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Experimental Investigations on Strength and Durability Characteristics of M110 Grade High Performance Concrete Using Silica Fume and Super Plasticizer

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Abstract- **In the recent past, there has been a remarkable growth in usage of admixtures in concrete 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 durable structure. Suitable addition of mineral admixtures such as silica fume (SF), ground granulated blast furnace slag and fly ash in concrete improves the strength and durability characteristics of concrete.**

This paper presents the results of an experimental investigation carried out in the laboratory on the performance of M110 grade of HPC trial mixes having different replacement levels of cement with SF. The strength and durability characteristics of these mixes are compared with the mixes without SF. Compressive strength of 110MPa at 28 days is obtained by using 10 percent replacement of cement with SF. The results also show that the SF concretes possess superior durability properties.

I.INTRODUCTION

According to Neville (2000), "HPC 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 (Metha, 1999). Addition of chemical admixtures such as super plasticizer improves the properties of plastic concrete with regard to workability, segregation etc.

II.MECHANISM OF HPC

Concrete is a three-phase composite material, the first two phases being aggregates and bulk hydrated cement paste (hcp) 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 possible by reducing water-binder (w/b) ratio and use of SF. SF improves the above properties by pozzolanic reaction and by reactive filler effect .SF contains a very high percentage of amorphous silicon dioxide which reacts with large quantity of $Ca(OH)_2$ 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 SF particles disperse in the presence of a super plasticizer to fill the voids between cement particles and accelerates the hydration of C_3S, since SF is fine reactive filler. These results in well packed, dense, strong and durable concrete mix. Due to pozzolanic reaction between SF and $Ca(OH)_2$, the large size crystals of $Ca(OH)_2$ 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 permeable concrete.

III.SIGNIFICANCE AND OBJECTIVES

The objective of the present investigation is to investigate the workability, strength and durability characteristics for HPC trial mixes of grade M110 by replacing 0, 2.5, 5, 7.5, 10, 12.5 and 15 percent of the mass of cement with SF and using a super plasticizer. Also, an attempt is made to find the optimum cement replacement level by SF for better strength and durability characteristics of HPC.

IV.EXPERIMENTAL PROGRAMME

Materials Used

1. Ordinary Portland Cement, 53 Grade conforming to IS:12269-1987.
2. SF as mineral admixture in dry densified form obtained from ELKEM INDIA (P) LTD., MUMBAI conforming to ASTM C-1240.
3. Super plasticizer (chemical admixure) based on sulphonated naphthalene formaldehyde condensate - CONPLAST SP430 conforming to IS: 9103-1999 and ASTM C - 494.
4. Locally available 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).
5. Locally available Karur river sand conforming to Grading zone II of IS:383-1970 with specific gravity 2.60 and fineness modulus 2.96 as Fine aggregates (FA).
6. Water: Drinking water supplied to Coimbatore city from Siruvani dam for concreting and curing.

Mix Proportions

Mix proportions are arrived for M110 grade HPC trial mixes based on absolute volume method of mix design (Joshi, 2001) by replacing 0, 2.5, 5, 7.5, 10, 12.5 and 15 percent of the mass of cement by SF and the material requirements per m^3 of concrete are given in Table 1.

Concrete Mixing

After weighing the materials, mixing was done in an ordinary drum type concrete mixer. Cement and SF were dry mixed prior to transfer to the mixer. Super plasticizer was added to the last liter of water to be added to the mix. Twenty four hours after casting, specimens were demoulded and transferred to curing tank.

V.DETAILS OF EXPERIMENTAL INVESTIGATIONS

Workability & Strength Related Tests

Workability tests such as slump test, compaction factor test and Vee-Bee consistometer test were carried out for fresh concrete as per IS specifications, keeping the dosage of super plasticizer as constant at 3 % by weight of binder. For hardened concrete, cube compression strength test on 150mm size cubes at the age of 1 day, 3 days, 7 days, 14 days,28 days and 56 days of curing were carried out using 3000 KN capacity AIMIL compression testing machine as per IS:516-1959. Also, compression strength and split tensile strength tests on 150mm x 300mm cylinders and flexural strength tests on 100mm x 100mm x 500mm beams were carried out on 28 days cured specimens as per IS specifications. The stress-strain graph for HPC is obtained using compressor meter fitted to cylinders during cylinder compressive strength test for finding Modulus of Elasticity for HPC mixes.

Durability Related Tests

The durability related tests such as Saturated Water Absorption (SWA) test, porosity test, sorptivity test, permeability test, acid resistance test, sea water resistance test, abrasion resistance test and impact resistance test were carried out on hardened concrete specimens at the age of 28 days of curing.

