCMs like fly ash help in producing concrete which can be easily pumped. Special care must be taken for long distance and high vertical pumping. Use of correct formulation of admixtures must be done right at the start of the project in such cases.
- Proper care must be taken in laying, fixing, cleaning of pipelines for smooth functioning.
- Proper compaction of concrete is essential for producing a structure free of honeycombing and voids. Strict inspection needs to be exercised during compaction.
- Type and size of vibrators must be calculated depending upon the type of concrete to be vibrated.
- Troubleshooting of various concrete issues must be analysed based on various factors as discussed in the chapter and solution designed as per requirement.

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CHAPTER 11

CURING OF CONCRETE

11.1 Introduction

Curing is the process of maintaining satisfactory moisture content and temperature in concrete for a required period of time immediately after finishing so that the desired properties of hardened concrete are developed. Curing has a strong influence on the properties of hardened concrete; proper curing will increase durability, strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing. Exposed flat concrete surfaces are especially sensitive to curing as strength development of the top surface of a slab can get reduced significantly when curing is defective.

A good curing practice involves keeping the concrete damp and preventing the moisture from concrete to evaporate until the concrete achieves desired properties. However, good curing practices are not always religiously followed in most of the cases, leading to a weak concrete. This chapters explains the various aspects and types of curing methods to be adopted at site for ensuring effective curing.

11.2 Importance of Curing

Curing is the process of controlling the moisture loss from concrete to ensure an uninterrupted hydration of Portland cement after concrete has been placed and finished in its final position. Curing also ensures to maintain an adequate temperature of concrete in its early ages, as this directly affects the rate of hydration of cement and eventually the strength gain of concrete.

When portland cement is mixed with water, a chemical reaction called hydration takes place. The extent to which this reaction is completed influences the strength and durability of the concrete. Freshly mixed concrete normally contains more water than is required for hydration of the cement; however, excessive loss of water by evaporation will hamper hydration process. The rate of evaporation of water from concrete surface can be calculated by Fig. 11.1 [1]. The surface is particularly susceptible to insufficient hydration because it dries first. If temperatures are favorable, hydration is very rapid for the first few days; therefore, it is important for water to be retained in the concrete during this period, that is, for evaporation to be prevented or substantially reduced.

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Curing of concrete must begin as soon as possible after placement & finishing and must continue for a reasonable period of time as per the relevant standards, for the concrete to achieve its desired strength and durability. Uniform temperature should also be maintained throughout the concrete depth to avoid thermal shrinkage cracks. Also, protective measures to control moisture loss from the concrete surface are essential to prevent plastic shrinkage cracks.

In a nut shell, curing process is designed primarily to keep the concrete moist by controlling the loss of moisture from the body of concrete, during the given period in which it gains strength.

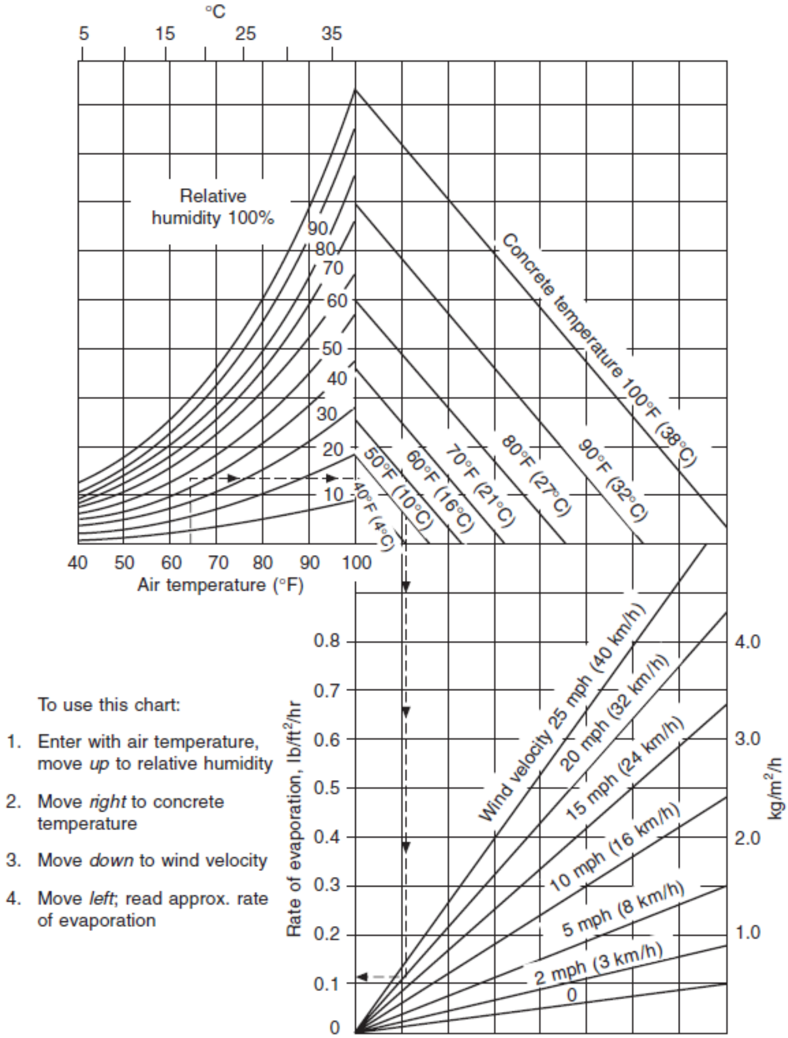

Fig. 11.1 Calculation of rate of water evaporation from concrete surface

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There are several important reasons why one should cure concrete:

- **Concrete strength gain -** Concrete strength increases with age if moisture is present for hydration of cement. Fig. 11.2 [2] illustrates a comparison of the strength of concrete at 180 days of moist curing with various periods of moist curing (0, 3, 7, 14 & 28 days) and then allowing it to dry out. From the graph below, it can be observed that concrete allowed to dry out immediately, achieves only 40% of the strength of the same concrete water cured for the full period of 180 days.

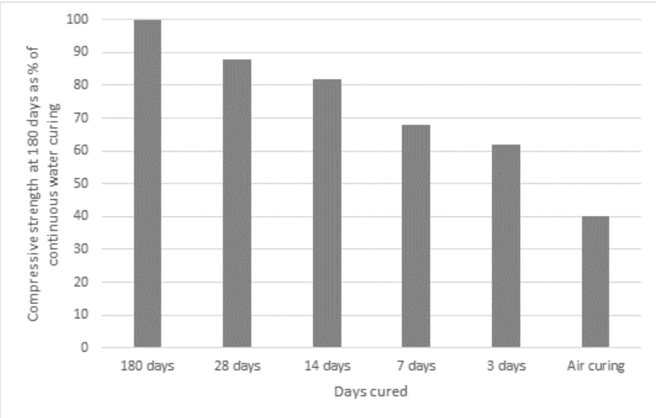

Fig. 11.2 Effect of curing period on strength gain of concrete

- **Improved durability of concrete –** The durability of concrete is affected by a number of factors including its permeability, porosity and absorptivity. Well cured concrete can minimize thermal, plastic & drying shrinkage cracks, making concrete more water tight, thus preventing moisture and water borne chemicals from entering into the concrete and thereby increasing its durability.
- **Enhanced serviceability -** Concrete that is allowed to dry out quickly undergoes considerable early age shrinkage. This can cause significant issues for structures like prestressed concrete, mass concrete, etc. where creep, shrinkage and volume change play a significant role.
- **Improved microstructure -** Material properties are directly related to their microstructure. Curing assists the cement hydration reaction to progress steadily and develops calcium silicate hydrate gel, which binds the aggregates firmly, makes the concrete denser, decreases the porosity and enhances the physical and mechanical properties of concrete.

11.3 Right Time to Start Curing

The curing is not required as along as bleed water is available on the concrete surface. The curing must begin in a situation where the concrete surface starts drying which depends on the evaporation rate of moisture from the concrete (Fig. 11.3 [3]). The evaporation rate is influenced by wind, radiant energy from sunshine, concrete temperature, climatic conditions, relative humidity. This situation may arise when:

- After concrete has been placed in its final position and during the initial set, bleed water rises to the concrete surface as plastic settlement occurs. During this period, if the rate of evaporation of bleed water is greater than the rising water, plastic shrinkage of the concrete occurs. Initial mist curing is necessary to keep the surface moist to prevent the surface from drying out.
- Between initial set and final set, intermediate curing would be needed if the finishing is complete prior to final set. This may be in the form of a barrier which prevents the loss of moisture from the concrete surface. e.g. covering the concrete surfaces with plastic sheets, waterproof paper, etc. This also eliminates / minimizes evaporation of water by wind action.
- After final set, meticulous curing will have to be done as per the procedures selected. e.g. water curing methods – ponding, misting, wet coverings with hessian cloth, impermeable membrane curing, curing compounds, etc.

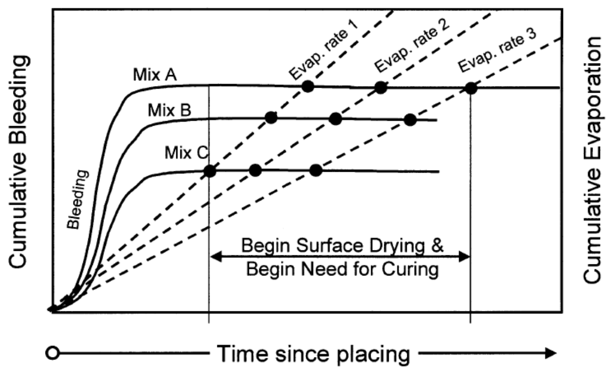

Fig. 11.3 Schematic illustration showing combined influence of bleeding characteristics and evaporation in determining the time at which the surface of concrete begins to dry

As briefly discussed above, there can be three types of curing situations:

Initial curing – For mixtures with a low to zero bleeding rate, or in the case of aggressively evaporative environments, or both, surface drying can begin well before initial set and well before initiation of finishing operations, as indicated in Fig. 11.4 [3]. When finishing begins immediately after the disappearance of the bleed water, it is unnecessary to apply initial curing measures. Initial curing measures should be applied immediately after the bleed water sheen has disappeared, because the concrete surface is protected against drying as long as it is covered with bleed water. Under such conditions, initial curing measures, such as fog-spraying to increase the humidity of the air or the application of a liquid-applied evaporation reducer, should be initiated immediately after strike-off, and in some cases, before bull floating. Such initial curing measures should be continuously maintained until more substantial curing measures can be initiated.

