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Effect of silica fume on the resistance to chloride ion penetration in high performance concrete

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Abstract: - The structures constructed during the past several decades have suffered from safety and serviceability problems due to deterioration of concrete and thus the durability of concrete has received significant attention. Therefore, in order to improve the durability of concrete, the mixture proportions of concrete should be carefully selected considering the effects on durability. In this paper M50 grade high performance concrete (HPC) for 5percent, 7.5percent, 10percent and 12.5percent replacement of cement with silica fumes was prepared and tests have been conducted to find its mechanical properties and resistance to chloride ion penetration. Conventional permeability test methods like water permeability test or gas permeability test cannot be applied to high-performance concrete because it is very dense and impermeable. Therefore rapid chloride permeability test method (RCPT) was adopted for determining the durability property of HPC. It was found that as percentage replacement of silica fume increases chloride ion penetration decreases.

Keywords: - *High performance concrete, Silica fume, Durability, Chloride ion, RCPT*

I.   INTRODUCTION

Recently, a large number of concrete highway bridges, concrete dams and nuclear power plants and other offshore structures have been actively constructed in many countries. These structures have suffered from safety and serviceability problems due to deterioration of concrete, and therefore the durability of concrete has assumed attention. The durability of cement concrete according to Ghorpade and Rao. [1] is defined as its ability to resist weathering action, chemical attack, or any other process of deterioration. The incorporation of pozzolanic materials such as Pulverised Fuel Ash (PFA) and Silica Fume (SF) has been reported to decrease the permeability; thereby increasing the resistance of concrete to deterioration by aggressive chemicals such as chlorides as discussed by Khan [2].Durable concrete will retain its original form quality, and serviceability when exposed to environment. Deterioration, long-term poor performance and inadequate resistance to hostile environment coupled with greater demands for more sophisticated architectural form led to the accelerated research into the microstructure of cements and concretes and more elaborate codes and standards. As a result, innovation of supplementary materials and composites has been developed. The penetration of water, chloride and other aggressive ions into concrete is the most important factor in the physical and chemical process of deterioration, and it is the microstructure of concrete that mainly controls the physical/chemical phenomena associated with water movements and the transport of ions in concrete. The microstructure of concrete is strongly affected by several factors including chemical composition of cement, water-to-cement ratio, types and amounts of mineral admixtures and particle size distribution of cementitious materials and aggregates. Therefore, in order to improve the durability of concrete, the mixture proportions of concrete should be carefully selected considering the effects on durability. [3]

American Concrete Institute defines High Performance Concrete as "Concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing and curing practices". The requirements may involve enhancements of characteristics such as placement and compaction without segregation, long-term mechanical properties, and

early age strength or service life in severe environments. Concretes possessing many of these characteristics often achieve High Strength, but High Strength concrete may not necessarily be of High Performance. [4]

II.   SCOPE OF THE STUDY

Since high resistance to chloride ion penetration can be directly related to low permeability that dominates the deterioration process in concrete structures, the resistance to chloride ion penetration is one of the simplest measures to determine the durability of concrete. In this study comprehensive tests have been conducted to find the mechanical properties and resistance to chloride ion penetration of M50 grade HPC for 0percent, 5percent, 7.5percent, 10percent and 12.5percent replacement of cement with silica fumes. Rapid chloride permeability test (RCPT) method was adopted to find the chloride ion penetration of concrete after finding the mechanical properties.

III.   EXPERIMENTAL INVESTIGATION

Determination of properties of materials

The constituent materials consist of Portland Pozzolana Cement (PPC) of standard consistency 34 percent, specific gravity 2.9 with 28 day compressive strength 33MPa, quarry sand confirming to Zone II of IS:383 [5] as fine aggregate, and coarse aggregate of 20mm nominal size. The water absorption of natural coarse aggregate was found to be 1 percent. Tests were conducted as per IS 2386 -part III [6] for fine aggregate and as per IS:383[5] for coarse aggregate to determine the different physical properties and are tabulated in Table 1. The superplasticizer used was CONPLAST SP-430 of specific gravity 1.18 and the specific gravity of silica fume used was 2.2. The chloride and sulphide content in water were found to be 17.5mg/l and 8mg/l respectively. Mechanical properties, namely, compressive strength, tensile strength, modulus of elasticity and modulus of rupture were determined.

