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Effect of Partial Replacement of Cement with Silica fume onthe Strength of High-Performance Concrete

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Abstract

Maintenance, repair and rehabilitation of existing cement concrete structures involve a lot of problem leading to significant expenditure. In the recent past, there has been considerable attention for improving the properties of concrete with respect to strength and durability, especially in aggressive environments. High performance concrete (HPC) appears to be better choice for a strong and durablestructure. Suitable addition of mineral admixtures such as silica fume (SF), ground granulated blastfurnace slag and fly ash in concrete improves the strength and durability of concrete due to considerable improvement in the microstructure of concrete composites, especially at the transitionzone Very few studies have been reported in India on the use of SF for development of HPC and also durability characteristics of these mixes have not been reported . In order to make a quantitativeassessment of different cement replacement levels with SF on the strength for M60 grade of HPC trial mixes and to arrive at the maximum levels of replacement of cement with SF, investigations were taken. This paper reports on the performance of HPC trial mixes having different replacementlevels of cement with silica fume. The strength of these mixes are compared with the mixes withoutsilica fume. Compressive strengths of 60 MPa at 28days were obtained by using 20%, 25% and 30% percent replacement of cement with silica fume.

Keywords: High performance concrete (HPC), strength and durability, Silica fume (SF), Replacement of cement, Superplasticizer, water-binder ratio.

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1. Introduction

According to Neville [1], " High performance concrete is concrete selected so as to fit for the purpose for which it is required. There is no special mystery about it, no unusual ingredients are needed, and no special equipment has to be used. But to understand the behaviour of concrete and will, to produce a concrete mix within closely controlled tolerances". Incorporation of mineral admixtures like SF acts as pozzolanic material as well as micro fillers; thereby the microstructure of hardened concrete becomes denser and improves the strength and durability properties [2]. Addition of chemical admixtures such as superplasticizer improves the properties of plastic concrete with regard to workability, segregation etc [3]. Hence, in the present investigation more emphasis is given to study the strength of HPC using silica fume and superplasticizer so as to achieve better concrete composite and also to encourage the increased use of silica fume to maintain ecology.

2. Mechanism of HPC

Concrete is a three-phase composite material, the first two phases being aggregates and bulk hydrated cement paste and the third being the "transition zone". The transition zone is the interfacial region between the aggregate particles and the bulk "hcp". It is the weakest link and if this is strengthened, then the strength and durability characteristics of concrete are improved to a greater extent This is made possibie by reducing water-binder (w/b) ratio and use of silica fume . Silica fume improves the above properties by pozzolanic reaction and by reactive filler effect silica fume contains a very high percentage of amorphous silicon dioxide which reacts with large quantity of Ca(OH) produced during hydration of cement to form calcium-silicate-hydrate (C-S-H) gel. This gives strength as well as improves impermeability. This is known as pozzolanic reaction (chemical mechanism). Another action, a physical mechanism called "filler effect" in which the small spherical shaped silica fume particles disperse in the presence of a superplasticizer to fill the voids between cement particles and accelerates the hydration of C3S, since silica fume is fine reactive filler. These results in well packed,dense, strong and durable concrete mix. Due to pozzolanic reaction between silica fume and Ca(OH). the larger size crystals of Ca(OH) converts to crystal of C-S-H gel which is leading to reduction of pore size. This effect along with improved particle distribution results in reduction of the thickness of transition zone and leads to densely packed stronger and less permeabie concrete.

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3. Objectives

The objective of the present investigation is

- To investigate the workability and strength for High performance concrete mixes of grade M60by replacing 20, 25 and 30 percent of the mass of cement with silica fume and using a superplasticizer.
- To optimum cement replacement level by silica fume for better strength of High performance concrete.

4. Experimental Investigation

Experimental investigations have been carried out on the M60 High performance concretespecimens to ascertain the workability, strength and durability related properties.

4.1 Materials Used

- Ordinary Portland cement, 53 Grade conforming to IS: 12269-1987.
- Silica fume as mineral admixture in dry densified form obtained from ELKEM INDIA (P)LTD., MUMBAI conforming to ASTM C-1240.
- Superplasticizer (chemical admixture) based on Sulphonated naphthalene Formaldehydecondensate – Glenium C315 conforming to IS codes
- Locally available quarried and crushed blue granite stones conforming to graded aggregate of nominal size 12.5mm as per IS:383-1970 with specific gravity 2.82 and fineness modulus 6.73 as Coarse aggregates (CA).
- Locally available river sand conforming to Grading zone II of IS: 383-1970 with specific gravity 2.75 and fineness modulus 2.73 as fine aggregates (FA).
- Water: Normal ground water for concreting and curing.