Test for Saturated Water Absorption & Porosity

The water absorption was determined on 100mm cubes as per ASTM C-642 by drying the specimens in an oven at a temperature of 105^o C to constant mass and then immersing in water after cooling to room temperature. The specimens were taken out of water at regular intervals of time and weighed. The process was continued till the weights became constant (fully saturated). The difference between the water saturated mass and oven dry mass expressed as a percentage of oven dry mass gives the SWA. The SWA of concrete is a measure of the pore volume or porosity in hardened concrete, which is occupied by water in saturated condition. It denotes the quantity of water, which can be removed on drying a saturated specimen. The porosity obtained from absorption tests is designated as effective porosity (Gopalakrishnan, 2001). It is determined by using the following formula.

Effective Porosity = (Volume of voids / Bulk volume of specimen) x 100

Test for Modified

Sorptivity measures the rate of penetration of water into the pores in concrete by capillary suction. When the cumulative volume of water that has penetrated per unit surface area of exposure 'q' is plotted against the square root of time of exposure '√t', the resulting graph could be approximated by a straight line passing through the origin. The slope of this straight line is considered as a measure of rate of movement of water through the capillary pores and is called sorptivity (Hall, 1981). In this present study, the test for sorptivity was conducted on 100mm cubes by immersing them in water and measuring the gain in mass at regular intervals of 30 minutes duration over a period of 2 hours.

Permeability Test

The tests for permeability were carried out on 100mm x 100mm cylinders as per IS:3085-1965, using a AIMIL concrete permeability apparatus and coefficient of permeability was calculated as per IS specifications.

Acid Resistance Test and Sea Water Attack Test

Cubes of 150mm size were weighed and immersed in water diluted with 1 % of sulphuric acid by weight of water and in water diluted with 3% of sodium chloride by weight of water for acid resistance test and sea water resistance test respectively for 45 days continuously and then the cubes were taken out and weighed. The percentage loss in weight and the percentage reduction in compressive strengths were calculated.

Abrasion Resistance Test

The tests for abrasion resistance were carried out on specimens of 70mm x 70mm x 35mm size, using Tile Abrasion testing machine. The specimen was kept in the abrasion testing machine after measuring the thickness accurately. The testing machine was allowed to rotate for 300 revolutions by keeping the speed of the machine as 30 rev/min. and then the specimens were taken out and weighed and final thickness were found out.

Impact Resistance Test

The tests for impact resistance were carried out on specimens of size 152mm diameter x 62.5mm thickness, using drop weight testing machine. The specimens were kept on the base plate and centered. A drop hammer weighing 45 N was used to apply the impact load. The number of blows required by dropping a hammer through a height of 457mm to cause the ultimate failure, was recorded.

VI.TEST RESULTS AND DISCUSSION

The results of workability, strength and durability related tests are listed in Table 2. The results of strength and durability tests have demonstrated the superior strength and durability characteristics of the concrete mixes containing SF .

Workability & Strength Related Properties

It was observed that the workability of concrete decreased as the percentage of SF content was increased. The optimum percentage of cement replacement by SF is 10% for strength related test for M110 grade of concrete. This is due to the fact that the increase of strength characteristics is due to the pozzolanic reaction and filler effects of SF. The flexural strength and Modulus of Elasticity values obtained experimentally are higher and lower than the values calculated by the expression 0.7 $\sqrt{f_{ck}}$ and 5000 $\sqrt{f_{ck}}$ respectively as per IS:456-2000.

Durability Related Properties

The results of durability related tests have demonstrated the superior durability characteristics of the concrete mixes containing SF.

Saturated Water Absorption, Porosity and Sorptivity

It has been observed that the optimum percentage of cement replacement by SF for M110 grade of concrete is 10% for achieving lowest SWA, porosity and sorptivity. It is also to be noted that the SWA, porosity and sorptivity of HPC mixes containing SF are lower compared to that of HPC mix without SF. This is due to the improvement in microstructure due to pozzolanic reaction and micro filler effects of SF, resulting in fine and discontinuous pore structure. The SWA and Sorptivity values of the concrete mixes were around 1.35 % and 0.043 $mm/min^{0.5}$ respectively. The Concrete Society, UK, classifies the concretes with SWA of around 3 % as good concretes. Taywood Engineering Ltd., (1993) has suggested that good concretes have sorptivity of less than 0.1 $mm / min^{0.5}$. These comparisons prove that the HPC mixes developed in the present study could be considered to have shown superior SWA and sorptivity performance.

Permeability

No percolation of water has been found for M110 grade of concrete trial mixes. Immediately after this, the cylinders were removed from the permeability mould and were split to measure the water penetration depth. Water penetration was found to be negligible in all samples of HPC mixes containing SF, whereas for the mixes without SF the depth of water penetration was more. This confirmed that use of SF and low w/b ratio had resulted in almost impermeable concrete.