Table 1 Properties of coarse and fine aggregates

Properties	Fine aggregate	Coarse Aggregate
Specific gravity	2.70	2.76
Sieve analysis	Conforming to zone II of IS:383(1970)	Conforming to 20 mm graded aggregate IS:383(1970)
Water absorption	1.75 percent	0.75 percent
Bulk density	1710 kg/m^3	1540 kg/m^3
Fineness Modulus	2.75	5.99

Mix proportioning

Proportioning of constituents was carried out by the method proposed by Aïtcin. The method follows the same approach as American Concrete Institute ACI 211–1[7] Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete. It is a combination of empirical results and mathematical calculations based on the absolute volume method. The water contributed by the superplasticizer is considered as part of the mixing water. The mix proportions for various mixes for 1m3 concrete are given in Table.2.

Workability tests were conducted using slump test, for fresh concrete as per IS specifications, keeping the dosage of superplasticizer as constant at 1 percent by weight of binder. For the compressive strength determination, 150mm x150mm x 150mm specimens were used.150mm diameter and 300mm height cylinders were used for determining the split tensile strength and modulus of elasticity. For finding the flexural strength, prisms of size 100mmx100mm x500mm were used. All the specimens were moist cured underwater at room temperature until testing.

Table 2 Mix proportion for various mixes

weight replacement ratio of Silica Fume (percent)	Admixture (Liters)	Water (kg)	Cement (kg)	Silica Fume (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)
0	9.5	163	455	0	1070	790
5.0	9.5	163	432	23	1066	787
7.5	9.5	163	421	34	1064	785
10.0	9.5	163	410	45	1062	784
12.5	9.5	163	398	57	1060	782

RCPT test for finding the chloride ion penetration

In order to find the chloride ion penetration of HPC, RCPT was conducted as per ASTM C 1202[8] as shown in Table 3. Specimens of size 100mm diameter and 50mm thick were prepared for 0percent, 5percent, 7.5percent, 10percent and 12.5percent replacement of cement with silica fumes. After 28 days of curing, the specimens were coated with epoxy and were vacuum saturated for 3 hours and then soaked for 18 hours. Fig 1 shows the experimental setup for vacuum curing. The specimens were then placed in the testing apparatus, where one end of the specimen is exposed to a solution containing sodium chloride (NaCl) and the other end is exposed to a solution containing sodium hydroxide (NaOH). To increase the rate of chloride ion penetration into the specimen, thus speeding up the test, a constant 60 V potential is applied across the specimen.

Fig 2 shows the experimental setup of RCPT. The current across the specimen is measured at an interval of 30 minutes during the 6-hour test. Using the values obtained the total charge passed through the specimen was calculated as per ASTM C 1202 [8]. This charge is then multiplied by correction factor as per ASTM C 1202 [8]. Results obtained were then compared with standard values and are shown in Table 7. Berke's equation given in Santhakumar.et.al [4] was used to calculate the Chloride Migration Diffusion Coefficient.

$$D_c = 0.0103 \times 10\text{-}12 \times Q_s\ 0.84 \qquad \text{Santhakumar et al. [4]}$$

Table 3. Chloride ion penetrability based on charge passed

Charge passed(coulombs)	Chloride ion penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

IV.   RESULTS AND DISCUSSIONS

Mechanical Properties

The results of different tests such as cube compressive strength, cylinder compressive strength, flexural strength, and modulus of elasticity for different percentage replacement of silica fume is given in Table 4. All the test results show an increasing trend up to a replacement ratio of 7.5 percent. This is due to the fact that the increase of strength characteristics is due to the pozzolanic reaction of amorphous silca present in the silica fume. The strength of concrete is found to be decreasing when the replacement ratio is greater than 7.5 percent. The CaO content in the silica fume is relatively lower compared to cement. Hence, the strength shows a decreasing trend when cement is replaced with silica fume above 7.5 percent.

Fig 1 vacuum curing

Fig 2 Test setup

Table 4 Strength test results for varying silica fume percentage

weight replacement ratio of silica fume (percent)	Cube Compressive Strength (N/mm^2)	Cylinder Compressive Strength (N/mm^2)	Split Tensile Strength (N/mm^2)	Flexural Strength (N/mm^2)	Modulus of Elasticity (x10^3 N/mm^2)
0	54.0	42.0	3.1	9.4	33.0
5.0	61.0	46.0	3.2	6.9	32.5
7.5	62.5	49.5	3.6	7.4	35.5
10.0	60.0	48.5	2.9	6.2	34.0
12.5	54.0	41.5	2.8	5.4	30.0

RCPT test results

The current across the specimen is measured at an interval of 30 minutes during the 6-hour test. Using the values obtained the total charge passed through the specimen was calculated as follows.

