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Effect of Clay Fines on Strength and Workability of Concrete

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Abstract—*The present study aims to represent the outcomes of effect of deleterious materials like clay fines on strength and workability of concrete. IS 383-2016 gives the maximum allowable percentage of clay fines as 1% of fine aggregate. This study is performed to understand the properties of concrete like strength and workability if there is any inadvertent addition or presence of clay fines in the sand and quantify the effects. The percentage of clay fines chosen for the study is 0.25%, 0.5%, 1%, 1.5% and 2.0%. A good range is assumed well below and above the codal limit. The results of this adulterated mixes were compared to properties of control mix with no clay fines. The strength test like compressive strength test was performed at different ages like 7, 14, 28, 63 and 91 days and it was found that there is steady decrease in the compressive strength value. A reduction of about 32% in compressive strength compared to reference mix is observed for mix with 2% clay fines. Moreover, presence of clay fines had minor effect on workability of concrete. A reduced rate of strength gain was observed for mixes with higher percentage of clay fines.*

1. INTRODUCTION

Concrete is the second most consumed material in the world after water [1]. Like India, many other developing countries are rapidly growing in construction and infrastructure segment. This growth in construction industry in past decade has increased the demand for concrete and its constituent material. Concrete is mainly made up of cement, coarse aggregate and fine aggregate. A high quality control is obtained on cement because of decades of experience gained in manufacturing cement. Coarse aggregates are generally extracted by stripping and blasting, crushed, washed and graded to requirement. A good quality control is hence maintained in manufacturing of coarse aggregates. However, due to the geology of the area, there is high possibility that excavated or stripped rocks may contain clayey matrix. It possesses a possibility that clay can get carried away with fine or coarse aggregate even after washing. This will lead to addition of clay fines in concrete. Clay fines, having clay minerals are high water absorbent and have high shrinkage ability. Apart from affecting strength properties of concrete, they increase the shrinkage of concrete[1]. This reduces the durability of concrete and the life of structure. Fines should not be present in excessive quantities because, owing to their fineness and therefore large surface area, fines increase the amount of water necessary to wet all the particles in the mix[2].

In view of the above, it is required to control the clay, silt and fine dust contents of aggregate used for production of concrete. IS: 383-2016 recommends the maximum quantity of deleterious material (shown in Table 1) when tested in accordance with IS:2386-1963.

Table 1 Limits of deleterious materials

Deleterio-us substance	Fine aggregate percentage by weight, Max		Coarse aggregate percentage by weight, Max	
	Un-crushed	Crushed	Un-crushed	Crushed
Clay fines	1.00	1.00	1.00	1.00

A good quality control check makes sure to limit the clay fines within tolerance as specified by standards. But at a large concrete production site, where daily hundreds of cubic meters of concrete is produced, chances of clay fines getting mixed with concrete mix is possible due to human or technical error. Hence, it is imperative to know the effect of clay fines on properties of green and hardened concrete both. Workability of concrete is an important characteristic which addresses the properties of green concrete like consistency, flow ability, segregation and compaction. Compressive strength of hardened concrete can be used to indirectly relate to durability of concrete. In the present study, an effort is made to study the effect of clay fines on compressive strength and workability of concrete when fines are added at difference concentration substituting fines aggregate with specified percentage.

2. LITERATURE REVIEW

Buth et. al. performed experiment to determine the effects of clay content on the strength, shrinkage and durability of concrete. It was found that activity (Liquid Limit) as well as the amount of fines fraction in concrete aggregates affects the properties of concrete. A decreasing trend in compressive strength was found with increasing clay content. Compressive strength was found to decrease by 20% and 45% of target compressive strength at 4% and 9% fines by weight of aggregate [3]. Munoz et. al. investigated the kinetics of coated clay on aggregates when it is mixed in concrete. Clay of three different mineralogy (Na-Montmorillonite, Ca-Montmorillonite and kaoline) was used for experiment. Each type of clay of coated on cleaned aggregates. Clays have high water retaining capacity owing to its high plasticity index. The minerals of clay adsorb the necessary structural water required for hydration of cement. Thus, hydration of cement becomes slow affecting the long-term strength of concrete [4]. Duan et. al. studied the effect of clay mineral kaoline on the pore structure, interfacial transition zone and compressive strength of concrete. They found that kaoline improves microstructure as well as compressive strength. Concrete with higher ratio of fine porosity, reasonable pore size distribution, higher ITZ microhardness and denser micromorphology has correspondingly higher compressive strength [5]. Kronlof found that that fine aggregate powder sharply reduces the water requirement in super plasticised concrete and increased strength at constant workability due to improved particle packing. Better workability is observed due to a consistent mix and increased durability because of decreased porosity [6].