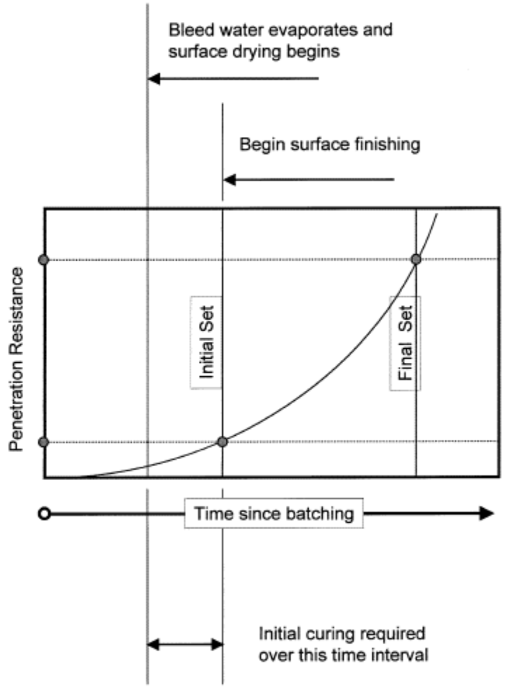

Fig. 11.4 Bleed water disappears and surface drying commences at some time before beginning finishing. Initial curing is required to minimize moisture loss before and during finishing operations

Application of initial curing measures is also frequently required for concretes that exhibit low or negligible bleeding. Such concrete mixtures often incorporate silica fume, fine cements, or other fine cementitious materials, low w/cm, high air contents, or water-reducing admixtures. Initial curing measures are frequently required immediately upon placing such concrete to minimize plastic-shrinkage cracking. Plastic shrinkage is initiated by surface drying, which begins when the rate of evaporative water loss from the surface exceeds the rate at which the surface is moistened by bleed water.

Intermediate curing – Intermediate curing measures are required whenever the concrete surface has been finished before the concrete has reached final set (Fig. 11.5 [3]). This can happen when the desired surface texture is rapidly achieved, when setting is delayed, or both.

Before reaching final set, the concrete surface is susceptible to damage by applying wet burlap, plastic sheets, or other curing materials. Intermediate curing methods can be a continuation of initial curing measures, such as evaporation reducers, or fogging, maintained until the final curing is applied. Membrane forming curing can be applied from a power sprayer, making it unnecessary to walk on the concrete surface, and can be applied immediately behind the final pass of the finishing tool or machine.

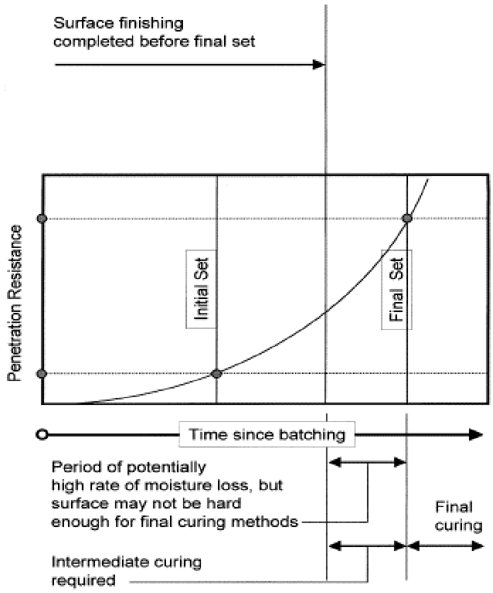

Fig. 11.5 Surface finishing has been completed before the concrete surface has reached final set

Final curing – The concrete surface should be protected against moisture loss immediately following the finisher or finishing machine. Significant surface-drying can occur when curing measures are delayed until the entire slab is finished because the peak rate of evaporation from a concrete surface often occurs immediately after the last pass of the finishing tool, as tool pressure brings water to the surface (Al-Fadhala and Hover 2001; Shaeles and Hover 1988). This is especially true when the finished texture has a high surface area such as a broomed surface (Shariat and Pant 1984). Therefore, it is necessary to control moisture loss immediately after finishing (Transportation Research Board 1979). When the conclusion of finishing operations coincides with the time of final set, final curing is applied at exactly the right time to reduce the peak rate of moisture loss. A delay in final curing can result in considerable water loss (Al-Fadhala and Hover 2001).

The combination of a curing compound as an intermediate curing method followed by water-saturated coverings as a final curing method is common practice to achieve effective curing in case of concrete roads for pavement quality concrete layer. The curing compound can be spray-applied to the concrete surface from the perimeter of the concrete immediately after the finishing is completed. By the time the curing compound has dried final set of concrete would normally be attained.

Final curing can be done by means of ponding, continuous sprinkling, wet hessian cloth, plastic sheet laid after saturating surface with water, or application of curing compound. Wet curing by ponding, sprinkling, or the application of saturated burlap not only prevents water loss but also supplies additional curing water to sustain cement hydration, which is important for low w/b mixtures that can self-desiccate.

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11.4 Duration of Curing

The reason for curing is to prevent plastic shrinkage, to have temperature control, to achieve strength and durability of concrete. The curing duration of concrete depends on:

- The size of concrete structural member
- The type of concrete grade and rate of hardening of concrete
- The temperature and moisture conditions of surroundings
- The exposure conditions of the concrete surface during and after curing
- The requirement of curing duration as per specification of concrete

American Concrete Institute (ACI) Committee 301 recommends a minimum curing period corresponding to concrete attaining 70 per cent of the specified compressive strength. The often specified 7 days curing for OPC concrete commonly corresponds to approximately 70 per cent of the specified compressive strengths. Indian Standard IS 456 – 2000 recommends that curing duration of concrete must be at least 7 days in case of OPC, at least 10 days for concrete with mineral admixtures or when blended cements are used. It also recommends that the curing duration should not be less than 10 days for OPC concrete exposed to dry and hot weather conditions and 14 days for concrete with mineral admixtures or with blended cement in hot and dry weather.

11.5 Types of Curing Methods

There are various methods of curing. The adoption of a particular method will depend upon the nature of work and the climatic conditions. The following methods of curing of concrete are generally adopted.

11.5.1 Shading of concrete works

The object of shading concrete work is to prevent the evaporation of water from the surface even before setting. This is adopted mainly in case of large concrete surfaces such as road slabs (Fig. 11.6). This is essential in dry weather to protect the concrete from heat, direct sun rays and wind. It also protects the surface from rain. In cold weather shading helps in preserving the heat of hydration of cement thereby preventing freezing of concrete under mild frost conditions. Shading may be achieved by using canvas stretched on frames. This method has a limited application only.

11.5.2 Covering concrete surfaces with wet hessian or gunny bags

This is a widely used method of curing, particularly for structural concrete. The exposed concrete surface is prevented from drying out by covering it with wet hessian (Fig. 11.7), canvas or empty cement bags. The covering over vertical and sloping surfaces should be secured properly. These are periodically wetted. The interval of wetting will depend upon the rate of evaporation of water. It should be ensured that the surface of concrete is not allowed to dry even for a short time during the curing

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period. If the hessian cloth dries, it will try to absorb water from the concrete surface causing more harm than good.

Special arrangements for keeping the surface wet must be made at nights and on holidays. Automatic sprinkling arrangement can be done so that water is sprinkled at periodic interval to keep the hessian cloth wet (Fig. 11.8). Alternatively, it can be achieved by placing drum filled with water connected to pipes having small holes (Fig. 11.9). The water will slowly seep from the pipes onto the hessian cloth keeping them wet all the time.

Fig. 11.6 Using shades for curing of fresh concrete

Fig. 11.7 Curing of concrete with wet hessian cloth

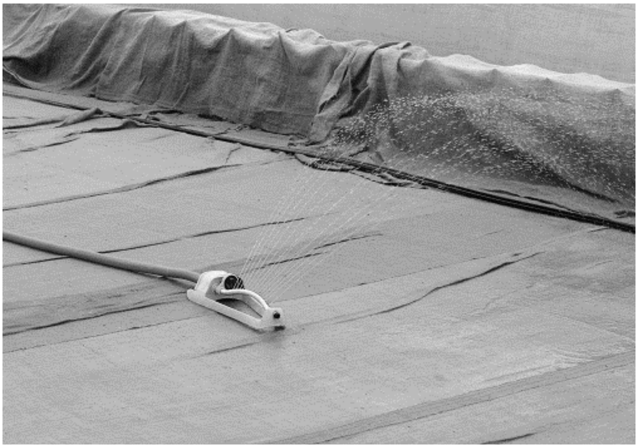

Fig. 11.8 Automatic sprinkling arrangement to keep hessian cloth continuously wet

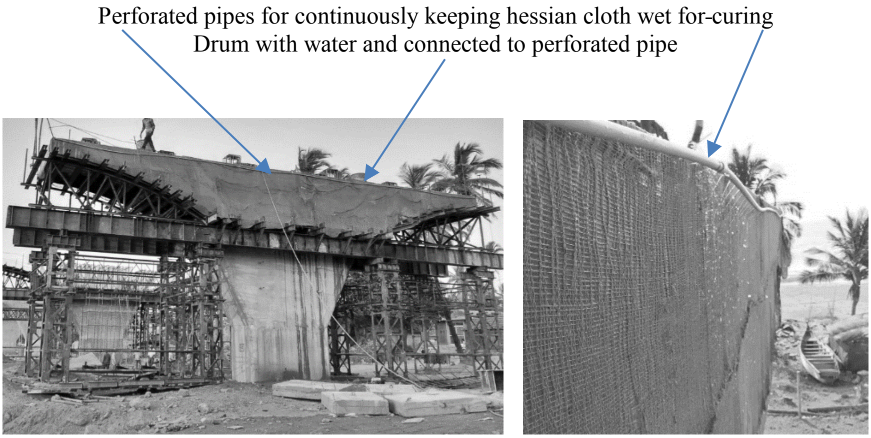

Fig. 11.9 Curing of vertical members with water kept in drum connected to perforated pipes

11.5.3 Sprinkling of water

Sprinkling of water continuously on the concrete surface provides an efficient curing. It is mostly used for curing floor slabs. The concrete should be allowed to set sufficiently before sprinkling is started. Sprinkling can be done using hand sprinklers for large jobs (Fig. 11.10). On small jobs sprinkling of water may be done by hand. Vertical and sloping surfaces can be kept continuously wet by sprinkling water on top surfaces and allowing it to run down between the forms and the concrete. For this method of curing the water requirement is high.

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11.5.4 Ponding method

This is the best method of curing. It is suitable for curing horizontal surfaces such as floors, roof slabs, road and air field pavements. The horizontal top surfaces of beams, pier caps can also be ponded. After placing the concrete, its exposed surface is first covered with moist hessian or canvas. After 24 hours, these covers are removed and small ponds of clay or mortar are built across and along the pavements. When area to be cured is large it is divided into a number of rectangles (Fig. 11.11). The water is filled between the ponds. The filling of water in these ponds is done twice or thrice a day, depending upon the atmospheric conditions. Though this method is very efficient, the water requirement is very heavy.