Calculated Charge, $Q_x = 900(I_0 + 2I_{30} + 2I_{60} + 2I_{90} + \ldots + 2I_{300} + 2I_{330} + I_{360})$ where $I_0, I_{30}, I_{60}, I_{90}$ etc. are current reading in amperes at 30 minutes interval after voltage is applied

This charge is then multiplied by correction factor as per ASTM C 1202 (2002).

Corrected Charge, $Q_s = Q_x (3.75/x)2$, where x = Diameter of the specimen in inches

$Q_s = Q \times (3.75/3.94)2 = 0.9 Q_x$

The total charge passed though each specimen and Chloride Migration Diffusion Coefficient Dc is given in Table 5. Fig 3.shows the graph between percentage replacement of silica fume and current passed through each specimen. The total current passed through the concrete specimen is found to be decreasing with increase in percentage replacement. The Chloride Migration Diffusion Coefficients show that the specimen with higher silica content has the lowest diffusion coefficient and vise versa. From this, it can be inferred that the chloride ion penetration and the diffusion coefficient decreases as the replacement percentage increases. It can be inferred that the good chloride resistance of silica fume blended concretes is due to the high refinement of the pore structure of concrete.
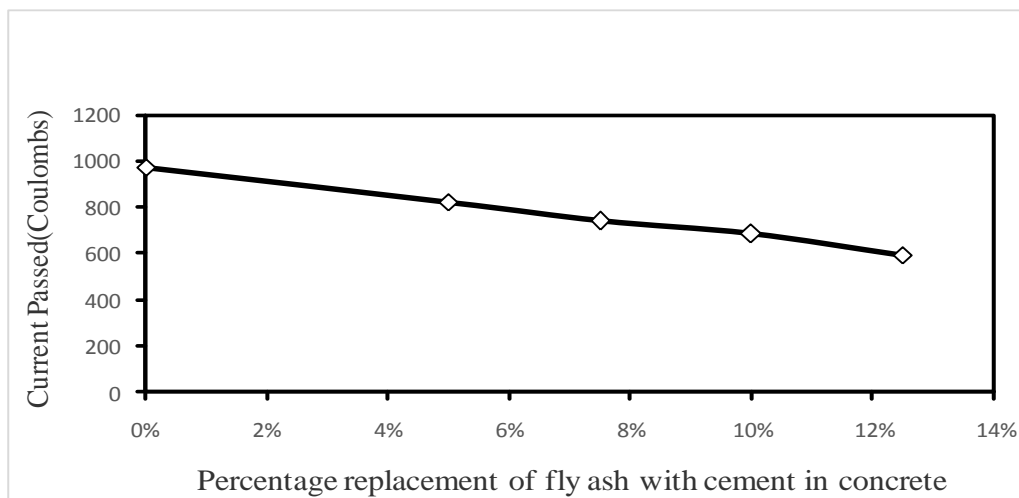

Fig 3 Effect of replacement of cement with fly ash on current passed in RCPT test

Table 5 Current passed through each specimen and Diffusion coefficient

Replacement of cement with silica fume (percent)	Calculated Charge (Coulombs)	Corrected Charge (Coulombs)	Chloride Ion Penetration	Chloride Migration Diffusion Coefficient (Dc)
0	1082.7	974.43	Very Low	3.34 x 10^{-12}
5.0	917.1	825.4	Very Low	2.90x 10^{-12}
7.5	823.5	741.1	Very Low	2.65 x 10^{-12}
10.0	774.3	686.8	Very Low	2.48 x 10^{-12}
12.5	661.5	595.4	Very Low	2.20x 10^{-12}

V.   CONCLUSION

The following conclusions have been drawn from the test results.

1. The increase in strength of the concrete up to 7.5 percent replacement of cement with silica fume is found to be significant. Hence the optimum replacement percentage of cement with silica fume may be taken as 7.5 percent.
2. The total current passed through the concrete specimen is found to be decreasing with increase in percentage replacement of cement with silica. Hence it may be concluded that the addition of the silica fume reduces the permeability or increases the durability of concrete.
3. The total charge passed is calculated according to the ASTM C 1202 [8]and charge passed through all the specimens were found to be in the range of 100 to 1000 coulombs, i.e. chloride ion penetration of all the specimens are very low which shows concrete containing silica fume is highly durable concrete.

VI.   ACKNOWLEDGMENT

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