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NO-SLUMP CONCRETE WITH FINE SAND AND CLAY

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ABSTRACT

The paper briefly reviews the effects of some deleterions materials on the strength of roller compacted and no slump concrete. The effects of fine sand and differing quantities of kaolinitic clay on the strength of no-slump concrete are reported. It is concluded that the use of fine sand caused a strength reduction in the no-slump concrete of about 22%. Further, the addition of 1% kaolinite resulted in a marked reduction in strength of the no-slump concrete. This reduction in strength is attributed, predominantly, to the interference of cement hydration due to the presence of the clay. However, further loss in strength of no-slump concrete due to the addition of kaolinite up to 10% of the total weight of the aggregate inclusive of clay seems to be a function of the overall increase in the surface area of the aggregate and a consequent increase in the water-cement ratio of the concrete. It is recommended that water curing of no-slump concrete containing silt and clay is very important for the proper strength development.

Dans cet article on examine brièvement l'effet de quelques matières nuisibles sur la résistance du béton de consistance terre humide (affaissement nul) compacté au rouleau. On indique les effets de sable fin et d'une argile kaolinitique sur la résistance du béton de consistance terre humide. On en conclut que l'utilisation du sable fin réduit la résistance d'environ 22%. En outre, l'addition de 1% de kaolinite réduit nettement la résistance de ce béton. Cette diminution de résistance est due essentiellement à la modification de l'hydratation du ciment provoquée par la présence d'argile. Toutefois, une diminution supplémentaire de résistance, due à l'addition de kaolinite jusqu'à 10% du poids total des granulats, y compris l'argile, semble être aussi une fonction de l'augmentation de la surface spécifique qui entraîne une augmentation du rapport eau-ciment du béton. Il est recommandé d'apporter un soin tout particulier à la cure du béton terre humide, contenant du limon et de l'argile, pour assurer un développement normal de la résistance.

Introduction

With the on-going energy crises, stringent requirements of the environmentalists, and with more and more economic pressures, engineers are and will be driven to use marginal and inferior materials for concrete making. Inferior quality aggregates have been used in the manufacturing of dry lean concrete (DLC) or roller compacted concrete (RCC) (1) and econocrete (2). DLC, RCC and econocrete have been utilized in the construction of dams, subbase of a pavement and fills etc. (3).

According to the ACI Committee 207(4) "Some of the deleterious substances, such as finer than 75μm, some friable materials etc.; in upper limiting quantities as specified by ASTM C33 which affect water requirements (hence strength) in conventional mixes may not be detrimental in the stiffer mixes required for RCC. However, silica and mica which may contribute to uncontrolled expansion and other undesirable effects must be avoided. - - -. Higher than normal precentages of fine material passing 75μm sieve may actually decrease the paste requirements for a given level of compactive effort". The Committee, however, recommends, "Limits of deleterious material for roller compacted application should, therefore, be established by test".

The presence of silt and clay fractions can affect the short-term and long-term properties of concrete (5,6). Small quantities of silt or clay are reported to be generally not harmful for they help to improve workability, and in lean mixes may improve strength of concrete. Solomon (7) observed that the substitution of stone dust increased the compressive and tensile strength of concrete while, as might be expected, decreased its workability and setting time. Lipowski (8) proposed that powdered and dried clays could be mixed with cement to produce a new cementing material desirable for the production of concrete. However, there are, as yet, no results available as to the effects of varying amounts of silt and clay on the strength of no-slump concrete. Accordingly, an attempt is being made on the utilization of clay minerals as an admixture in concrete. This preliminary study presents the effects of differing quantities of kaolin clay and a fine sand on the strength of no-slump concrete.

Experimental Details

Aggregate Used

The aggregate selected for this investigation are river gravel, crushed gravel, river sand, fine sand (brick layer sand) and a commercially available kaolin. The grading analyses of the aggregate used are included in Table 1. The two coarse aggregates and the river sand are the standard concrete making good quality aggregates. The fine sand has a fraction passing 75μm of 16%, which is indicative of its poor quality for concrete making. The atterberg limits for the kaolinitic clay are as given below

Liquid limit:	80%
Plastic Limit:	31%
Plasticity Index:	49%
Linear Shrinkage:	12.5%

Test Details

Two main series, each consisting of 5 test mixes, of no-slump concrete of aggregate cement ratio of 6 were cast (see Table 2). In C series the coarse aggregate used was crushed gravel whereas in the R series the coarse aggregate was a river gravel. In both the series, the first mix contains the normal sand (S stands for standard sand) and the rest of the four mixes are cast with the fine sand (F stands for fine sand) and 0,1,5 and 10%

kaolinite of the total weight of the aggregate inclusive of the clay. The combined grading analysis both for C and R series is identical because of the similarity in the grading of the two aggregate used (see Tables 1 and 2). Numeral which follows C or R is indicative of the percentage of the clay of the total aggregate used.