Fig. 11.10 Sprinkling water for curing concrete slab

Fig. 11.11 Curing of concrete by ponding method

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11.5.5 Membrane curing

Curing concrete with membrane or plastic sheeting is the most practical and efficient way to cure concrete in today's construction industry – sometimes water is unavailable for water curing. If it's done improperly, it can affect the strength or the surface finishing of the concrete product.

Concrete should be covered with a membrane, either plastic or chemical compound that will seal off the pores and retard the evaporation of water from concrete.

Two common types of membrane curing are:

- **Plastic sheeting:** Curing concrete with plastic sheeting requires covering all exposed areas of the concrete as soon as possible without damaging the concrete finish. When plastic sheeting is used over flat surfaces, such as pavements or slabs, it should extend beyond the edges of the slab by a length of at least twice the thickness of the slab (Fig. 11.12).

Fig. 11.12 Curing concrete by covering with plastic sheet

- **Membrane-forming curing compounds:** Curing compounds are chemical products usually sprayed directly over the concrete surface and allowing it to dry. The compound forms an impermeable membrane that retards the loss of moisture from the concrete.

  Liquid membrane-forming compounds consisting of waxes, resins, chlorinated rubber, and other materials can be used to retard or reduce evaporation of moisture from concrete. They are the most practical and most widely used method for curing not only freshly placed concrete but also for extending curing of concrete after removal of forms or after initial moist curing. However, the most effective methods of curing concrete are wet coverings or water spraying that keeps the concrete continually damp. Curing compounds should be able to maintain the relative humidity of the concrete surface above 80% for 7 / 10 days for OPC concrete (10 / 14 days for blended concrete) to sustain hydration.

Curing compounds should be applied by hand-operated or power-driven spray equipment immediately after final finishing of the concrete (Fig. 11.13). The concrete surface should be damp when the coating is applied. On dry, windy days, or during periods when adverse weather conditions could result in plastic shrinkage cracking, application of a curing compound immediately after final finishing and before all free water on the surface has evaporated will help prevent the formation of cracks.

Power-driven spray equipment is recommended for uniform application of curing compounds on large paving projects (Fig. 11.14). Spray nozzles and windshields on such equipment should be arranged to prevent wind-blown loss of curing compound. Normally only one smooth, even coat is applied at a typical rate of 3 to 4 m^2 per litre; but products may vary, so manufacturer's recommended application rates should be followed. If two coats are necessary to ensure complete coverage, for effective protection the second coat should be applied at right angles to the first. Complete coverage of the surface must be attained because even small pinholes in the membrane will increase the evaporation of moisture from the concrete. Hence, unless workmanship is very good, it is very desirable to have two coats for pinholes free coverage.

Generally, curing compounds are clear, white pigmented or with fugitive dyes. Curing compounds with two different fugitive dyes can be used for first and second coats, so that it is easily identified whether the same has been applied. The dye used in the curing compounds is such that it slowly oxidizes and wears off from the surface within a few days when exposed to sunlight. Additional cleaning may be necessary to completely remove the film in areas not exposed to sunlight or in vertical applications.

The effectiveness of curing compound must be checked by applying the recommended application rate to cubes and comparing the strength at various ages with that of cubes cured in water. In case the performance is not achieved in the manufacturer's recommended application rate the same can be increased and the performance rechecked. Curing compound is considered effective when the strength of concrete cube with curing compound application is at least 85% of strength of cube immersed in water for 28 days curing period. The cost per sq. metre should be calculated based on the actual application rate for optimal cost.

Some curing compounds, especially wax based, will create an issue in bonding the subsequent layer – concrete, plaster or paint, if applied. It is advisable to avoid using wax based curing compounds if an overlay is to be applied.

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Fig. 11.13 Spraying curing compound on flat concrete surface

Fig. 11.14 Applying curing compound with spray machine on concrete pavement

11.5.6 Formwork left in place

Leaving formwork in place is often an efficient and cost-effective method of curing concrete, particularly during its early stages. In very hot dry weather, it may be desirable to moisten timber formwork, to prevent it drying out during the curing period, thereby increasing the length of time for which it remains effective. It is desirable that any exposed surfaces of the concrete (e.g. the tops of beams) be covered with plastic sheeting or kept moist by other means. It should be noted that, when vertical formwork is eased from a surface (e.g. from a wall surface) its effectiveness as a curing system is significantly reduced.

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11.5.7 Internal curing

In the present situation, there is a need for the search of alternate materials in the place of water for curing not only to save water for the sustainable development of the environment, but also to promote indoor and outdoor construction activities even in remote areas where there is scarcity of water.

IS 456-2000 recommends a curing period of 7 / 10 days for OPC concrete, and 10 / 14 days for concrete prepared using mineral admixtures or with blended cements. But, being the last act in the concreting operations, it is often neglected or not fully done. Consequently, the quality of hardened concrete suffers, more so, if the freshly laid concrete gets exposed to the environmental conditions of low humidity, high wind velocity and high ambient temperature. To avoid the adverse effects of neglected or insufficient curing, which is considered a universal phenomenon, concrete technologist and research scientists in various countries including India, are working on the development of self-curing concrete.

ACI-308 Code states that "internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing water." Conventionally, curing of concrete means creating conditions such that water is not lost from the surface i.e., curing is considered to happen 'from the outside to inside'. In contrast, 'internal curing' is allowing for curing 'from the inside to outside' through the internal reservoirs (in the form of saturated lightweight fine aggregates, superabsorbent polymers, or saturated wood fibers) (Fig. 11.15 [4]). 'Internal curing' is often also referred as 'Self–curing.'

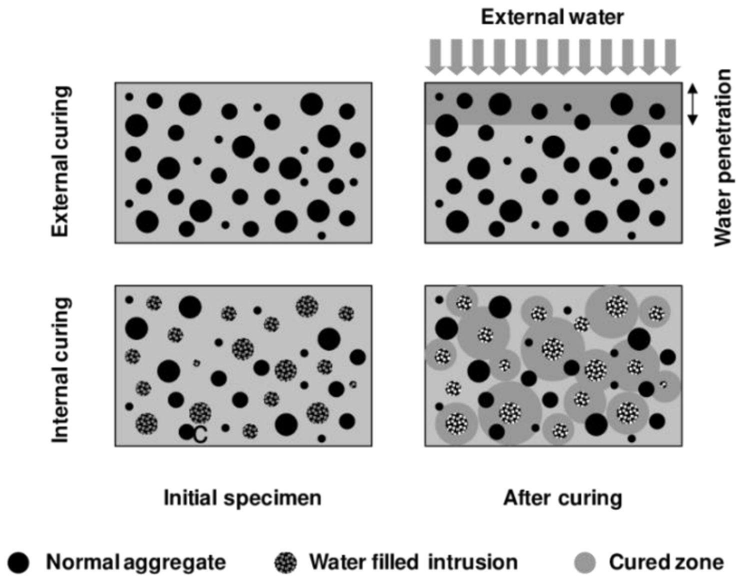

Fig. 11.15 Concept of Self Curing Concrete with SAP or LWA

The following materials can provide internal water reservoirs:

- Lightweight Aggregate (LWA) (natural and synthetic, expanded shale, wood powder) having high water absorption capacity (15-20%)
- Super-absorbent Polymers (SAP) (60-300 mm size)
- SRA (Shrinkage Reducing Admixture) (propylene glycol type i.e. polyethylene-glycol)

Use of SAPs or LWAs in fine aggregate ~~a~~re more effective in providing internal curing due to the uniform dispersion of water units in the concrete. Polyethylene glycol is a condensation polymer of ethylene oxide and water with the general formula $H(OCH_2 CH_2)n OH$, where n is the average number of repeating oxyethylene groups typically from 4 to about 180. It is water soluble, nontoxic and odourless. The specific gravity is 1.13. The polyethylene-glycol is used to reduce water evaporation from concrete, and hence increases the water retention capacity of concrete which leads to improved compressive strength. [4]

11.5.8 Advantages of self-curing concrete / internal curing

In low w/b ratio mixes (generally lower than 0.35) the degree of hydration of cementitious material is much lower than for higher w/b ratios. Use of absorptive lightweight aggregate, replacing some of the sand, provides water that is desorbed into the mortar fraction (paste) to be used as additional curing water. The cement, not hydrated by low amount of mixing water, will have more water available to it. Internal curing (IC) is thus a method to provide water for improving the degree of hydration of cementitious material in concrete, accomplishing what the mixing water alone cannot do.

Some of the advantages are as mentioned below:

a. IC provides water to keep the relative humidity (RH) high, preventing self-desiccation from occurring.
b. IC largely eliminates autogenous shrinkage.
c. IC maintains the strengths of mortar/concrete at the early age (12 to 72 hrs.) above the level where internally & externally induced strains can cause cracking.
d. IC can make up for some of the deficiencies of external curing, both human related (critical period when curing is required is the first 12 to 72 hours) and hydration related (because hydration products clog the passageways needed for the fluid curing water to travel to the cement particles thirsting for water).

Following factors establish the dynamics of water movement to the unhydrated cement particles:

i. Thirst for water by the hydrating cement particles is very intense,
ii. Capillary action of the pores in the concrete is very strong, and
iii. Water in the properly distributed particles of LWA (fine) is very fluid

Some of the improvements of concrete due to internal curing are:

- Reduces autogenous cracking, largely eliminates autogenous shrinkage,
- Reduces permeability,
- Protects reinforcing steel,
- Increases mortar strength,
- Increases early age strength sufficient to withstand strain,
- Provides greater durability,
- Higher early age (say 3 day) flexural & compressive strength
- Lower turnaround time,
- Improved rheology
- Greater utilization of cement,
- Lower maintenance,
- Use of higher levels of fly ash & GGBS,
- Higher modulus of elasticity,
- Sharper edges,
- Greater curing predictability,
- Higher performance,
- Improves contact zone,
- Does not adversely affect finishability,
- Does not adversely affect pumpability,
- Reduces effect of insufficient external curing

The concept of internal curing is still in experimental stages, especially in India. But it has a high potential in improving concrete properties. Internal curing does not replace conventional surface curing, but works with it to make concrete more robust. Internal curing can also help compensate for less than ideal weather conditions and poor conventional curing that is often seen in the real world. IC is gaining momentum in all areas of concrete construction including concrete paving, concrete flatwork, bridges, structural units, pavers and mass concrete applications.