4.2 Mix proportions

Mix proportions are arrived for M60 grade of concrete based on Absolute volume method of mix design [4] by replacing 20, 25 and 30 percent of the mass of cement by SF and the materialrequirements per m^3 of concrete are given in Table 1.

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Table 1 : Details of HPC Trial Mixes for M60 Grade

Mix	Silica fume %	w/b ratio	Cement (kg)	Silica fume (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Super plasticizer (litres)	Water (litres)
C1	0	0.32	453.6	0	811.1	1070	11.15	141.84
C2	20	0.32	362.6	72.52	782.4	1070	11.15	141.84
C3	25	0.32	340.0	85.00	777.9	1070	11.15	141.84
C4	30	0.32	317.4	95.22	773.4	1070	11.15	141.84

4.1 Test Specimens

The experimental programme includes testing of Concrete cubes of size 150mm×150mm×150mm, cast. cured for 7 days, 14 days and 28 days in potable water and tested for compressive strength in a AIMIL compression testing machine of 3000 KN capacity as per IS:516-1959.

The flexural test was carried out on beam specimens of size 100 x 100 x 500mm to determine the flexural strength of the specimens. The specimens were subjected to two-point loading. The 7 days, 14 days and 28 days compressive strength and 28 days flexural strength values of various mixes of HPC are tabulated in Table 2.

Reinforced concrete beams with M60 High performance concrete were cast. All tested beams had a rectangular cross section of 150mm width and 200mm depth and an effective lengthof 1500mm. The dimension of the beam are shown in Figure 1.

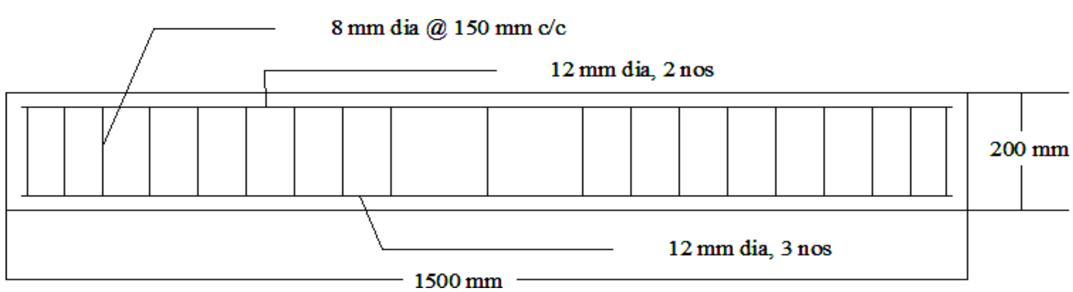

Figure 1. Reinforcement details of the beam

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The test set up is shown in Figure 2. The beams were tested in a loading frame of 40 kN capacity under two point loading. The load was applied incrementally by means of hydraulic jack until the beam failed. The deflection at mid span was recorded.

Figure 2. Test Set-up of Reinforced Concrete (HPC) Beam5 Results and

Discussions

Workability test such as slump test was carried out for fresh concrete as per IS specifications, keeping the dosage of superplasticizer (CONPLAST) as constant at 3 % byweight of binder.

For hardened concrete, cube compression strength test on 150 mm size cubes at theage of 7 days, 14 days and 28 days of curing were carried out. Also, flexural strength testswere carried out on 28 days cured specimens as per IS specifications and the results are shown in Figure 3.

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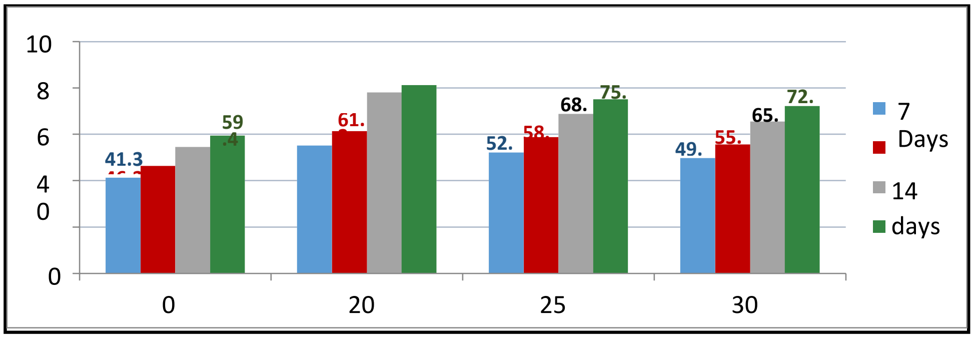