TABLE 1

Grading Analysis of Aggregate Used

Sieve Size mm/μm	% Passing			
	Crushed Gravel	River Gravel	River Sand	Fine Sand
19	97	97.1		
9.5	3.2	3.1		
4.75	1.2	1.1	100	
2.36	1.0	0.9	90.6	100
1.18	0.9	0.8	67.6	99.5
600	0.8	0.6	45.0	97.8
300	0.6	0.6	22.3	88.1
150	0.4	0.5	8.5	50.6
75	0.2	0.3	2.3	16.4

TABLE 2

Grading Analysis of Combined Aggregate for Different Mixes

	% Passing								
	Sieve Size (mm)								
Mix	19	9.5	4.76	2.40	1.20	0.60	0.30	0.15	0.075
COS ROS	98	35.4	34.1	30.9	23.1	15.5	7.8	3.1	0.9
COF ROF	98	35.4	34.1	34.0	33.7	33.1	29.8	17.2	5.6
C1F R1F	98	36.0	34.7	34.7	34.7	34.0	30.4	18.0	6.6
C5F R5F	98.1	38.6	37.3	37.3	37.3	36.7	33.3	21.8	10.4
C10F R10F	98.2	41.8	40.6	40.6	40.6	40.0	37.0	25.5	15.0

The specimens used were 200 x 100mm diameter cylinders for strength test and 100 x 100 x 510mm prisms for ultrasonic pulse velocity tests. 18 cyclinders and 4 prisms were cast for each mix.

Specimen Conditioning

The aim was to simulate the on-site curing conditions and hence to assess the effect of non-standard curing on the strength of the concrete test specimens. Accordingly, the following two curing regimes were adopted:

(i) Specimens were allowed to dry out after demoulding within the confines of the laboratory where the temperature and relative humidity varied between day and night (maximum and minimum temperature recorded was 30° and 7°C respectively and the relative humidity varied between 40 and 70% approximately).

(ii) Specimens were continually immersed in an unheated water curing tank at an average temperature of 17°C.

Testing Procedure

For the C series, 3 specimens were tested both for compressive and indirect tensile strength in a given regime. However, for the R series compressive and ultrasonic tests were performed. The results of testing for both the series are included in Tables 3 and 4.

TABLE 3

Mix Information
Aggregate Cement Ratio = 6

Mix	Effective W/C Ratio	Unit Mass fresh Concrete (kg/m^3)	Curing regime	Compressive Strength (MPa)		Indirect Tensile Strength- 28 Day (MPa)
				7 Day	28 Day	
C05	0.40	-	Air	27.5	33.5	2.25
			Water	32.5	40.5	3.00
C0F	0.54	2348	Air	23.0	27.0	2.50
			Water	24.0	36.0	2.95
C1F	0.55	2371	Air	18.0	19.5	1.70
			Water	24.5	29.0	2.25
C5F	0.61	2261	Air	10.5	13.5	1.30
			Water	11.5	22.0	1.90
C10F	0.90	2209	Air	6.5	7.6	0.68
			Water	9.4	11.5	1.62

TABLE 4

Mix Information

Aggregate Cement Ratio = 6

Mix	Effective W/C Ratio	Unit mass fresh Concrete (kg/m^3)	Curing Regime	Compressive Strength (MPa)		Ultrasonic Pulse Velocity (M/S)		
				7 Day	28 Day	After Demoulding	7 Day	28 Day
ROS	0.38	2510	Air	27.7	34.0	-	3700	4000
			Water	34.1	41.0		4010	4320
ROF	0.55	2328	Air	14.9	21.7	2910	3603	3794
			Water	19.0	33.0		3863	4198
R1F	0.60	2360	Air	15.3	18.3	2520	3405	3487
			Water	17.7	26.1		3781	3812
R5F	0.82	2216	Air	10.4	10.9	2367	3071	3191
			Water	10.2	16.4		3322	3631
R10F	1.00	2148	Air	5.6	5.6	2442	2493	2638
			Water	6.0	9.7		3035	3307