11.6 Summary

- Effective curing of concrete is very important for achieving strength and durability of concrete structure.
- The method of curing needs to be decided based on the actual site condition.
- When hessian cloth is used for curing, care must be taken that the hessian cloth is never dried, else it will absorb moisture from the concrete surface causing more harm than good.
- Curing compound can be effectively used as an alternative to water curing, but efficiency must be checked in the field. The rate of application of curing compound must be determined for maximum efficiency. Required efficiency of curing compound is minimum 85% with respect to the strength of cube cured by submergence in water.
- Internal curing does not replace conventional surface curing, but works with it to make concrete more robust.

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- Internal curing can also help compensate for less than ideal weather conditions and poor conventional curing that is often seen in the real world.

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CHAPTER 12

OTHER FACTORS AFFECTING QUALITY OF CONCRETE

12.1 Concrete Cover and Cover Blocks (spacers)

Concrete cover is defined as the clear distance between outer surface of concrete to the nearest surface of rebar including stirrup and binding wire. Sufficient cover is required for the reinforcement in concrete structure for protection against corrosion. Though several standards have specified minimum cover required for various exposure conditions, it is often not maintained in practice.

According to IS 456:2000, Cl. 12.3.2, the actual cover should not deviate from the specified value by (-)0, +10 mm. Lower than specified value of cover will lead to chlorides reaching the reinforcement early and causing durability problems. Higher cover will lead to micro cracks at the surface of the concrete, thereby allowing ingress of chlorides and sulphates into concrete and causing durability issues. Thus, correct cover is the first line of defense against all durability issues.

Cover to reinforcement is required to:

- Protect the reinforcement against corrosion for the required service life of the structure or element
- Provide an adequate period of fire protection to the reinforcement
- Permit the safe transmission of bond forces between reinforcement and concrete to ensure the structure works as designed with respect to load carrying and control of crack widths

The required cover is dependent upon the size of reinforcement, the maximum size of aggregate in the concrete, the exposure conditions and the type, quality of concrete (e.g. water/cement ratio, cement content, type of aggregate, i.e. normal/lightweight) and period of fire resistance. Cover to reinforcement also has a large influence on crack width and permissible crack width may be a determining factor in deciding on the required cover. Failure to achieve the specified concrete cover to steel reinforcement is probably one of the main single factor influencing the premature deterioration of reinforced concrete. In order to achieve the required cover, use of correct type and size of cover blocks is very essential.

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12.1.1 Minimum Cover Requirement as per Various Standards

For durable concrete structures, it is imperative that the steel embedded in concrete is protected adequately against corrosion. Minimum cover specified is related to the exposure conditions, water binder ratio, concrete strength, nominal size of aggregate and likely exposure to fire. [1] The requirements for minimum cover as specified in IS 456-2000 and IRC 112-2011, based on the exposure condition is as given in Table 12.1. Table 12.2 gives the minimum cover as specified in BS 8110. Fig. 12.1 [1] shows the largest minimum covers specified for reinforced concrete exposed to severe climatic conditions in the design codes of 14 countries. It can be observed that the minimum cover specified in Indian codes is the highest.

Table 12.1 Minimum cover as specified in IS 456-2000 & IRC 112-2011

Exposure condition	Minimum cover as per IS 456-2000, mm	Minimum cover as per IRC 112-2011, mm
Mild	25	-
Moderate	30	40
Severe	45	45
Very severe	50	50
Extreme	75	75

Table 12.2 Minimum cover as specified in BS 8110

Conditions of exposure	Nominal cover (mm)				
Mild	25	20	20[a]	20[a]	20[a]
Moderate	-	35	30	25	20
Severe	-	-	40	30	25
Very severe	-	-	50[b]	40[b]	30
Most extreme	-	-	-	-	50
Abrasive	-	-	-	See Note c	See Note c
Max. water/cement ratio	0.65	0.60	0.55	0.50	0.45
Min. cement content (kg/m^3)	275	300	325	350	400
Lowest grade of concrete	M30	M35	M40	M45	M50

Notes:

- *These covers may be reduced to 15 mm provided that the nominal maximum size of aggregate does not exceed 15 mm.*
- *Where concrete is subject to freezing whilst wet, air-entrainment should be used (see 5.3.3 of BS 5328-1:1997) and the strength grade may be reduced by 5 MPa.*
- *Cover should be not less than the nominal value corresponding to the relevant environmental category plus any allowance for loss of cover due to abrasion*

12.1.2 Importance of quality of cover from durability point of view

The cover provided to the reinforcement is the first line of defense against corrosion. The cover protects the reinforcement from the attack of chlorides and other chemicals. It is important that the quality of concrete in the cover is as good as the main concrete itself. The time required for the chloride ions or carbonation effect to reach the reinforcement is more with increase in the cover of concrete (Fig. 12.2). Thus, increasing the cover will prolong the initiation of corrosion. However, too much increase in the cover is also not good.

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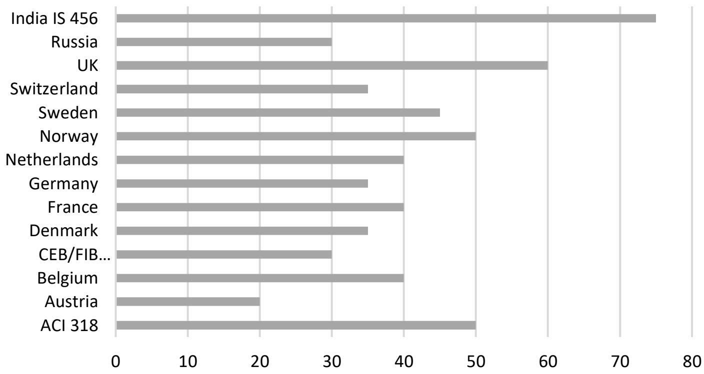


Fig. 12.1 Minimum cover in mm for worst exposure condition in various codes / standards

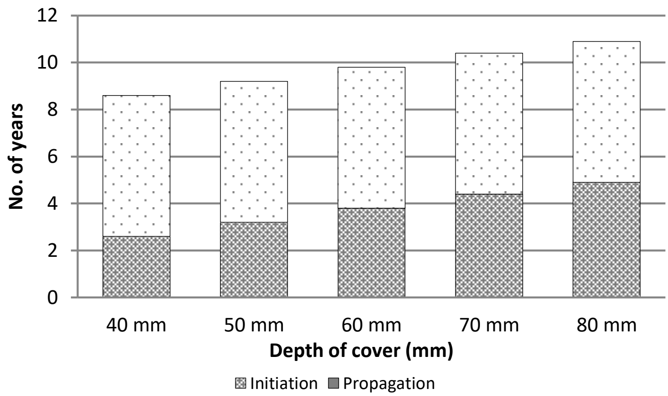


Fig. 12.2 Effect of depth of cover on corrosion of reinforcement for concrete with w/b of 0.40

Generally, when concrete is compacted using vibrators the lightest material in concrete, i.e. air and water tend to rise towards the surface. On a horizontal surface, the air may escape from the surface but the water remains in the cover zone. On a vertical surface like walls, the air as well as water tends to remain at the surface. This causes the cover concrete to be weaker than the actual concrete because of higher water binder ratio.

If proper curing is not done to concrete in the early ages, especially for the flat surfaces, the water from the surface evaporates causing shrinkage cracks. These cracks allow water, oxygen and chlorides easy passage through the surface facilitating early corrosion. One of the best ways of having a good cover concrete is to ensure thorough curing. A strong impermeable cover is the best defense against durability issues.

Lack of required cover on bars results in loss of durability, pop outs and corrosion of reinforcement. The rate of corrosion depends on the concrete properties, thickness of cover and temperature and humidity conditions at the steel surfaces and in the cover zone. Excess cover should also be avoided as micro cracking due to bending stress can develop resulting in accelerated corrosion of reinforcement. Cl. 12.3.2 of IS 456 specifies a maximum tolerance of +10 mm and (-) 0 mm from specified cover.

For reinforced concrete, it is necessary to create a suitable bond between steel bars and the surrounding concrete. The bond ensures that there is little or no slip of the steel bars relative to the concrete and the means by which stress is transferred across the steel-concrete zone. A loss of bond between the concrete and reinforcement could lead to failure of the structure.

It is also very important to ensure that the required cover is maintained using the correct type of cover blocks. After the concreting is complete, it is often a good idea to randomly check if the right amount of cover is actually being maintained in the structure. This can be easily done using cover meter. Cover meter is a device used to determine the concrete cover depth and to pinpoint the exact location of the rebars in the concrete. It is recommended to select a place on the structure where there is sufficient spacing between the rebars. It must be kept in mind that the cover depth of the concrete influences the accuracy of the cover meters. The accuracy of the cover meters decreases with the increase of the concrete cover. Various types of cover meters available in market are shown in Fig. 12.3.

Fig. 12.3 Various types of cover meter available in market

12.1.3 Types of cover blocks/ spacers

In order to achieve the required cover, use of correct type and size of cover blocks is very essential. According to BS 7973 Part 1, there are basically three types of spacers:

1. Plastics spacers.
2. Cementitious spacers
3. Wire chairs.

Three categories of spacers and one of chairs are included in the Standard, and the applications are specified in Table 1 of BS 7973 -1. The categories for spacers are light, normal and heavy.

Light category: Light category spacers provide the cover in vertical members to the reinforcement nearest to the surface of the concrete, or to horizontal reinforcement in small sections not subject to foot traffic, e.g. pre-cast concrete products. They are used on reinforcement up and including 16mm in size.

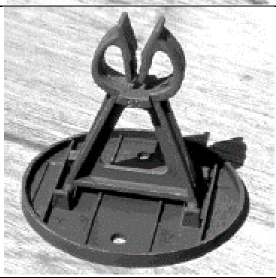
Normal category: Normal category spacers are used for most of the in-situ concrete work and can be used for larger pre-cast products. They provide the cover where the size of the reinforcement to which they are fixed is 20mm or less.

Heavy category: Heavy category spacers provide the cover where the size of the reinforcement is greater than 20mm. This is typically in bridge decks and heavily reinforced foundations.

Chairs: Chairs are used to support the top reinforcement from the bottom reinforcement in slabs to provide the required top cover. They are also used to separate layers of reinforcement e.g. between the reinforcement in opposite faces of a wall. They are manufactured as continuous, individual, or circular. Continuous chairs are widely used for separating layers of reinforcement. Individual chairs with protective tips can be used to support the top reinforcement in slabs where there is no bottom reinforcement provided e.g. cantilevers.

Various types of spacers and chairs are as specified in Fig. 12.3 [2].