3. GAP AREAS

An abundant literature is present on concrete with fine aggregates substituted by recycled concrete aggregate, blast furnace slag, fly ash, waste glass etc. Lesser is known about concrete where fine aggregates are replaced with clay fines. Moreover, lesser effort is made to study the variation of concrete strength at and around the limits specified by standard. Work is being performed by replacing quarry dust of different source at variable workability. In the present study, fines produced during the crushing of rocks and boulders was used to replace fine aggregate of mix design with used manufactured aggregates of same source. Hence, replacing the fine aggregates with clay fines for different concentration at variable workability will give the variation in strength of concrete due to inadvertent addition of clay fines in concrete mix.

4. DELETERIOUS MATERIAL: CLAY FINES

The origin of the clay is from Vindhyan range of sedimented thick layer of reddish black soil (Bharadwaj, 1981). The clay fines have a liquid limit of 42% and plasticity index of 27%, which classifies the fines as clay of intermediate compressibility as per IS 1489. The clay fines have a free swell index of 53% lying in the range of very high degree of expansiveness.

5. EXPERIMENTAL PROGRAMME

5.1 Materials

Cement is Portland Pozzolana cement fly ash (20% flyash) based. The properties of cement are shown in Table 2.

Table 2 Properties of cement

Sr No.	Test on cement	Result	Acceptance criteria as per IS 1489 (Part 1): 2015
1	Fineness	0.7%	10% max.
2	Initial setting time	150 min	30 minutes min.
3	Final setting time	225 min	600 minutes max.
4	Soundness test	0.5%	10% max.
5	Strength test (at 28 days)	58 MPa	33 MPa min

Aggregates have source of excavated hard rock of sandstone origin at Rawatbhata, Rajasthan civil work project. These rocks are crushed by crusher plant installed at site to make fine and coarse aggregate. The crusher plant produces coarse aggregate of 20mm and 10mm dia. This single sized 20mm and 10mm aggregates are graded in 60:40 ratio respectively to obtain a graded aggregate of 20mm nominal size confirming to codal specification. The fine aggregate is crushed sand meeting the gradation requirement of zone-II as per IS: 383-2016. These other properties of aggregates refer to the mechanical properties of aggregate required to confirm with IS: 383-2016. This mechanical property of aggregates mainly governs the strength of concrete. The test is performed as per the relevant Indian standard as shown in Table 3.

Table 3 Properties of crushed aggregates

Sr. No.	Test	Result	Acceptance criteria as per IS 383: 2016	Standard for Tests
1	Combined flakiness and elongation	6%	40% Max	IS: 2386 (Part 1)-1963
2	Crushing value	13%	30% Max	IS: 2386 (Part 2)-1963
3	Aggregate Impact value	16.5%	45% Max	IS: 2386 (Part 2)-1963
4	Aggregate abrasion value	23%	50% Max	IS: 2386 (Part 2)-1963

5.2 Control Mix Design

The trials for concrete mix design was done at site as per IS: 10262:2009 and mix design of concrete with grade M25 was obtained. The recipe for the control mix (CM) which is also the control mix is given below in Table 4.

Table 4 Mix design of control mix

W/C Ratio	Quantities of materials per cubic meter of concrete						Slump (mm)
	Cement (kg)	Water (lit.)	Plasticizer (kg)	Sand (kg)	Coarse Aggregate (kg)		
					20mm	10mm	
0.48	334	160	2	806	624	416	120

5.3 Concrete mix design with clay fines

Deleterious materials for the study is clay fines present in fine aggregates. The Indian standard code limits for fines is 1% for fine aggregates, by weight. It is intended to study the variation in concrete properties around the code specified values. Thus, the mixes are proportioned such that partial replacement of sand is done with clay fines as shown below in Table 5. All other ingredients of mixes are kept unchanged.

Table 5 Replacement of sand with clay fines

Cube Mark	Percentage of clay fines by weight w.r.t fine aggregate	Partial replacement of fine aggregate with clay fines	
		Sand	Clay fines
CM	Nil	806	Nil.
C1	0.25	804	2
C2	0.50	802	4
C3	1.00	798	8
C4	1.50	794	12
C5	2.00	790	16

5.4 Casting of Cube Samples

The below statement covers the SOP adopted for casting of experiment cubes for the given study. Casting of cubes are done as per Indian Standard IS: 516-1959.

a. Preparation of materials
The cement samples are thoroughly mixed dry by hand so as to ensure the greatest possible blending and uniformity in the material. Aggregates for each batch of concrete is air dried before using in mix. Water is potable water and at room temperature.