TABLE 5

Effect of Fine Sand and Clay on The Compressive Strength of no-Slump Concrete

Mix	% Change in Strength as compared to the Strength of COS Mix			
	Air Cured		Water Cured	
	7 Day	28 Day	7 Day	28 Day
COF	-16	-19	-27	-11
C1F	-35	-42	-25	-28
C5F	-62	-60	-65	-46
C10	-76	-77	-71	-72

TABLE 6

Effect of Fine Sand and Clay on the Ultrasonic Pulse Velocity of no-Slump Concrete

Mix	% Change in Velocity as Compared to the Velocity of ROS Mix			
	Air Cured		Water Cured	
	7 Day	28 Day	7 Day	28 Day
R0F	-3	-5	-4	-3
R1F	-8	-13	-7	-12
R5F	-17	-20	-17	-16
R10F	-33	-34	-24	-23

Results

Compressive Strength

(i) Effect of fine sand

Tables 3, 4 and 5 clearly indicate that the substitution of fine sand in the mix caused a reduction in the compressive strength under both the curing regimes for the mixes containing both the crushed gravel and the river gravel. The average loss in the 28 days' air cured strength is 28% whereas for the water cured is 15%. The loss in strength because of the substitution of fine sand is due to the fraction passing 75μm sieve, the overall change in grading of the mix and the resultant change in the water-cement ratio. On the substitution of fine sand, the water cement ratio had to be increased, on the average, by 0.155. Accordingly, the loss in strength which can be attributed to the increase in silt content and the consequent increase in water demand is shown graphically in Figs. 1 and 2.

(ii) Effect of clay content

Addition of 1% kaolinite, over and above 5.6 silt, decreased the 28 days air cured strength of concrete, on the average, by 22%. The loss in strength in case of concrete containing crushed aggregate was more pronounced. Again, on water curing, the average loss in strength is 20%. As shown in Fig. 1, there is a marked reduction in the strength of concrete on the additon of 1% clay. Since the change in water-cement ratio is only nominal (see Fig. 2), the loss in strength can be attributed to interference in the hydration process because of clay.

On further increasing the clay content up to 5%, the loss in strength was 50 and 45% on air and water curing respectively as compared to the concrete containing silt only. It seems that at this high clay content the type of coarse aggregate had no specific effect. Fig. 1 indicates, however, that the rate of strength loss because of the addition of kaolinite decreased as compared to its initial rate. At 10% clay content there was a further reduction in strength. On the average, there is a 71% reduction in the 28 days strength of the specimens containing 10% kaolinite as compared to specimens containing silt only. As shown in Fig. 1, the rate of strength loss on the addition of clay beyond 1 and up to 10% is almost linear. Fig. 2

