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Experimental Study on the Durability of Concrete with Partial Replacement of Sand with Fly Ash

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Abstract

To fulfil the massive demand for concrete in construction, the need for natural aggregates is growing day by day, negatively impacting the environment. The river ecosystem is harmed by sand collected from the river bed. Fly ash, on the other hand, is a substantial solid waste created during the combustion of coal in thermal power plants. Despite the multiple applications of fly ash in cement making, brick production, and land filling, some percentages stay unused, requiring vast amounts of land while creating environmental pollution. These two issues can be mitigated if fly ash can be used for partially replacing sand in concrete. In this paper, laboratory trials were conducted to replace 0, 20, and 40% of fine aggregate in concrete. Later carbonation test was conducted on the samples to understand their effects on real life conditions.

Keywords: Concrete; Fine aggregate; Fly ash; Carbonation test

INTRODUCTION

Concrete is one of the important materials in civil engineering construction work. About 2700 million m3 of concrete was generated worldwide in 2002 and is expected to be tripled by 2050. Of this amount of concrete, cement is about 10%, while aggregates (fine and coarse) amount to more than 70%. The requirement for aggregates is going to affect Mother Nature. Consumption of cement has been reported at 328 million tons in India in 2019 and is going to rise rapidly in the near future. On the other hand, fly ash, a solid waste generated during burning coal for thermal power generation, was around 213 million tons in 2016 in India and is expected to be increased by 3–4 times in the coming two decades. Less than 60% of the amount is utilized in making bricks, cement, land filling, and other works. The rest of the amount requires huge space for disposal. At the same time, fly ash has a bad effect on the environment. The two problems may be tackled if fly ash is further utilized in making concrete. In some cases, partial replacement of cement with fly ash has shown positive results. However, the field of partial replacement of sand (fine aggregate) by fly ash has not been much investigated. Several investigations have already been conducted on fly ash as a cement substitute in concrete. However, there is only a few literatures on the utilization of fly ash as a partial replacement for sand. Choure and Chandak [1] conducted a compressive strength test of M-30 concrete, replacing cement with fly ash in various percentages (0, 5, 10, 15, and 20). Due to the pozzolanic action of fly ash, strength was found to increase with the addition of fly ash. 20% was found to be the best. Sikder and Ghosh [2] conducted tests using a nominal mix of 1:1:2 with sand replacement by fly ash in different amounts (10, 20, 25, 30, 35, and 40) and found that fly ash (class F) could be utilized by partly substituting sand in structural concrete. However, workability was affected to some extent due to the addition of fly ash.

Sabarish et al. [3] conducted tests on M25 and M40 concrete, replacing cement by 10, 20, 30, and 40% by weight of fly ash. The result was not good, and they concluded that for the use of fly ash in concrete, judicial decisions are required from the engineers. Rafieizonooz et al. [4] conducted tests on cubes replacing OPC by 20% fly ash and replacing sand by different amounts (0, 20, 50, 75, and 100%) by bottom ash. No significant improvement was noticed in 28 days of strength, but after 90 days of curing, concrete with coal ash mixtures was found to have greater strength. Mujibur Rahman et al. [5] conducted experiments in Djakarta, Indonesia, replacing sand with fly ash by 0, 20, 35, and 50%. Their findings were positive, and they concluded that fly ash as a replacement for sand would be economical and environmentally friendly. Patil et al. [6] worked on the fly ash of the Deep Nagar thermal power plant in Jalgaon district, Maharashtra. The cement in concrete was replaced by 5% to 25% in steps of 5%. They used M20-grade nominal mix as per IS 456-2000 and found that the addition of fly ash lowered the compressive strength by 28 days and delayed hardening. But with 10% fly ash, the 90 strength was higher than in a normal mix. As disposal is a critical problem, they suggested using fly ash in small amounts in different construction works.