Figure 3 : Compressive Strength Test Results

It can be seen from Figure 3 that the maximum compressive strength was achievedwhen the silica fume replacement was 20% and Table 2 shows higher values of compressive strength and flexural strength for specimens with silica fume replacement 20%. The IS: 456-2000 code underestimates the flexural strength for HPC. The use of silica fume and low w/b ratio resulted in practically impermeable concrete. The compression failure patternof concrete is due to the crushing of coarse aggregate and not due to bond failure.

Table 2 : Cube Compressive Strength and Flexural Strength of HPC Mixes for M60 Grade

Specimens	C1	C2	C3	C4
Silica Fume (%)	0	20	25	30
Cube compressive strength (MPa),				
7 days	41.25	55.22	52.11	49.75
14 days	46.33	61.33	58.75	55.65
28 days	54.65	72.22	68.84	65.50
56 days	59.44	78.15	75.10	72.15
Slump(mm)	82	55	45	34
Flexural strength (MPa),				
28 days	6.80	8.30	8.10	7.90

Further investigation was done on Reinforced concrete control beam without silica fume replacement and Reinforced concrete beam with 20% silica fume replacement for cement to investigate the load carrying capacity of the beams.

5.2 Load versus Deflection Behaviour

In order to investigate the load carrying capacity of the beams, the ultimate load, deflection and the load-deflection behaviour of control beam without silica fume replacement and the reinforced concrete beam with 20% silica fume replacement are observed. Figure 3 shows the load- deflection curves of beam specimens.

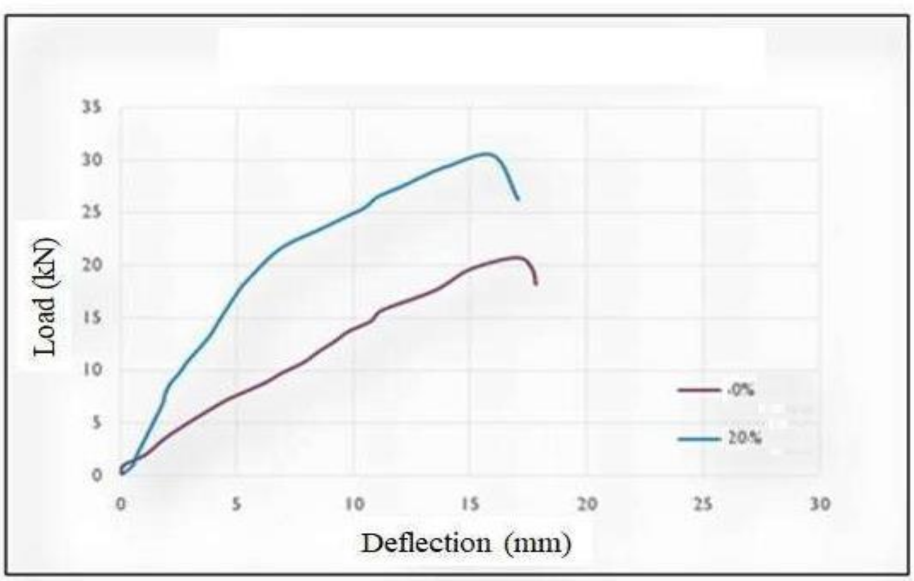

Figure 3 Load vs Deflection

The ultimate load carrying capacity of M40 grade concrete beam with replacement of cement using 20% silica fume is 24.9% more than that of the control beam without replacement.

6. Conclusion

Based on the results of investigation reported in this paper, the following conclusions are were drawn.

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○ Cement replacement level of 20 percent with silica fume in M60 grade of HPC mixes is found to be the optimum level to obtain higher values of compressive strength and flexural strength at the age of 28 days.

○ The use of silica fume and low w/b ratio resulted in practically impermeable concrete.

○ The compression failure pattern of concrete is due to the crushing of coarse aggregate and not due to bond failure.

○ Even a partial replacement of cement with SF in concrete mixes would lead to considerable savings in consumption of cement and gainful utilization of SF. Therefore, it can be concluded that replacement of cement with SF up to 20 % wouldrender the concrete more strong and durable. This observation is in par with the maximum limit of 20 % for mineral admixture in concrete mixes is recommended byIS: 456-2000.

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