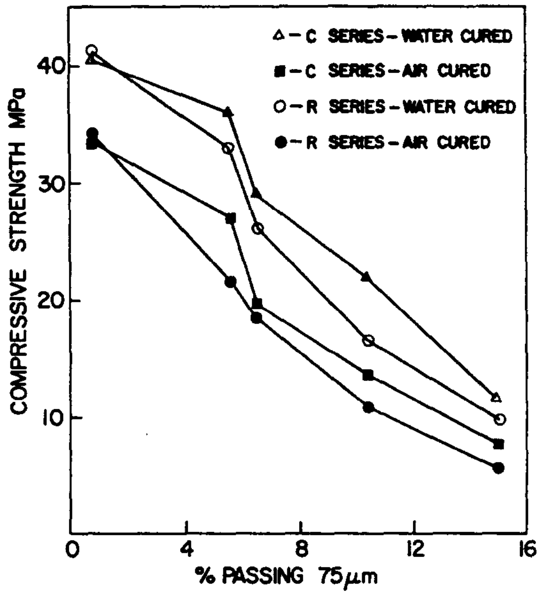

Fig. 1

Effect of Silt and Clay on the Strength of Concrete

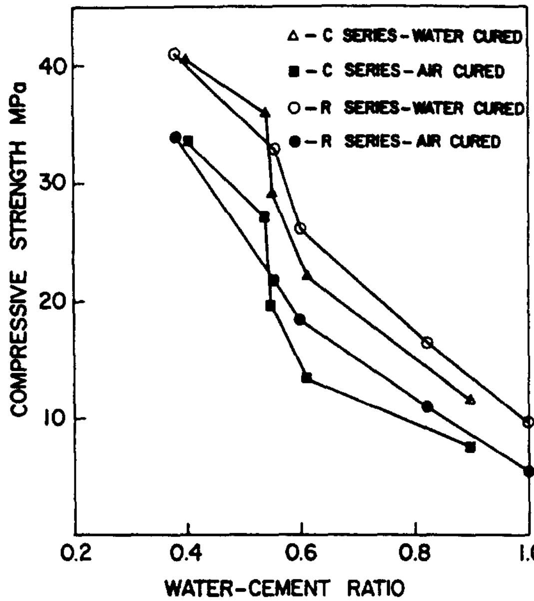

Fig. 2

Effect of Water-Cement Ratio on the Strength of No-Slump Concrete

also depicts that the water demand is proportional to the quantity of clay in the concrete. It can be surmised, from the results, that the predominant loss in strength beyond 1 and up to 10% clay is because of the increased surface area of the aggregate.

(iii) Effect of curing regime

Marked effect of water curing on the strength of no-slump concrete are well documented in Tables 3 and 4. The proper curing of concrete containing silt and clay promotes hydration of cement and reduces the extent of shrinkage-cracking which leads to an increase in compressive strength.

Unit Mass of Concrete

The unit mass of fresh concrete with river sand is 2500 kg/m^3 and it decreased on the substitution of fine sand and, on the average, there is about 7% loss in the unit mass of no-slump concrete. There is a marginal increase in the unit mass on the addition of 1% clay as compared to the concrete with fine sand, COF and ROF mixes. With further increase in the clay contents the unit mass decreased and the maximum decrease at 10% kaolinite compared to the COS and ROS mixes, on the average, is 13%. Again, the effect of the type of coarse aggregate is not pronounced.

Ultrasonic Pulse Velocity

Pulse velocity measurements are indicative of quality and strength of concrete. The pulse velocities for water cured concrete are higher than the corresponding air cured concrete. Further, with the increasing silt and clay content the pulse velocity kept on decreasing (see Table 4). As indicated in Table 6, the maximum loss in the pulse velocity between ROS and R10F concrete, on the average, is 28%. However, the loss in pulse velocity on air curing is more than that on water curing, which was, of course, expected.

Discussion

Handy (9) emphasized that chemical bonds developing between the cement and mineral surfaces become more important in finer grained mixtures such as soil-cement than in coarse graded mixtures such as concrete. Noble (10) indicated that the hydration of cement grains may be restricted by encapsulation of the cement by very fine grained clay. Croft (11) also demonstrated that soils characterized by montmorillonite and mixed layer minerals and degraded weathering products retarded the hydration and hardening of cement. It is reported (8) that the specific surface of the powdered clays highly affects the hydration of cement. Kawamura (12) and Haque (13, 14) have also observed that while small quantities of silt fraction lower the strength of soil-cement and concrete, large quantities of silt content do improve the strength.

The loss in compressive strength of the COF and ROF mixes (as compared to the COS and ROS mixes respectively - see Tables 3 and 4) on the substitution of fine sand which amounted to 5.6% silt of the total aggregate is attributed to the presence of silt and collaborate the earlier findings (13, 14). Possibly, silt interferes with the hydration of cement and also impedes the proper bonding of aggregate and the hydrated cement. According to Neville (5), silt and fine dust should not be present in excessive quantities because, owing to their fineness and therefore large surface area, silt and fine dust increase the amount of water necessary to wet all the particles in the mix. The increased demand in water and hence the consequent loss in strength of the concrete containing silt is clearly depicted in Fig. 2.