MATERIALS AND METHODS

Materials

a) Cement: The cement used was OPC-53 grade, and its specific gravity was found to be 2.78 by laboratory testing.
b) Fine Aggregate: The fineness modulus is 2.6333, and G is 2.63. Natural river sand (maximum size 4.75 mm) from Zone II was taken as fine aggregate, and tests were done as per IS 383-1970.
c) Coarse Aggregate: Commercially available crushed stone chips, 20 mm down and retained on a 10 mm sieve, are used as coarse aggregates. Sp. gravity, G = 2.85
d) Fly Ash: Fly Ash (Class F) was acquired from Kolaghat Thermal Power Station (KTPS) in West Bengal. The G value is 2.10.

Mix Proportions

The mix proportions were determined following IS 10262 (20090), IS 456 (2000), and IS 12269. For Set A, G of fine aggregate was taken at 2.63, and for Set B and Set C, weighted averages of G were taken at 2.524 and 2.418, considering G of fly ash at 2.10. The amount of cement was considered to be 330 kg/m3 of concrete, and the volume of coarse to the total volume of aggregate was 0.62. The mix design results are given in Table 1.

Table 1. Different Mixes

	Set A	Set B	Set C
Cement, (kg)	1	1	1
Water, (L)	0.54	0.54	0.54
Sand, (kg)	2.17	1.67	1.19
Fly Ash, (kg)	0	0.42	0.79
Coarse Aggregate,(kg)	3.84	3.84	3.84

WORKABILITY TEST

Concrete workability relates to how easy it is to mix, pour, and finish concrete. The slump cone test is carried out using a metal cone with a base diameter of 200 mm and a top diameter of 100 mm. Fresh concrete is poured into the cone in three levels, each of which is tamped 25 times using a rounded-end tamping rod. The cone is then placed on a smooth, flat surface. After the third layer of concrete has been tamped down, the surface is wiped off using a trowel. Following a slow vertical ascent of the cone, the concrete drop is measured.

CUBE CASTING AND CURING

The fresh concrete was placed in the mold (150mm x 150mm x 150mm) in 3 layers. Each layer was tamped with a rod 25 times. Then the surface was finished and left for 24 hours. On the next day, the cubes were taken out of the molds and properly numbered, presenting the test set and the date of casting. Then these were placed in a curing tank filled with water. The 7-day, 14-day, and 28-day strength values were aimed at Three specimens per sample were tested. To study the effect of the extreme curing environment, specimens from each of the three sets were cured in saline water for 28 days (salt intensity was 20 g/l, salt in sea water was 30–35 g/l).

COMPRESSION STRENGTH TEST

The cubes were taken out of the curing tank and left to surface dry for 2–3 hours. Then the cubes were placed in the compression testing machine (CTM) with a capacity of 2000 kN. The compressive strength is taken as the peak load (N) divided by the area (150 mm x 150 mm).

RESULTS

The results of slump test are as follows (Table 2)

Table 2. Results of Slump Test

Test Set	Slump
A	20 mm
B	35 mm
C	True

In Table 3, the comparative strength values of normal concrete, M20 (Set-A), for different days are given. The 28-day strength value of 17.56 N/mm2 (87.8%) in place of the target value of 20 N/mm2 has been obtained. The 7-day and 14-day strength values have been found to be 75% and 94.9%, respectively, of the 28-day value. The value for the specimen cured for 28 days in saline water has been obtained at 75.9% of the 28-day value.

In Table 4, the compressive strength values of New Mix Concrete-1 (Set-B), where 20% sand was replaced by FA, are given. The 28d strength has been found to be 16.67 N/mm2, and the 7d and 14d strengths are 73.3% and 97.3% of it, respectively. However, the specimen cured in saline water has shown a value of 20 N/mm2, which is higher than the value obtained with normal water, i.e., 16.67 N/mm2.

In Table 5, the values of New Mix Concrete-2 (Set-C), where 40% sand was replaced by FA, are given. The 28d strength is 12.22 N/mm2, and the 7d and 14d strength values are 80% and

85.4%, respectively. In the case of a specimen cured in saline water, the value is 11.55 N/mm2, which is 94.5%.

The target strength of M20 (Set A) has not been achieved due to an underestimation of the cement amount. The amount of cement was chosen as 330 kg/m3 of concrete. As a result, the mix proportion became 1: 2.17: 3.84, which is closer to 1: 2: 4 (the nominal mix of M15) than to 1: 1.5: 3 (the nominal mix of M20).

