Study of Permeability and Compressive Strength of Silica Fume Concrete

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Study of Permeability and Compressive Strength of Silica Fume Concrete

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Abstract*— *Qualitatively permeability within concrete may be defined as the ease with which water, air and other substances such as chloride ions or contaminants pass through the concrete pore structure. In general, the relative magnitude of permeability for a given permeant (water, air or any other ion/ salt contaminant) may act as a prima facie indicative parameter of durability of concrete. More the permeability, lesser may be the durability. As durability governs the service life of the structure, thus permeability indirectly affects the service life of the structure. Besides, in relation to durability, permeability invariably becomes a very important aspect for the design of over-head tanks, water retaining structures and open flat roofs where permeability of concrete becomes objectionable. As such making concrete least permeable without harming its compressive strength is of a primal importance for researchers.

Present state of knowledge about permeability and methods to decrease it are discretely available from literature. Few pozzolanic materials have been reported to decrease the permeability remarkably.

Efforts in this experimental study were primarily aimed at evaluating effect of Silica Fume on important characteristic properties of hardened concrete like crushing strength and permeability. The study was also aimed at optimizing the weight of cement replacing additive (% by weight of the cement), which may be required to cause favorable effects like relatively impermeable concrete, without compromising the strength aspect of the hardened concrete mix. With potential optimization of replacement, the study may also serve as a contrast/guideline, for relative effectiveness of Silica Fume Concrete over conventional Portland Cement Concrete.

Index Terms*— *Concrete Permeability, Epoxy Sealing, Permeability cell, Silica Fume, Superplasticizer

I. INTRODUCTION

Today concrete is one of the most widely used, manufactured, construction material in the world because of its many valuable properties such as high compressive strength, stiffness, low thermal and electrical conductivity and low combustibility and toxicity. The durability/ permeability of concrete have proven to be a formidable obstacle in the service life of new and existing structures. Permeability is governed by the capillary pores in the cement paste. It is known that permeability controls deterioration of concrete in aggressive environments, because the processes of such deterioration like carbonation, chloride attack and sulfates attack are governed by the fluid transportation in concrete pore structure.

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Fillers and pozzolanic materials are introduced to improve the strength and other properties of concrete for necessary conditions [1].

Ordinary Portland Cement (OPC) being one of the main ingredients used for the production of concrete, has no alternative in the civil construction industry. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming, hence it is necessary either to search for another material or partly replace it by some other material [2]. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact.

To deal with above mentioned problems, pozzolanic materials such as; Fly ash, Ground Granulated Blast furnace Slag, Rice husk ash, High Reactive Metakaolin, *Silica Fume* can be used in concrete as partial replacement of cement [3]. The American Concrete Institute defines Silica Fume as "very fine non- crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon" . It is usually a grey colored powder, with an average diameter of about 0.1 μm.

The hydration of Portland cement produces many compounds including calcium silicate hydrates (CSH) and calcium hydroxide (CH). The CSH gel is known to be the source of strength in concrete. When Silica Fume is added to fresh concrete it chemically reacts with the CH to produces additional CSH, imparting more strength to hardened concrete. Apart from this since Silica Fume is 100 to 150 times smaller than cement particle it can fill the voids created by free water in the matrix rendering a least permeable concrete.

Thus addition of silica fume to concrete improves the durability of concrete through reduction in the permeability, refined pore structure, leading to a reduction in the diffusion of harmful ions, reduces calcium hydroxide content which results in a higher resistance to sulfate attack. Improvement in durability will also improve the ability of silica fume concrete in protecting the embedded steel from corrosion [4]. Khaloo and Houseinian [5] investigated the influence of Silica Fume on compressive strength and durability of concrete. The percentage of Silica Fume used was between 1% to 15% and the water-cement ratios ranged from 0.3 to 0.6. The coarse and fine aggregate consisted of river gravel and sand with maximum size of 25 mm and 5 mm, respectively. The test results indicated 5 to 10% by weight replacement of Silica Fume for cement provided the highest strength for short and long terms. Compressive strength of Silica Fume concrete at 28 days compared to conventional concrete increased by 20 to 40 per cent, for all the variables considered. Also the concrete containing silica fume was more durable than the reference sample concrete.

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Duval and Kadri [6] observed that Silica Fume increased both compressive strength (25%) and the workability of concretes when its content was between 4 and 8 %. And both compressive and tensile strength is reduced when silica fume content exceeds 15%.