On the addition of 1% kaolinite there is a marked reduction in the strength of concrete (see Fig. 1). However, as shown in Fig. 2, the overall increase in water-cement ratio as compared to the loss in strength is nominal. It is most probable that the clay with large surface area adsorbed much of the water provided for lubrication, resulting in insufficient water available for hydration of the cement. Also the presence of kaolinite even in a small quantity seems to interfere with and restrict the hydration of cement. Nonetheless, the results indicate that beyond 1 and up to 10% of kaolinite the drop in strength of the concrete is more likely due to the large surface area of the clay and hence due to the consequent increase in the water-cement ratio (see Fig. 2).

Shrinkage-cracking and wetting are significant problems in soil-cement and clays develop higher total shrinkage and swelling. Standard shrinkage specimens were cast for the C series of concrete. However, the studs in the specimens containing silt and clay became unstable and shrinkage strain could not be monitored. The water curing of concrete containing silt and clay seems to reduce the extent of shrinkage-cracking and hence a higher compressive strength as compared to air curing is obtained (see Table 5). The results of ultrasonic pulse velocity, included in Table 6, also substantiate this.

Conclusions

The summary of the results obtained is:

1. The strength of a no-slump concrete is affected by the silt fraction of the aggregate. Use of fine sand which increased the silt fraction from about 1 to 5.6% of the aggregate caused a strength reduction of about 22% in the no-slump concrete. The loss in strength was a little more in concrete with natural aggregate than with crushed gravel.

2. Addition of 1% kaolinite in aggregate containing 5.6 silt resulted in a marked reduction in strength of no-slump concrete. This reduc-

tion in strength is attributed, predominantly, to the interference of cement hydration because of the presence of clay. However, further loss in strength of no-slump concrete due to the addition of kaolinite up to 10% of the total weight of the aggregate, inclusive of clay, seems to be a function of the overall increase in surface area of the aggregate and a consequent increase in the water-cement ratio of the concrete. The effect of aggregate shape seems to be played down in no-slump concrete containing kaolinite.

3. Water curing of no-slump concrete containing silt and clay is very important for the strength development.

References

1. E.K. Schrader, "Roller Compacted Concrete", The Military Engineers, Vol. 69, No. 451, pp. 314-317, (Sept. - Oct. 1977).

2. H.J. Halm and J.E. Eisenhour, "ECONOCRETE. . . What it is and How it is Used", ACI Journal, Proceedings Vol. 71, No. 12, pp. 644-651 (December 1974).

3. P.C. Chao and H.A. Johnson, "Rollcrete Usage at Tarbela Dam", Concrete International: Design and Construction, Vol. 1, No. 11, pp. 20-33 (Nov. 1979).

4. ACI Committee 207, "Roller Compacted Concrete", ACI Journal, Proceedings Vol. 77, No. 4, pp. 215-236 (July - Aug. 1980)

5. A.M. Neville, "Properties of Concrete", p. 687, Pitman Publishing Ltd; (1975).

6. Cement and Concrete Association of Australia, "Making Good Concrete", Publication G9/64, p. 11 (1964).

7. K.T. Solomon, "The Substitution of Stone Dust for Natural Sand in Concrete Mixes", Australian Road Research, Vol. 7, No. 3, pp. 27-30 (Sept. 1977).

8. L. Lipowski, "Physikochemishe Ersheinungen beim Erharten von Zement-Lehm Gemischen", Zement-Kalk-Gips, Nr. 11, pp. 476-483 (1968).

9. R.L. Handy, "Cementation of Soil Minerals with Portland Cement or Alkalis", Highway Research Board, Bulletin 198, pp. 55-64 (1958).

10. D.F. Noble, "Reactions and Strength Development in Portland Cement-Clay Mixtures", Highway Research Record No. 198, pp. 39-56 (1967).

11. J.B. Croft, "The Influence of Soil Mineralogical Composition on Cement Stabilization", Geotechnique, Vol. 17, No. 2, pp. 119-135 (1967).

12. M. Kawamura, "Fundamental Studies on the Fabric of Soil-Cement Mixture and its Mechanical Properties", Ph.D. Thesis, Kyoto Univ. Japan, p. 136 (1970).

13. M.N. Haque, "Some Effects of Silt Contents on the Strength of All-In-Aggregate Concrete", Cement and Concrete Research, Vol. 10, pp. 13-22 (1980).

14. M.N. Haque, "Use of Marginal Aggregates in Rolled Dry Lean Concrete", Australian Road Research, Vol. 10, No. 4, pp. 21-26 (1980).