Table 12.3 Types of spacers and chairs

Type of spacers and chairs	**Photo**	**Description**
Single cover A spacer		It is used for most purposes in building including foundations, columns, beams, slabs, and walls. It is designed for use with conventional formwork and 8mm up to 20mm size reinforcement. The spacer clips fit into the reinforcement and they do not need tying with binding wire thereby reducing the time and providing the effective cover required.
Soft substrata A spacer		Where a plastic “A” spacer has to rest on soft substrata (i.e. not on conventional formwork) such as thermal insulation a spreader base is used. This clips to the base of the “A” spacer and spreads the load carried by the spacer into the insulation. The spreader base can also be used in vertical applications such as basement walls where, for example, a reinforced concrete wall is cast against a waterproof membrane.

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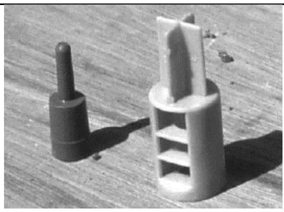
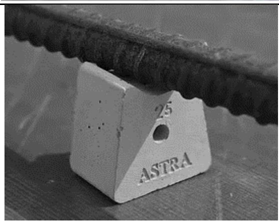
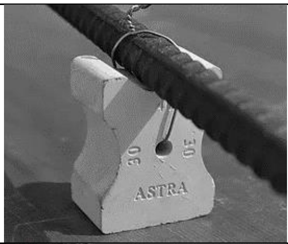
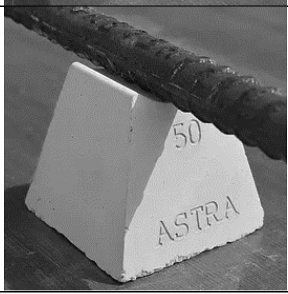
End spacer		End spacers are used at the ends of the wires of welded steel fabric and reinforcing bars to ensure the correct end cover. The left hand one shown in the picture is for the wires of the smaller sizes of welded steel fabric. The right hand one is for the wires of larger size welded steel fabric and for the smaller sizes of reinforcing bars.
Circular spacers		Circular (or "wheel") spacers have been used in the past, mainly on vertical concrete members such as walls and columns. However, they contain more plastic than is necessary for a single cover spacer and are therefore not a good use of resources. The "A" spacer provides the same cover more efficiently, so circular spacers are normally no longer needed.
Single cover cementitious spacer		Cementitious spacers, such as the one shown on the left, are used where the surface of the concrete may be subject to abrasion, e.g. in the seaward side of a sea wall. They require to be wired on to the reinforcement. The wire is traditionally 16 or 18 gauge soft iron wire but in marine environments galvanised tying wire may be used.
Multiple cover cementitious spacer		Multiple Cover Spacers are widely used for infrastructure and precasting works.
Heavy duty spacer		Heavy Duty Spacer are used in members with very high reinforcement load e.g. Heavy Rafts or Footings

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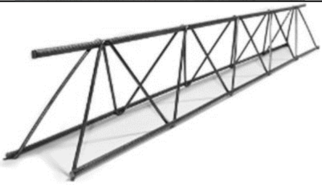
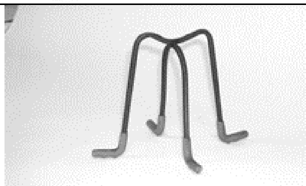
Circular spacer		Circular Spacers are most effective for vertical applications, such as in columns, piles and pile caps.
Continuous wire chair		Continuous wire chairs are manufactured from three longitudinal steel or stainless steel wires of the same size in order to carry the design load.
Individual wire chair		Individual wire chairs can be used where there is no bottom reinforcement to support a continuous chair. For example, it can support the top reinforcement in a cantilever slab where there may be no bottom reinforcement.

Note: Cementitious spacers are to be preferred over plastic spacers from sustainability and strain compatibility point of view.

Spacer positioning is based primarily on acceptable deflection at maximum loading. Therefore, small diameter rebars require more spacers than larger diameter rebars. Table 12.4 below gives guidelines for recommended quantities for spacers based on rebar size and application.

Table 12.4 Guidelines for recommended quantities of spacers

Slabs		
Rebar diameter	**Maximum distance**	**Spacers required (per m^2)**
All	70 cms	2
Beams and columns		
Spacer Distance in the longitudinal direction		
Rebar diameter	**Columns**	**Beams**
Up to 10 mm	50 cms	25 cms
12 to 20 mm	100 cms	50 cms
Over 20 mm	125 cms	75 cms
Spacer Nos. required in the transverse direction		
Width/Height of Beam/Column	Columns	Beams
Up to 100 mm	2	2
Over 100 mm	3 or more	3 or more

12.1.4 Tying of reinforcement in position

Binding wire is used for tying reinforcement. Binding wire is also called annealed wire and is made of mild steel. Annealing endows it with the properties like flexibility and

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softness, required for its main use. Reinforcement needs to be tied together to prevent displacement of the bars before or during concreting. The various type of ties used are as shown in Fig. 12.4 [3]. The tying forms an integral part of the system to achieve the correct positioning of the reinforcement. Binding wire of 16 or 18-gauge wire is used for tying reinforcement. Basically, binding wire required to tie 1 ton of 8 mm bars will be approx. 7 kgs. Binding wire required to tie 1 ton of 28 mm or 32 mm bars will be close to 4 kgs. More the diameter of the bar, lesser the requirement of binding wire. On an average, it is taken as 5 kgs per ton of reinforcement. For this binding wires are to be cut to the required lengths.

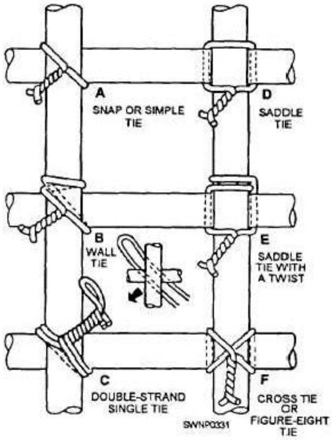

Fig. 12.4 Types of ties

Note: Ensure that the ends of the tying wire are folded inwards and not outwards towards the cover. If so, cover will be reduced. Authors have observed that sometimes they even extend beyond cover which can initiate early corrosion of reinforcement.

12.1.5 Cover blocks manufactured at project site

The concrete cover blocks may either be manufactured in a factory (Fig. 12.5) or produced at site. Generally, cover blocks manufactured in a factory are produced in a controlled environment and have a good quality and strength. Cover blocks manufactured at site (Fig. 12.6) are usually not produced with the same controls. It is important that serious attention is given to production of cover blocks at site. For proper compaction of concrete in cover blocks, use of vibratory table is a must at site. Good quality cover blocks are manufactured by some companies, but they are naturally costlier than those manufactured at site.

The cover blocks must be designed with the same or higher grade of concrete as that of the concrete in with they will be used. Proper compaction, curing and storage must be ensured in order to achieve the required finish and strength. The production capacity of cover blocks must be such that at least 7 days of water curing is given to them before they are put to use.

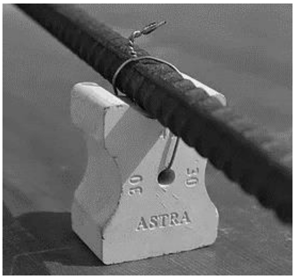

Fig. 12.5 Factory made cover blocks

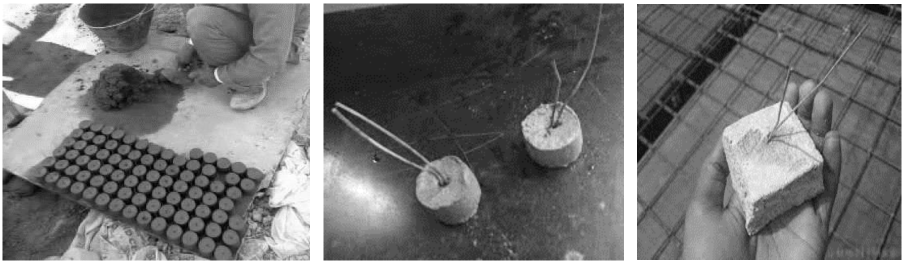

Fig. 12.6 Cover blocks made at project site with use of vibratory table

12.2 Formwork

Formwork is an important activity for concreting. Good quality of formwork can contribute significantly to good quality of concrete. It not only holds the concrete during its wet stage but has many other important functions in this activity of concreting. The surface finish of the form is reflected on the surface of the finished concrete.

Good formwork should satisfy the following requirements:

1. It should be strong enough to withstand all types of dead and live loads.
2. It should be rigidly constructed and efficiently propped and braced both horizontally and vertically, to retain its shape.
3. The joints in the formwork should be water-tight against leakage of cement grout/slurry.
4. Erection of formwork should permit removal of various parts in desired sequences without damage to the concrete.
5. The material of the formwork should be cheap, easily available and should be suitable for repetitive reuse.
6. The formwork should be set accurately to the desired line and levels. It should have plane surface.
7. It should be as light as possible.
8. The material of the formwork should not warp or get distorted when exposed to the elements.
9. It should rest on firm base.

Formwork can be made of timber, plywood, steel, precast concrete or fibre glass used separately or in combination. Steel forms are used in situation where large numbers of re-use of the same forms are anticipated. For small works, timber formwork proves useful. Fibre glass and aluminum are used in cast-in-situ construction such as slabs or members involving curved surfaces.

Among the advantages of timber/plywood shuttering are as follow:

1. Easy handling because it's light weight
2. Easy to disassemble
3. Damaged parts can be replaced with new one

Among the advantages of steel shuttering are as follow:

1. Steel formwork is stronger, durable and have longer life than timber formwork and their number of reuses is higher.
2. It can be installed and dismantled with greater ease and speed.
3. It does not absorb moisture from concrete.
4. It does not shrink or warp.

Plywood

This is by far the most common material used for the facing panel. It is easily cut to shape on site, and if handled and stored carefully, it can be used many times. A standard plywood thickness on site is 18 mm. This is usually sufficient for general purpose concrete works like footings, slabs, beams, columns, etc. However, if the formwork is curved, a thinner plywood is used to facilitate bending. Thicker plywood may be used when the weight of concrete causes a standard thickness plywood to bow out, distorting the concrete face. This can happen when the rate of pouring of concrete is very fast causing higher pressure development on the formwork. It is advisable to protect the sides and edges with timber for longevity of plywood formwork.

Steel formworks

Steel forms are stronger, durable and have longer life than timber formwork and their reuses are more in number. Steel forms can be installed and dismantled with greater ease and speed. The quality of exposed concrete surface by using steel forms is good and such surfaces need no further treatment. Steel formwork does not absorb moisture from concrete. Steel formwork does not shrink or warp.