Table 3. Compressive Strength of Normal Concrete (M20) - Set A

Characteristics	7d	14d	28d	28d (EX)
Ultimate Load, kN	296	375	395	300
Compressive Strength, N/mm^2	13.2	16.7	17.56	13.33
Compressive Strength as % or 28 d strength *	75	94.9	100	95.9
S_r, Strength Ratio taking Normal as 100% **			1.0	

$$* \frac{\text{Actual Strength}}{\text{28 d strength}} \text{ x } 100\ \%$$

$$** \ S_r,\ \text{Strength Ratio} = \frac{\text{Strength of New Mix Concrete}}{\text{Strength of Normal Concrete}}$$

Table 4. Compressive Strength of New Mix Concrete -1 (20% Sand Replaced by FA) - Set B

Characteristics	7d	14d	28d	28d(EX)
Ultimate Load, kN	220	235	275	260
Compressive Strength, N/mm^2	9.8	10.44	12.2	11.55
Compressive Strength as % or 28 d strength	80	85.4	100	94.5
S_r, Strength Ratio taking Normal as 100%			0.69	

Table 5. Compressive Strength of New Mix Concrete - 2 (40% Sand Replaced by FA) - Set C

Characteristics	7d	14d	28d	28d(EX)
Ultimate Load, kN	275	365	375	450
Compressive Strength, N/mm^2	12.2	16.2	16.6	20
Compressive Strength as % or 28 d strength	73.3	97.3	100	> 100
S_r, Strength Ratio taking Normal as 100%			0.94	

Table 6. Tensile Strength of samples kept in normal and saline water condition for curing

Curing Condition	Tensile Strength (MPa)		
	(0%)	20%	40%
Normal Curing (28 Days)	2	1.87	1.53
Saline Water (28 Days)	2	2.12	2.01

Small samples are obtained after the concrete cubes have been tested, and they are then analyzed by being sprayed with a phenolphthalein solution. Concrete will become purple if carbonation hasn't taken place (Figures 1–5).

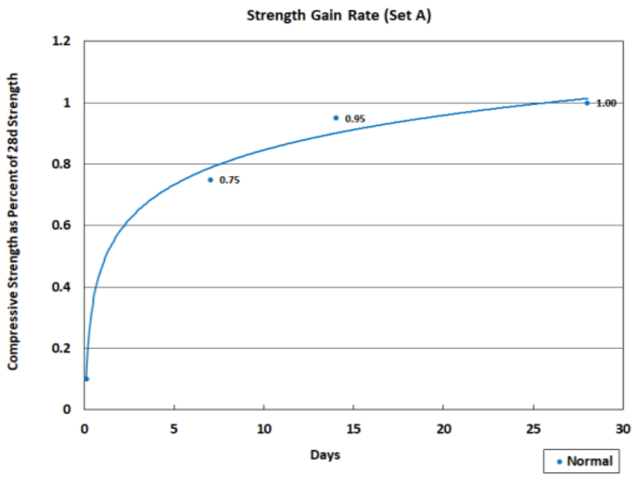

Figure 1. Strength Gain Rate (Set A)

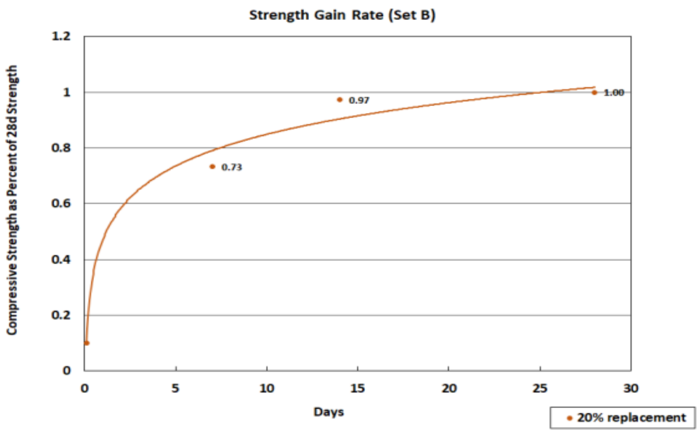

Figure 2. Strength Gain Rate (Set B)