In present research study Silica Fume was incorporated as replacement for Portland Cement in the percentage of 5, 10 and 15 (by weight of cement), to evaluate its effect on permeability of water (as permeant) through hardened concrete pore structure. Wherever required to maintain uniform workability of all the mixtures, superplastisizer in suitable dosage was added. Compressive Strength and Permeability tests were conducted on the samples and an optimum Silica Fume content was determined.

II. EXPERIMENTAL PROGRAM

In this study four mixtures; one control and three Silica Fume concrete (SFC) samples, were prepared in each casting. Water cement ratio of 0.33 was kept constant for all the mixtures and was maintained by addition of suitable dose of superplastisizer in mixtures containing Silica Fume. Silica Fume was used in the content of 5%, 10% and 15% as replacement by weight of cement. The addition of superplastisizer was purely done on the basis of requirements for workability. A total of 56 cubes were casted in a total of 9 castings. For each mix 14 cubes of size 150mm x150mm x150mm were prepared, of which 4 were used for conducting permeability test, 10 for 7 and 28 day compressive strength test. The workability of fresh concrete for each casting was checked to ensure an approximate uniform workability. The samples were cured and then tested for compressive strength and permeability. The results were analyzed and conclusions were drawn.

A. Material

Ordinary Portland Cement (OPC) 43 Grade (Khyber cement) was used with fineness 2.3%, standard consistency 28%, initial setting time of 1 hour 53 min, final setting time of 5 hour 9 min, soundness 1.67 mm, 7- day compressive strength 32.38 N/mm^2 and 28- day compressive strength of 45.47 N/mm^2. Values obtained from various tests conducted on cement as per standard procedures [7], [11], [12]. Good Quality River sand passing through 4.75 mm IS sieve, conforming to grading zone-II [8] was used as fine aggregate. Crushed natural rock stone aggregate available from local sources were used as coarse aggregates in two sizes 20 mm and 10 mm. Sieve analysis was performed as per standard procedures [8] and fineness modulus of 8.1868 and 5.9562 were obtained for 20 mm and 10 mm aggregates, respectively. Other tests conducted on Coarse Aggregates and the values obtained from each test are given in Table I. Tap water conforming to IS Code was used for mixing as well as curing of concrete specimens. The pH of water was checked by using litmus paper and the pH was 6.4. Silica fume used had an average relative density of 2.3, specific gravity 2.27, bulk density (densified) 625 kg/m^3, bulk density (undensified) 550 kg/m^3, as specified by principal manufacturer. Water reducing superplastisizer namely cico visco plast was used to maintain workability of fresh concrete.

Table I. Properties of coarse aggregates.

S.No.	Test	Property	Obtained Values
1.	Aggregate Crushing Value Test	Strength	10 %
2.	Los Angeles Abrasion Test	Hardness	9 %
3.	Aggregate Impact Test	Toughness	7 %
4.	Shape Test	Elongation Index	20%
		Flakiness Index	25 %

B. Mixture Proportioning

The various mixture proportions used in this study are given in Table II. In SFC, 75% of water was first added to coarse aggregates and mixed thoroughly, to this Silica Fume was added and mixed for 1.5 minutes then cement and sand were added and all the ingredients were washed with remaining 25% of water containing Cico Viscoplast [9].

Table II. Various mix proportions (kg/m^3).

Mix ID	C	FA	CA	W/C	SF (%)	SF	SP (%)
PC	400	600	1200	0.33	0	0	0
5SF	380				5	20	0.3
10SF	360				10	40	0.4
15SF	340				15	60	1.4

PC: Plain concrete W/C: water to cement ratio
SF: Silica Fume C: Cement
FA: Fine Aggregates CA: Coarse Aggregates
SP: Superplastisizer

C. Tests Conducted

Workability Test: Slump test and Compaction Factor test were conducted on fresh concrete to ensure medium workability in all the mixes.

Compressive Strength Test: It was conducted on cubes which were loaded on their opposite faces in a Compression Testing Machine (CTM).The load at which first crack appeared, was considered as failure load and the compressive strength was calculated corresponding to that load (Fig 1).

Fig. 1 – Sample at failure.

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Permeability Test: The aim of the test was to subject the sealed concrete sample, contained in a specially designed cell called permeability cell (Fig. 2a), to a known hydrostatic pressure from one side, measuring the quantity of water consumed by the sample during a fixed (72 hours) time. Samples were sealed on four sides using epoxy sealant (Dr. Fixit product).The test was conducted as per standard guidelines [10]. The specimen was kept under pressure of 10 kg/cm^2 for 72 hours. The permeability machine that was used comprised of three water reservoirs, dials, valves (Fig. 2b) and a compressor. Each of the reservoir columns was calibrated. Calibration was done at a pressure of 5 kg/cm^2. The calculations are presented in the Table V. The drop in calibrated water columns, corresponding to each specimen was noted in terms of number of divisions of the scale. This dip (d) was then multiplied with the calibration constant (C) of respective reservoir to get the volume of water in milliliters intruded in the sample [10]. Refer Table VI.