Aluminium formworks

Often used in pre-fabricated formwork, that is put together on site. Aluminium is strong and light, and consequently fewer supports and ties are required. The lighter sections will deflect more, but this can be avoided by simply following the manufacturers recommendations. Mivan system (Fig. 12.7) is one of the patent systems popularly used in India. In this system of formwork construction, cast-in-situ concrete wall and floor slabs are cast monolithically in one continuous pour. Large room sized forms for walls and floors slabs are erected at site as shown in the Fig. 12.8. These forms are strong, easy to handle and are fabricated with accuracy. They can be used repetitively around 250 times.

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Plastic formworks

Glass reinforced plastics (GRP) and vacuum formed plastics are used when complicated concrete shapes are required (e.g. waffle floors). Although vacuum formed plastics will always need support, GRP can be fabricated with integral bearers making it self-supporting. Like steel, plastic formwork (Fig. 12.9) can be re-used many times, as long as care is taken not to scour the surface whilst vibrating the concrete.

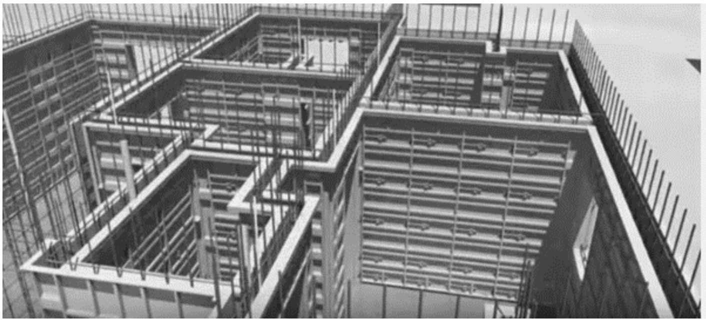

Fig. 12.7 Mivan aluminium formwork system

Fig. 12.8 Mivan aluminium formwork system

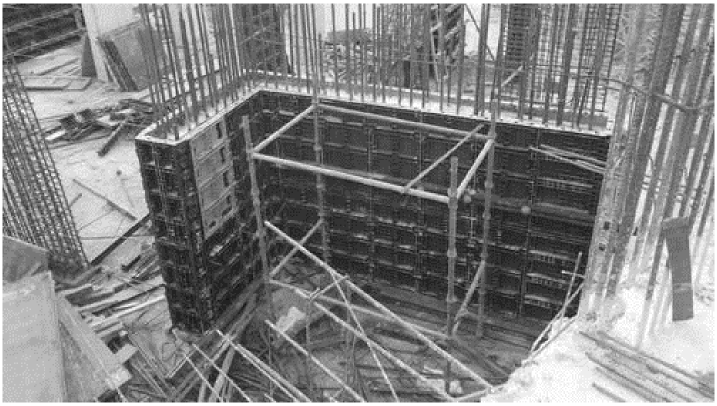

Fig. 12.9 Plastic formwork

12.2.1 Checklists for formwork

12.2.1.1 Pre-concrete checks for formwork

Before the concrete is poured into the formwork, it must be checked by someone who has been trained to inspect formwork. Depending on how big or complicated the pour is, the inspection may just take few minutes or it could take hours. Only when the formwork has been approved along with reinforcement, the concrete pour is approved for execution.

Formwork pressures are function of height (including the height from which concrete is dropped into the forms) and are affected by concrete workability, rate of stiffening and rate of placing. One task of the temporary works co-ordinator is to consider such factors as ambient temperatures and concrete composition, when calculating maximum permissible rate of concrete placing and pressure on formwork. For example, for self-compacting concrete, formwork is to be designed for higher hydraulic pressure than normal concrete.

Exceeding this limit may lead to unacceptable formwork deflections, loss of grout / concrete at joints, or even collapse. The cost of remedial work due to formwork deflection may exceed the original cost of doing the job properly.

Below are the checks that should be verified before concrete pour begins: [4]

1. Is the formwork erected in accordance with the approved drawings?
2. Is the formwork restrained against movement in all directions?
3. Is it correctly aligned and levelled?
4. Are all the props plumb as required, and at the right spacing?
5. Are bolts and wedges secured against any possible loosening?
6. Has the correct number of ties been used? Are they in the right places and properly tightened?
7. Are all inserts and cast-in fixings in the right position and secure?
8. Have all stop ends been properly secured?
9. Have all the joints been sealed to stop grout loss (especially where the formwork is against the kicker)?
10. Can the formwork be struck without damaging the concrete?
11. Are the forms clean and free from rubbish such as tie wire cuttings, and odd bits of timber or metal?
12. Have the release agents been applied, and is it the correct one?
13. Are all projecting bars straight and correctly positioned?
14. Is there proper access for placing the concrete and compacting?
15. Have all the toe-boards and guard rails been provided?
16. Is provision of reinforcement as per the drawing? Is cover to reinforcement adequate?
17. Are immersion rods of required diameter available? If external vibrations are to be used, are they properly fixes to the formwork?

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12.2.1.2 Formwork checklist for walls [4] (Fig. 12.10 and Fig. 12.11)

1. Ensure lateral bracings provided firmly support the forms at all points of support.
2. Block out (stop end) braced to resist vertical and lateral loads.
3. Form panels are adequately braced and tied with each other.
4. Formwork corners shall be adequately tied to prevent leakage or bulging and spreading of concrete.
5. Ensure sufficient length is provided for wall ties and has sufficient strength and spacing as required.
6. Check wales for proper spacing, joints in formwork should be staggered from one tier to the next.
7. In double member wales, one member should be continuous across the location of form ties.
8. Wall ties and bolts are to be tightened properly.
9. In case double member wales are used, both wales should have identical depths.
10. Check for adequate lap between forms and previously cast concrete.
11. Ensure that grout leakage does not occur at joints between panels and joints between old concrete and panels above them.
12. Check the provision of resistance against uplift in case of sloping faces of concrete formwork.
13. Ensure experienced supervisor is available at site while installing the wall forms and while placing concrete.

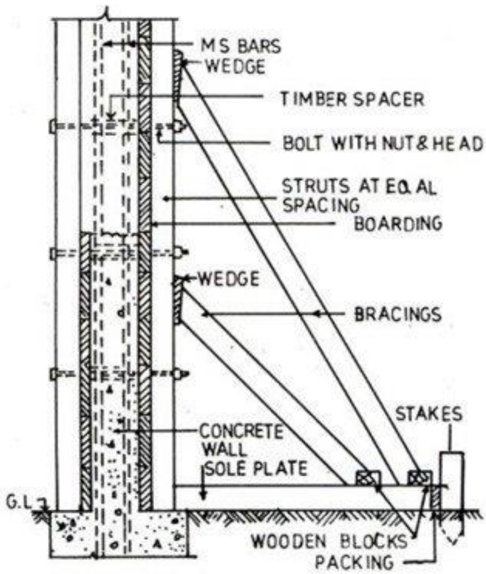

Fig. 12.10 Formwork for walls

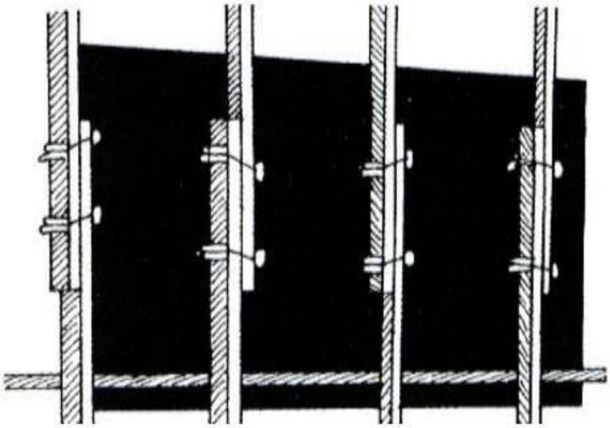

Fig. 12.11 Wall ties

12.2.1.3 Formwork checklist during concreting [4]

1. Before concreting commences ensure proper access for workers involved in placing, compacting and finishing concrete.
2. Ensure presence of experienced supervisor for keeping a continuous watch for any dangerous situation that may arise
3. Ensure adequate supply of spare props, clamps, bolts, wedges and skilled workers at site are available
4. Ensure that the alignment, camber, level and plumb (verticality) are maintained while concreting is in progress.
5. Check that the effective depth between top and bottom reinforcement not disturbed.
6. Cover of concrete around reinforcement steel shall be maintained as specified.
7. Grout loss due to movement at joints should be checked periodically and corrective action taken to stop it.
8. Check for loosening of wedges and fixings due to vibrations transmitted to the formwork and take corrective action if required.
9. Spilt concrete and/or grout to be cleaned immediately.
10. All wooden spreaders, to hold vertical form faces apart shall be removed after placing of concrete.
11. Wooden members for creating pockets shall be eased before concrete sets fully.
12. Check if the concrete pouring sequence is followed as per that shown on formwork drawing (avoid eccentric loading).
13. Prevent heaping of concrete and high impact drops from concrete buckets.
14. Rate of concreting shall be within allowable limits as shown on working drawing or as assumed while designing the formwork against lateral pressures.

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15. Ensure proper bond between layers of concrete, in case concrete is placed in layers, by making sure that needle vibrator while vibrating the top layer also penetrates the lower layer.

12.2.1.4 Checklist during formwork stripping or removal [4]

1. Formwork design and layout should be such that smooth striking of formwork in sequential manner is possible.
2. Strength of concrete shall be adequate for taking self-weight and construction load on it.
3. Removal time shall be ascertained depending on size, shape and span of the member, grade of concrete mix and its rate of gain of strength, type of cement, ambient temperature and weather conditions and extent of curing implemented.
4. At the time of removal of side form, corners and edges should not get damaged.
5. Ties, clamps and wedges shall be loosened and removed gradually.
6. Stripping time should be in line with those specified in code of practice (IS 456-2000).
7. Props, in case of beams and slabs shall be removed in stages from mid-span working outwards.
8. Bolts, nuts, clamps, wedges shall be collected in a box and not dropped carelessly.
9. Use of crowbars to forcibly open forms should be avoided.
10. Formwork is to be loosened using wooden wedges.
11. Formwork should be carefully lowered and not dropped and damaged.
12. Panel faces should be carefully removed and lowered without them hitting the scaffold projections.
13. Panels should be placed on levelled surface after removal.
14. Nail projections should be hammered down.
15. Cordoning off the area below the location where formwork removal is proposed.
16. Presence of competent crane operator and foreman, if required.

12.2.1.5 Checklist for cleaning and storage of formwork [4]

1. Formwork as soon as it is removed, shall be cleaned with a stiff brush.
2. Dust, dirt, stubborn bits of concrete or grout shall be removed.
3. Timber surface and uncoated ply shall be coated with release agent before storing.
4. Steel form coated lightly with oil to prevent corrosion.
5. Damaged formwork shall be sorted out and repaired before storage.
6. Depressions, nail holes shall be repaired with suitable materials and lightly rubbed down to give smooth surface.
7. Panels and plywood sheets shall be stored on a horizontally levelled floor.
8. Panels are stored face to face to protect the surfaces.
9. Storage area is to be protected from rain and moisture and well ventilated.
10. All formwork materials stacked off the ground.