b. Proportioning
The proportion of the material is done by weight per cubic meter of concrete. Weigh batching is used for proportioning.

c. Mixing
The sequence of loading material is as per IS 516-1959. The period of mixing is kept no less than 2 minutes after all the materials are in the drum and is continued till the resulting concrete is uniform in appearance.

d. Casting of cubes
Each sample consist of three cube test specimens of 150×150×150mm size confirming to IS: 10086-1982. The average strength of three test specimens is taken as compressive strength of sample.

e. Compacting
The concrete is filled into the mould in layers approximately 5cm deep. 35 strokes per layer is given with tamping rod.

f. Cube identification.
The cubes after initial setting was labelled with permanent marker with mark as show in Table 5 and date of casting.

g. Curing
The test specimens are stored in a place, free from vibration and away from direct sunlight for 24±1/2 hours form the time of addition of water to the dry ingredients. After this period, the specimens are marked and removed from the moulds and it is submerged in clean, fresh water. The water or solution in which the specimens are submerged is renewed every seven days.

5.5 Testing of green and hardened cube samples

Casting of cubes are done as per Indian Standard IS: 516-1959. The concrete strength is evaluated as per IS: 516-1959 and slump of green concrete is evaluated as per IS: 1199-1959.

6. RESULTS AND DISCUSSION

6.1 Slump Value

Table 6 present the results of slump value for concrete mix with clay fines. It is observed that no much variation is observed in the slump value at the present concentration of 0.25% (C1 Mix), 0.5% (C2 Mix), 1% (C3 Mix), 1.5% (C4 Mix) and 2% (C5 Mix) clay as replacement of fine aggregate. The amount of clay fines replaced is smaller in percentage. Hence the water absorbed by surface of clay fines is small with negligible disturbance in water cement ratio. The free water available to maintain the workability remain undisturbed at present concentration of clay fines. In other words, it can be said that around the limit of clay fines specified by the Indian standard and other codes, workability of concrete remains unaffected.

Table 6 Summary of slump value of green concrete mix with clay fines

Mix	SM	C1	C2	C3	C4	C5
Slump (mm)	135	125	120	110	110	105

Figure 1 represent the variation of slump value for different proportion of clay fines. It can be observed that no much variation is observed in the slump value at increasing percentage of clay fines. The overall drop in slump value for C5 mix is only 15%. Hence, a very insignificant reduction in workability takes place due to presence of clay fines in proportions close to codal limit. Thus, it becomes difficult to track the decontamination of sand with clay in green concrete at limiting values. The very gradual decrease of around 5mm average slump value is seen. Though clay being a highly water absorbent soil, the small proportion of clay did not affect the workability on significant scale.

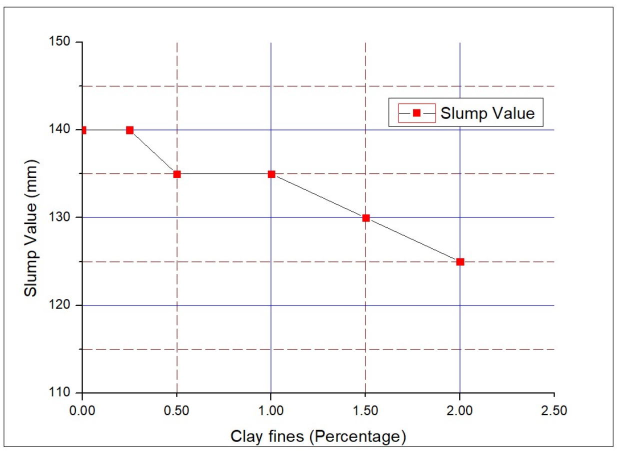

Figure 1 Variation of slump value at different percentage of clay fines

6.2 Compressive strength values

The test results for compressive strength of concrete mixes at different percentage of clay fines and ages is summarized in Table 7 below.

Table 7 Summary of compressive strength of hardened concrete with clay fines

Mix	Average strength (N/mm2)				
	7days	14days	28days	63days	91days
SM	31.08	38.27	41.78	47.45	48.71
C1	32.07	36.77	39.73	43.94	46.39
C2	31.88	35.96	37.28	42.34	44.15
C3	30.07	32.95	35.80	39.69	41.35
C4	27.14	30.79	33.30	36.34	38.25
C5	23.13	25.91	28.34	31.30	33.04