Fig. 2(a) – Permeability Cell.

Fig. 2(b) – Parts of Permeability Machine showing pressure dials, valves, water columns and installed assembly of samples.

Fig. 2(c) – Sealing of sample using Epoxy sealant.

III. RESULTS AND DISCUSSIONS

Table III. 7-Day Compressive Strength of Concrete Mixtures (N/mm^2).

Casting No.	Designation			
	PC	5SF	10SF	15SF
1	24.99	33.61	34.35	28.87
2	25.2	32.90	35.15	28.31
3	25.25	35.02	35.02	26.80
4	26.13	34.69	35.74	27.60
5	25.2	33.89	34.96	29.13

Table IV. 28-Day Compressive Strength of Concrete Mixtures (N/mm^2).

Casting No.	Designation			
	PC	5SF	10SF	15SF
1	36	49.33	49.78	40.44
2	35.56	49.55	50.22	40.67
3	36.22	49.42	49.33	40
4	37.33	49.33	50.67	40.44
5	36.89	49.11	51.8	41.67

Table III and IV shows that the maximum 7 and 28 day Compressive Strength of control concrete is 26.13 N/mm^2 and 37.33 N/mm^2 respectively. From Table III, Table IV, Fig. 2 and Fig. 3 it is clear that all the SFC samples have more Compressive Strength than PC and the 7 day and 28 day Compressive Strength of SFC is maximum for 10SF followed by 5SF and 15SF. 7 and 28 day compressive strength increased to a maximum by 38.22% and 38.35% respectively. The high strength obtained in SFC is attributed to the fact that Silica Fume is a highly pozzolanic substance which consumes the by product, lime, formed during the hydration of cement, which otherwise leaches out of concrete body at later stages leaving behind pores which make concrete weak and reduces its strength.

Table V. Calculation of Reservoir Constants (C).

S.No.	Parameters	Column 1	Column 2	Column 3
1	Initial reading (cm)	6.9	9.5	2
	Final reading (cm)	15.1	17.1	7.4
	Drop (cm)	8.2	7.6	5.4
	Volume (ml)	217	200	136
	Volume/mm	2.65	2.63	2.52
2	Initial Reading (cm)	12.8	14.4	7.7
	Final Reading (cm)	20.9	21.9	12.8
	Drop (cm)	8.1	7.5	5.1
	Volume (ml)	215	220	135
	Volume/mm	2.65	2.93	2.65
3	Initial Reading (cm)	21	23.2	13
	Final Reading (cm)	29.2	30.7	18.3
	Drop (cm)	8.2	7.5	5.3
	Volume (ml)	220	205	138
	Volume/mm	2.68	2.73	2.60
	Average Value of Calibration Constant (C)	2.66	2.763	2.625

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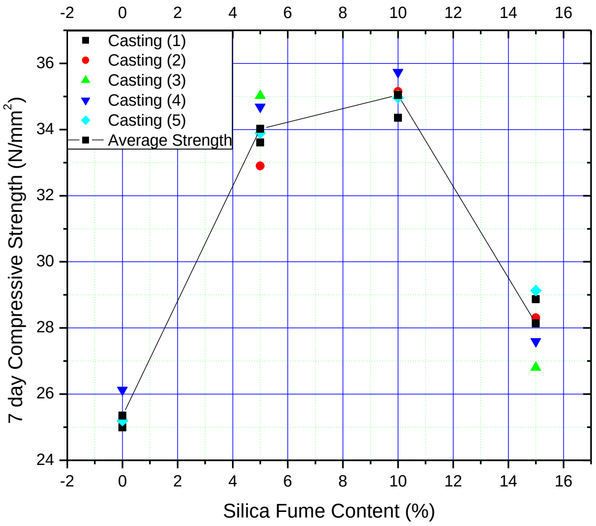

Fig. 2 – Effect of Silica Fume Content on 7 day Compressive Strength.