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11. Loose wailings, soldiers (struts) etc. are to be stored with respective panels after numbering for proper match when reused.
12. Bolts, nuts, champs, pins, wedges, keys and ties shall be stored in separate bins or boxes.

12.2.2 Formwork removal time

The removal of formwork also called as strike-off or stripping of formwork should be carried out only after the time when concrete has gained sufficient strength, at least twice the stress to which the concrete may be subjected to when the formworks are removed. It is also necessary to ensure that stability of the remaining formwork is adequate during formwork removal.

The rate of hardening of concrete or the concrete strength depends on concrete mix design and temperature and affects the formwork removal time. For example, time required for removal of concrete in winter will be more than time required during summer. Special attention is required for formwork removal of flexural members such as beams and slabs. As these members are subjected to self-load as well as live load even during construction, they may deflect if the strength gained is not sufficient to handle the loads.

The strength development of concrete member depends on:

Grade of concrete – Higher the grade of concrete, the rate of development of strength is higher and thus concrete achieves the strength in shorter time.

Grade of cement – Higher cement grade makes the concrete achieve higher strength in shorter time.

Type of Cement – Type of cement affects the strength development of concrete. For example, rapid hardening cement gains higher strength in shorter period than the Ordinary Portland Cement. Similarly, in case of blended cement concrete, addition of UFS, UFFA or SF results in early strength gain. Low heat cement takes more time to gain sufficient strength than OPC.

Temperature – Higher the temperature of concrete, faster it achieves early strength. Wooden formwork helps the concrete to insulate it from surrounding, so longer the formwork remains with concrete, the less is the loss of heat of hydration and higher is the rate of gain of strength. Size of the concrete member also affects the gain of concrete strength. Larger concrete section members gain strength in shorter time than smaller sections. Accelerated curing is also a method to increase the strength gain rate with the application of heat.

Generally, values of concrete strength as given in Table 12.5 and Table 12.6 are considered for removal of formwork for various types of structural concrete members. [5].

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Table 12.5 Strength of concrete vs. structural member type & span for formwork removal

Concrete strength	Structural member type and span
2.5 MPa	Lateral parts of the formwork for all structural members can be removed independent of span length
70% of design strength	Interior parts of formwork of slabs and beams with a span of up to 6m can be removed
85% of design strength	Interior parts of formwork of slabs and beams with a span of more than 6m can be removed

Table 12.6 Formwork stripping time (when ordinary portland cement is used)

Type of formwork	Formwork removal time
Sides of walls, columns and vertical faces of beam	16 hours to 24 hours (as per engineer's decision)
Slabs (props left under)	3 days
Beam soffits (props left under)	7 days
Removal of props of slabs:	
i) Slabs spanning up to 4.5m	7 days
ii) Slabs spanning over 4.5m	14 days
Removal of props for beams and arches	
i) Span up to 6m	14 days
ii) Span over 6m	21 days

It is important to note that the time for formwork removal shown above is only when Ordinary Portland Cement is used and ambient temperature higher than 15°C. In case SCMs like fly ash or GGBS are used in concrete or the ambient temperature falls below 15°C, there may be a delay in strength gain. Under such circumstances, delayed stripping times are recommended.

12.2.3 Controlled permeability formwork

In recent years, the number of reinforced concrete structures experiencing premature deterioration has grown considerably. It is worth noting that in many cases the structures which were designed for 100 years have deteriorated in less than 30-40 years and in some cases even within 10-15 years. The amount of money spent on repairs, maintenance and strengthening of these structures is phenomenal.

This deterioration, in many cases, has happened in spite of all the codal provisions of minimum cement content, use of cementitious material and chemical admixtures, proper compaction and curing. Though the codal and best practices ensure good quality concrete which when tested in laboratory for strength and durability exhibit excellent results, it does not cater to one major fundamental issue – the durability of concrete in cover portion.

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Structural designers and concrete specifiers are under the false illusion that a given cement content and water cement ratio, homogeneously mixed and placed within a structural element, will have the same levels of cement and w/b ratio throughout the cast element. The reality however is somewhat different. Once fresh concrete is placed within a steel, timber or plastic formwork, the compaction process and resultant hydraulic pressures force excess mix water and entrapped air towards the formwork surface affecting the quality and durability of concrete. As the formwork surface is impermeable, the water and air are retained in the concrete in cover zone.

Visually the most obvious sign of this is the presence of blowholes and surface blemishes observed after removal of the formwork. It results in concrete in the cover zone with a lower cement content and higher water/binder ratio and lower strength than specified. In other words, the quality of concrete in cover zone is inferior to the other concrete in terms of both strength and durability.

Controlled Permeability Formwork (CPF) is a thermally bonded polypropylene fibre membrane that is tensioned and attached to the internal face of the formwork with staples or other fixing devices. Once in place the concreting may be undertaken conventionally. Unlike conventional formwork surfaces which are impermeable, a CPF liner provides a mechanism through which surplus water and air can pass in a controlled manner through a permeable fibre membrane. Although the liner facilitates excess water removal, the filter is fine enough to retain cement particles carried within the water at the filtering side. This results in a quantifiable reduction in the w/b ratio and porosity (Fig. 12.12, [6]), thereby improving the surface strength, durability and overall appearance of the finished concrete. The surface is relatively free from blowholes and other surface blemishes when compared to conventional formwork concrete (Fig. 12.13, [6]).

The three basic elements of a CPF system are as illustrated in Fig. 12.14 [7]. These are:

A filter membrane: to allow the passage of excess water and air from the concrete forced towards the formwork surface during compaction, but designed with a pore size to retain cement and other small fines.

A drain: through which entrapped water and air may escape.

A structural support: commonly timber, steel or plastic structural formwork support provides a face against which the CPF system may be attached.

The liner thickness is typically 2.5 mm with the filter portion having a pore size of approx. 0.03 mm. Liner can be re-used for three to four times after which it needs to be removed and new liner needs to be fixed to the formwork.

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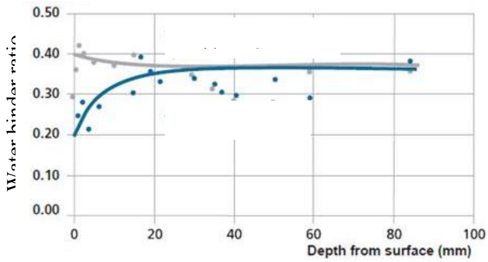

Fig. 12.12 Reduction in w/b ratio in cover concrete with use of CPF

With CPF **Without CPF**

Fig. 12.13 Improvement in surface quality with use of CPF

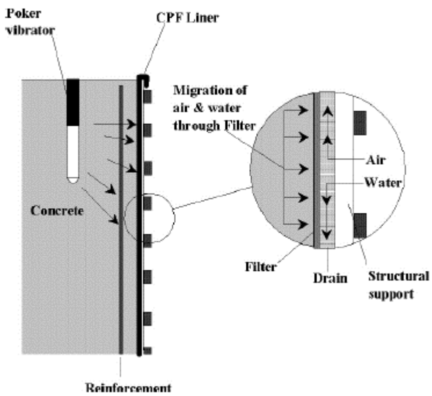

Fig. 12.14 Mechanism of CPF

12.3 Testing of Concrete Samples

The quality of concrete produced is finally judged by the results obtained from various tests conducted on concrete samples. The concrete structure is deemed satisfactory if the test results are passing the specified criteria. Thus, the entire process of collecting the right representative sample, casting the samples correctly, preserving the samples as per the standard requirement and testing the samples correctly is extremely important for the concrete structure to be considered as passed.

Unfortunately, proper attention to the above is seldom given and the end result may be a good structure meeting all the requirements of good specification but may fail in required performance. Concrete is usually tested in fresh concrete state for workability and temperature. In hardened state, the number of tests conducted may be for strength, volume change and durability.

12.3.1 Collecting representative samples for testing

The samples for testing must be representative of material / concrete required to be tested. Minimum sample size to be taken for various tests shall be as per relevant codal requirements. Following precautions must be taken while collecting samples.

1. For material sampling, collect small portions of samples from various locations and mix them together thoroughly. Ensure that the sample collected is at least 25% more than the minimum quantity required for testing.
2. For concrete sample taken from transit mixer, allow some quantity of concrete to be discharged before collecting sample for testing. Generally initial concrete discharging from the transit mixer will have higher aggregate content and will not be representative. Collect the sample on a hard non-absorptive tray or wheel burrow. Mix the sample collected thoroughly.
3. In case of concrete, if the fresh concrete properties are to be tested after a certain period of time, say, 1 hour or 2 hours, ensure that the concrete sample is properly covered with wet hessian cloth.
4. Ensure continuous mixing of concrete sample while taking small portions for filling of slump cone or cube moulds, etc.

Of all the tests that are conducted on hardened concrete, the cube test is considered the most important test which determines the strength of concrete. Following procedure must be followed while casting of concrete cubes to get consistent and actual test results with least variation:

1. Cube moulds must be cleaned properly by opening the individual plates of the mould. After cleaning it is important to apply oil to the inside of all plates before assembling them (Fig. 12.15). This is important because once the mould is assembled it is practically impossible to apply oil at the edges effectively. Without proper application of oil to the edges, the corners of the cube will be broken (Fig. 12.16). unfortunately, this incorrect system is generally adopted by most laboratories. For lubricating the surface of the cube mould, demoulding agent may be applied to the mould surfaces. It gives better surface, sharp edges and less air voids.
2. Once the moulds are assembled, it is important to check the diagonal dimensions to ensure the right angles of the mould. If bolts of the mould are not properly tightened, we may have parallelogram rather than square (in plan) mould. The diagonal of 15cm x 15cm mould will be 21.213 cm (Fig. 12.17).

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3. The concrete must be cast in cube mould as per the guidelines given in IS 516. After the sample has been remixed, immediately fill the cube moulds and compact the concrete, either by hand or by vibration. Any air trapped in the concrete will reduce the strength of the cube. Hence, the cubes must be fully compacted. It is essential that during casting of the cube, continuous tamping of the mould by two wooden/rubber mallets is done to eliminate/minimize air voids. Tamping is to be done simultaneously on two opposite faces of the mould (Fig. 12.18) from bottom of the mould upwards. Such tamping is to be done on all the four faces, two at a time and by rotation. In absence of such tamping, large number of air voids will be visible on the faces of the concrete cube (Fig. 12.16). Unfortunately, such a requirement has not been mentioned in IS 516.
4. Immediately after casting the cubes in the mould they should be marked clearly. This can be done by writing the details of the cube in ink on a small piece of paper or carving it on fresh concrete or painting it on top of concrete surface. The cube must be kept covered with moist hessian cloth till the time of demoulding.
5. Once demoulded, the cubes must be carefully transported to the curing tank where the water temperature must be maintained at 27±2°C.