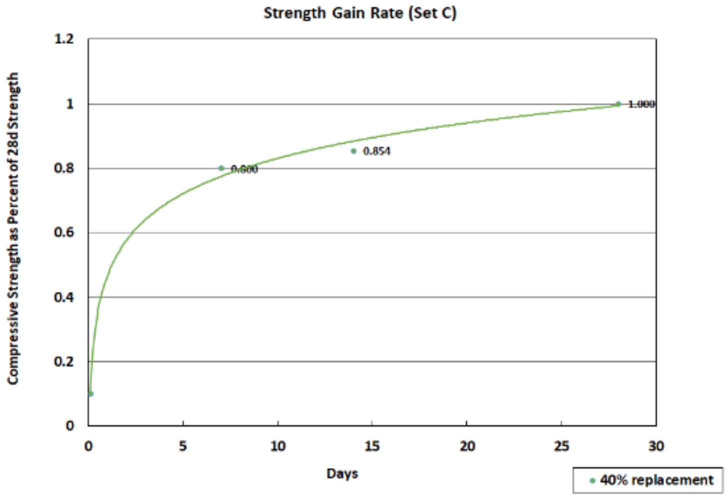

Figure 3. Strength Gain Rate (Set C)

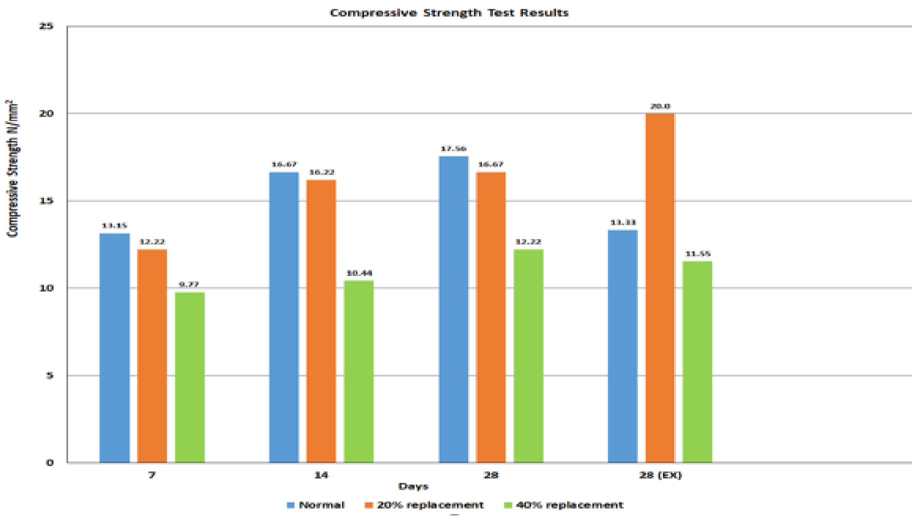

Figure 4. Compressive Strength Values of Different Mixes, Normal (M20) and New Mixes with Sand 20% and 40% Replaced by Fly Ash [28(EX) denotes curing in saline water.]

Figure 5. Carbonation Test Sample

CONCLUSION

The following conclusion can be drawn from these sets of tests done in this study:

(1) The workability of mix is improved with 20% replacement of fly ash but falls with 40% replacement of Fly ash.

(2) 87.8% of the target strength of M20 could be achieved, possibly due to an underestimation of the required cement amount. With a 20% replacement, the results are good. A higher percentage of replacement is not ascertained in this test set, as the results with 40% sand replacement by fly ash are not satisfactory.

(3) The tensile strength result shows that although the tensile strength has decreased with the addition of fly ash in normal curing conditions, it has drastically improved in saline water conditions. So, 20% replacement of sand with fly ash can be recommended for marine conditions as it will be resistant to chloride ions, which eventually will reduce the effect of corrosion on steel bars present in concrete.

(4) The carbonation test, when done on the broken samples, turned purple, which indicates the inner portion of the cubes has not been carbonated.

CONFLICT OF INTERESTS

The authors confirm that there is no conflict of interests associated with this publication.

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