Acid Resistance and Sea Water Resistance

From the results of percentage loss in weight and percentage reduction in compressive strengths, it has been observed that M110 grade of HPC trial mixes containing SF were less attacked by acid and sea water compared to the HPC mixes without SF. Hence, HPC mixes containing SF are more durable against acid and sea water attack.

Abrasion Resistance and Impact Resistance

The results of average loss in thickness obtained from abrasion resistance test and the average number of drops at failure from the impact resistance test for M110 grade of HPC trial mixes showed that the concrete mixes containing SF have higher abrasion and impact resistance. This is due to the formation of stable calcium – silicate – hydrates (C-S-H gels).

VII.CONCLUDING REMARKS

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

- Cement replacement level of 10 percent with SF in M110 grade of HPC is found to be the optimum level to obtain higher values of compressive strength, split tensile strength, flexural strength and elastic modulus and lower values of SWA, porosity and sorptivity at the age of 28 days.
- The compression failure pattern of concrete is due to the crushing of coarse aggregate and not due to bond failure.
- The use of SF and low w/b ratio resulted in practically impermeable concrete.
- Concrete mixes containing SF showed higher values of acid resistance, sea water resistance, abrasion resistance and impact resistance.
- The results of the strength and durability related tests have demonstrated superior strength and durability characteristics of HPC mixes containing SF. This is due to the improvement in the microstructure due to pozzolanic action and filler effects of SF, resulting in fine and discontinuous pore structure.
- 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 10% would render the concrete more strong and durable. This observation is in par with the maximum limit of 10% for mineral admixture in concrete mixes as recommended by IS:456-2000.

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Table 1 Details of HPC Trial Mixes for M110 Grade

Mix	SF (%)	w/b ratio	Cement (kg)	SF (kg)	FA (kg)	CA (kg)	Super plasticizer (lit)	Water (lit)
M80 Grade								
C1	0	0.232	625.00	0	666.30	1070	15.37	138.75
C2	2.5	0.232	609.40	15.60	660.70	1070	15.37	138.75
C3	5	0.232	593.70	31.30	655.20	1070	15.37	138.75
C4	7.5	0.232	578.10	46.90	649.60	1070	15.37	138.75
C5	10	0.232	562.50	62.50	644.00	1070	15.37	138.75
C6	12.5	0.232	546.90	78.10	638.50	1070	15.37	138.75
C7	15	0.232	531.20	93.80	632.90	1070	15.37	138.75

Table 2 Strength and Durability Related Properties of HPC Mixes for M110 Grade

Properties	C1	C2	C3	C4	C5	C6	C7
Silica Fume (%)	0	2.5	5	7.5	10	12.5	15
Cube compressive strength (MPa)							
1 day	31.78	38.14	41.22	43.55	50.66	49.58	45.12
3 days	49.24	56.89	57.07	64.22	72.38	66.96	65.50
7 days	68.87	75.75	79.22	88.33	93.66	88.11	85.38
14 days	78.38	85.07	88.74	93.55	106.22	102.68	101.11
28 days	91.22	97.80	103.22	108.66	121.22	115.22	112.46
56 days	99.15	105.40	109.66	116.75	126.20	120.88	118.33
Cylinder compressive strength (MPa)							
28 days	71.06	77.16	82.35	86.92	98.14	91.60	89.65
Split tensile strength (MPa)							
28 days	6.20	6.72	7.55	7.94	8.45	8.21	8.05
Flexural strength (MPa), 28 days	8.90	9.40	9.80	10.10	10.90	10.30	9.70
Elastic modulus (GPa), 28 days	39.7	40.6	40.9	41.4	44.4	43.1	42.9
Slump (mm)	29	28	27	25	24	17	14
Compaction factor	0.90	0.88	0.86	0.84	0.83	0.80	0.75
Vee-Bee degrees (secs)	16	18	19	19	21	55	65
S.W.A (%)	1.35	1.25	1.20	1.10	1.05	1.10	1.15
Porosity (%)	2.50	2.30	2.15	2.05	1.95	2.00	2.10
Sorptivity(mm/min$^{0.5}$)	0.043	0.0215	0.0195	0.0175	0.0140	0.0170	0.0185
Permeability (cm/sec)	nil	nil	Nil	nil	nil	nil	nil

Acid resistance							
Loss in wt. (%)	2.55	1.20	1.10	1.00	0.90	0.85	0.80
Loss in comp.st.(%)	10.25	4.50	4.05	3.50	3.00	2.75	2.70
Sea water resistance							
Loss in wt. (%)	2.15	1.00	1.95	1.85	0.80	0.75	0.75
Loss in comp.st.(%)	8.50	3.35	3.05	2.90	2.60	2.50	2.35
Abrasion resistance							
Average loss in thick(mm)	1.65	1.10	1.05	0.95	0.85	0.80	0.75
Impact resistance							
Average number of drops at failure	230	240	246	260	275	286	308