Fig. 12.15 Lubricant properly applied on all inner surfaces on de-assembling the mould

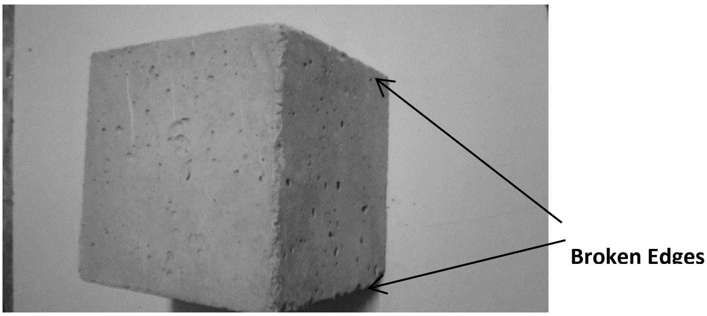

Fig. 12.16 Concrete cube with broken edges and lot of air voids

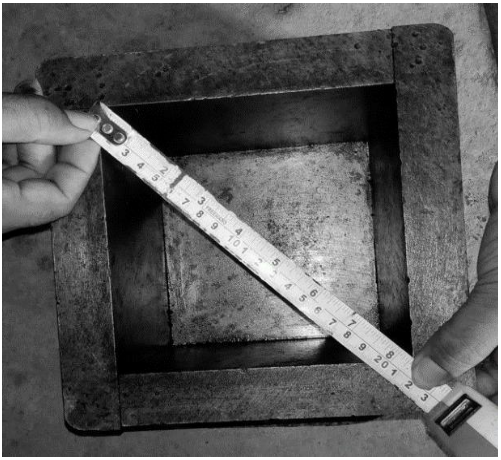

Fig. 12.17 Measuring the diagonal of the cube mould

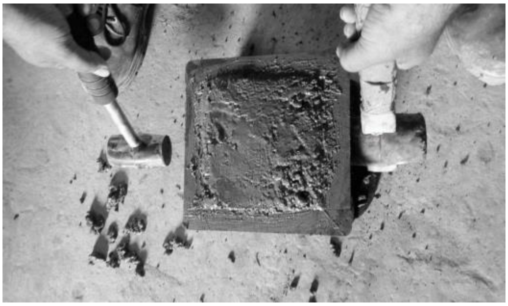

Fig. 12.18 Tamping by wooden / rubber mallets on both sides of the mould simultaneously

Recently, plastic cube moulds (Fig. 12.19) with stiffeners are also available in India. These plastic moulds were imported till recently but now they are being manufactured in India also. (The plastic moulds are also available without stiffeners. However, authors refrain from recommending them). The advantages are as follows:

- Light weight as compared to iron moulds (approx. half the weight)
- No requirement for demoulding and refitting. Saves lot of time and labour
- Easy to clean and make ready for use again
- No issues of distortion of shape of mould. It has good stiffeners.
- Quick extraction of sample. A small hole is provided at bottom of the mould through which compressed air is to be applied for extraction of the cube.
- Very quick application of lubricant. Spraying is effective way of application, particularly at the edges.

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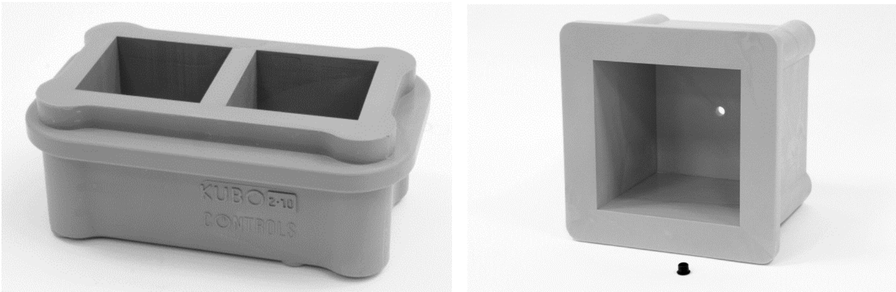

Fig. 12.19 Plastic moulds with stiffeners

12.3.2 Testing of concrete samples

Once the samples are correctly cast and cured, the next important step is to ensure correct testing of these samples. The following steps must be undertaken to ensure correct testing:

1. Wipe clean the surface water of the cubes after taking out of curing tank.
2. Check the dimensions and weight of the concrete cubes taken out of curing tank before testing. The dimensions and weight must be within limits specified from the theoretical value. The dimensional accuracy is very important, as any variation will lead to lower results. As per IS 10086-2008, 150 mm cube mould has a tolerance of ±0.2 mm.
3. Clean the cube as well as the platen of compression testing machine (CTM) before placing the cube at the centre of the platen. It is desirable to mark circle on the platen to ensure cube is correctly placed. Further, cube should be so placed on platen of CTM such that the face with the cube marking is towards or away from the testing person.
4. Ensure that the CTM is calibrated.
5. Ensure that the rate of loading applied is as per the relevant specification.
6. Record the results correctly for further analysis.

12.4 Significance of Proper Specifications on Durability and Sustainability of Concrete

The ultimate performance of concrete during its service life depends on various factors. Considering a good control on incoming materials, production, transportation, placing and curing of concrete, the performance of concrete during its service life depends on the mix design. The mix design depends on:

- Minimum cement content and maximum water binder ratio as per the relevant codes for the specified exposure conditions
- Today all Indian as well as International codes allow use of SCMs in concrete. But many times, the contract specifications restrict use of SCMs in concrete. This is mainly due to mindset of the concerned authorities.

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The choice of SCMs to be used in designing the concrete will depend on the performance required in terms of strength and durability. Concrete strength upto M55 to M60 can be easily achieved with 100% OPC mixes, but these mix designs will not be as durable as concrete designed with SCMs. Unfortunately, strength is still being considered as the final performance parameter of concrete and very often durability of concrete is ignored while writing the specifications. This is likely to lead designing a concrete which may not serve the design service life of 100 years and deterioration may start much earlier.

The performance of the structure during service life depends on the type of specifications prescribed in the contract. And in most cases the quality of specifications more often than not, depends on the individual clients' / consultants' mind-set.

Concrete designed without SCMs has the following disadvantages:

- It is not as durable as concrete designed with SCMs
- Use of 100% OPC is not a sustainable solution as it has a huge carbon footprint
- Using SCMs help solve the issues of disposal of these waste materials into landfills causing environmental hazards
- Concrete designed without SCMs deteriorate faster requiring early and overall costly repairs
- Use of SCMs make concrete economical
- Use of SCMs minimizes the depletion of natural resources, viz., limestone

Another major issue is the age-old culture of having prescriptive specifications. The dominant cause of premature deterioration of concrete structures is due to reinforcement corrosion resulting from chloride ingress and carbon dioxide attacking the concrete and reducing the pH value of passivating layer surrounding the reinforcement. Traditional durability design approaches are based on prescribed limiting values for selected mix design parameters such as water/binder ratio, compressive strength and cement content. However, prescriptive mix design parameters fail to adequately characterize the concrete's resistance against carbonation or chloride ingress, and other aggressive actions on concrete. They ignore to a large extent the different performance of various binder types and of mineral components added to the cements or to the concrete itself, as well as the type of aggregate, and do not allow to take into account the influences of on-site practice during the construction process. Prescriptive approaches also cannot explicitly account for a rational service life requirement.

Performance approaches, in contrast, are based on the measurement of material properties that can be linked to deterioration mechanisms under the prevalent/expected exposure conditions. The measurement of actual concrete material properties of the as-built structure allows accounting for the combined influences of material composition, construction procedures, and environmental influences and therefore forms a rational basis for durability prediction and service life design. Performance approaches can be applied in different stages and for different purposes, including design, specification, pre-qualification and conformity assessment of the as built structure. Most test methods for the assessment of the structure's resistance against reinforcement corrosion are based on the quantity and quality of the cover concrete.

The biggest advantage in performance specifications is that it defines required results, criteria by which performance will be judged, and methods of evaluation, without requirements for how the results are to be obtained. Durability criteria of concrete is based on where it to be used; durability requirements for exposed concrete will be more stringent than concrete not exposed to environment directly though the strength might be same. Performance criteria for an exposed concrete might include strength, permeability, scaling, cracking and other criteria related to durability since the concrete will be subjected to a harsh environment. There is no restriction of min. cement, max. w/b ratio, SCMs, use of manufactured sand, etc. as long as the performance criteria is met. This gives the concrete producer flexibility of using various SCMs to the best of their advantages without any hindrance from the client / consultant.

12.5 Summary

- Concrete cover acts as the first line of defense against the environmental attacks. It is very important to maintain the required quality cover.
- Quality of cover block must be checked regularly, especially cover block manufactured at site. Curing of these cover blocks must be done thoroughly before they are put to use.
- Cover blocks must have same or higher strength as that of concrete
- Binding wires used for tying of reinforcement must be as per the codal requirements. Care must be taken to avoid binding wire from touching the formwork during concreting. If binding wire is exposed to environment directly, it will act as area of accelerated corrosion. Projecting binding wire should be bent inwards and not outwards in the cover zone
- Proper checklists must be prepared and followed while erecting formwork and concreting.
- Ensure proper supports to formwork to avoid buldging due to concrete pressure.
- Formwork removal depends on the strength required to take the dead weight and any construction load. Care must be taken to remove formwork and supports only after the required strength is achieved.
- Conventional formwork is impermeable in nature and as a result the extra water and air expelled during compaction remains in the concrete in the cover zone. This increases the water binder ratio in the cover zone thereby reducing the durability of the concrete in the cover zone.
- Use of controlled permeability formwork facilitates expulsion of this additional water and air from the concrete cover zone, thereby reducing the effective water binder ratio in the cover zone making it more impermeable

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and durable. The surface finish obtained is much superior than that achieved with conventional formwork.

- Samples collected for testing of concrete must be representative of the entire concrete produced. Due care must be taken while collecting samples
- Cube moulds must be cleaned and oil applied before assembling the moulds for uniform lubricant application even at the edges. If this is not done, the cube edges and corners are broken.
- Ensure proper dimensional verification of cube moulds and calibration of CTM to avoid variation in cube results.
- It is important to have appropriate specification of concrete to achieve the desired service life of the structure. Incorrect specifications may lead to early deterioration of the structure leading to high repair and maintenance costs or in some cases complete demolition of the structure
- Performance based specification provides better robustness to the concrete structure than the conventional prescription based specification.

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