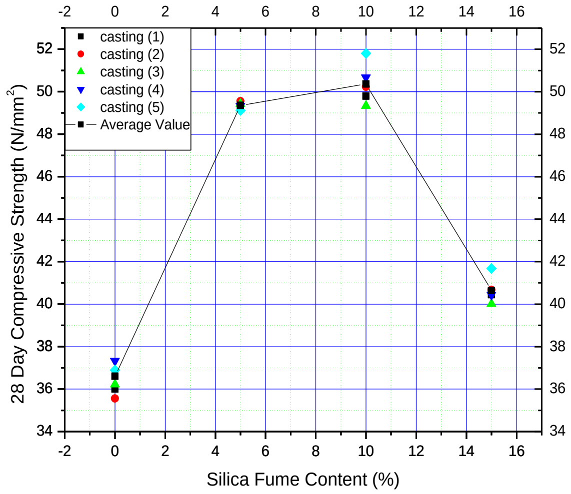

Fig. 3 – Effect of Silica Fume Content on 28 day Compressive Strength.

Table VI. Calculation of Average Volume of water (V) in ml Consumed by various samples in 72 hours.

Mix ID	d (in mm)	(C) (ml/mm)	V (in ml) = d x C	Average V (in ml)
PC	93	2.66	247.38	247.57
	91.92	2.763	254	
	90.22	2.66	240	
	89.53	2.763	247.38	
5SF	42	2.763	116.05	117.725
	44.26	2.763	117	
	43.49	2.66	118	
	44.51	2.625	116.85	
10SF	41.56	2.66	110.56	110.66
	42.13	2.763	116.42	
	39.92	2.625	104.81	
	41.66	2.66	110.84	
15SF	38.32	2.763	105.89	106.14
	36.51	2.763	100.89	
	41.65	2.66	110.79	
	40.76	2.625	107	

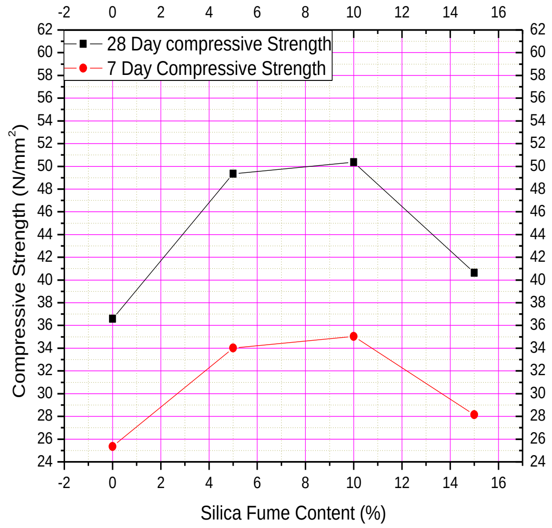

Fig. 4 – Comparative graph showing effect of Silica Fume Content on 7 and 28 Day Compressive Strength.

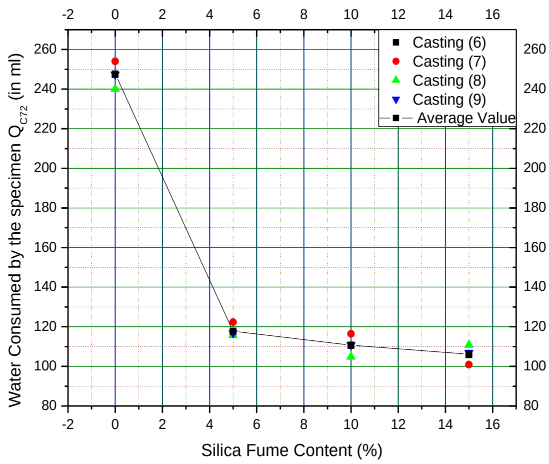

Fig. 5 – Effect of Silica Fume Content on water consumed by the sample in 72 hours.

An indicative parameter of permeability in terms of water intruded into the sample in 72 hours was measured. Table VI and Fig. 5 indicate that higher the Silica Fume content in the concrete lesser is the water intrusion into the specimen. 15SF consumes least amount of water (106.14 ml), followed by

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10SF, 5SF and lastly PC (247.57 ml). Silica Fume being very small in size fills into the voids and results in dense packing of concrete, rendering it less porous and reducing water permeability. Permeability was reduced to a maximum by 57% by incorporating Silica Fume (15%) as a partial replacement by weight of cement into the concrete.

IV. CONCLUSION

Permeability in terms of water intrusion is least for 15SF. With the increase in SF content, permeability decreases. The optimum SF content to get least permeable concrete without adversely affecting its compressive strength is 15% as partial replacement by weight of cement. At this content of SF since workability is remarkably reduced, use of superplastisizer is necessary.

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