The Table 7 is represented graphically (Ref Figure 2) with compressive strength of concrete against age of concrete. It can be seen that the slope of strength gain between age 7days and 14days is steeper for Mix CM that other mixes. This shows that rate of strength gain for reference concrete is more than concrete with clay fines as substitution to fine aggregate. The strength gain for Mix SM from 7 days to 28 days is 34.4% more than at 7 days. Whereas, for Mix C1 is 24% and for remaining Mixes that is C2, C3, C4 and C5 is around 20%. This shows that rate of strength gains or the rate hydration is affected due to presence of clay fines. This is attributed to high water absorbing property of clay minerals. A considerable strength gain takes place beyond 28 days age. An increase of 16% on average is observed in strength from 28 to 91 days. This is because of fly ash based cement. The pozzolanic reaction at later ages improves the strength of concrete. A lower compressive strength is observed for concretes with higher percentage of clay fines. This is because the presence of clay fines in cement paste matrix. Clay fines are soft, have high affinity to water and exhibit high swelling properties. At the time of mixing green concrete, water is absorbed by clay fines amounting to its swelling. This swelled clay particles are dried with progress of hydration of cement and time. On shrinkage, these clay particles leave a several loose voids within concrete making its strength reduced to considerable value. Further their presence in the interfacial transition zone reduced the concretes mechanical properties.

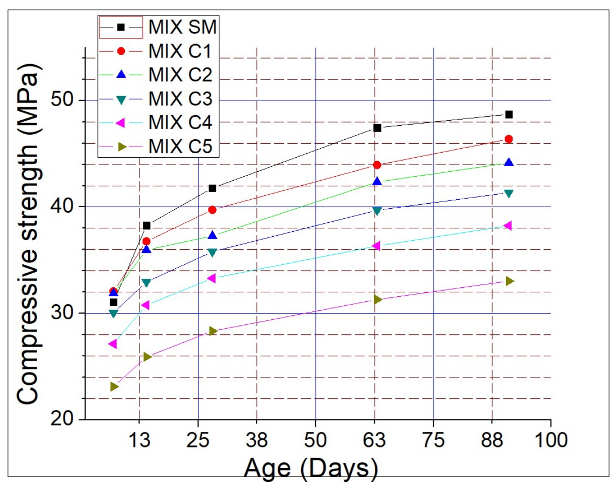

Figure 2 Compressive strength of concrete with clay fines against different ages.

The results are further represented in graphical manner for comparing compressive strength of all mixes at same ages. A graph is plotted in Figure 3 showing the same. It is seen that compressive strength follows a decreasing trend with increase in percentage of clay fines. The marginal increase of 1 MPa for Mix C1 and C2 at 7 days of age is negligible and can be because of experimental variations. Apart from this, a decrease in compressive strength with increase in clay fines percentage is seen at similar ages for all mixes when compared. When the strength of Mix S1, S2, S3, S4 and S5 is compared with reference Mix SM at age of 91 days, a reduction of 4.77%, 9.36%, 15.12%, 21.47% and 32.17% is observed respectively.

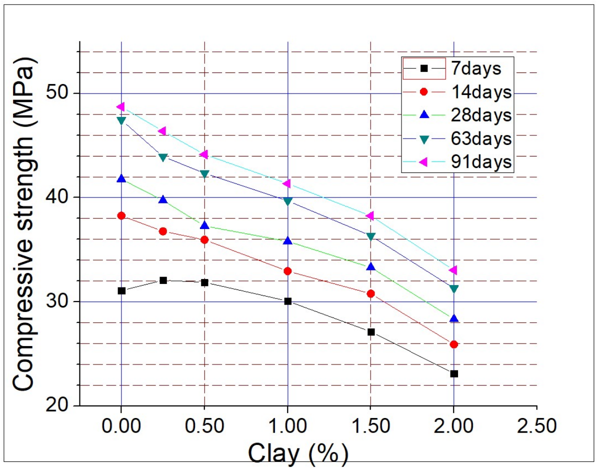

Figure 3 Compressive strength values against percentage clay fines

7. CONCLUSION

Negligible reduction in the slump value was observed for mixes with clay fines.

The decreasing trend in concrete strength was observed in mixes with clay fines. The reduction in strength was to the order of 32% when compared to reference mix. This is due to high water absorbent nature of clay mineral disturbing the water available for hydration of cement. More over this clay fines creates loose and weak pockets in concrete, mainly in transition zone, providing a weak link for failure initiation at lower loads.

A 15% reduction in strength is observed for mix with 1% clay fines that is at codal limit.

It was observed that as percentage clay fines increase, the initial rate of strength gain is affected. The percentage strength gain for control mix from 7 days to 14 days is 23 percent whereas, for mix with 2% clay fines, it is only 12 percent. At 1% clay fines the, the percentage strength gain is 9.5%.

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