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High Strength Silica Fume Concrete: A Wonder of Construction Industry

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Abstract—*High strength and high performance concrete are being widely used in various civil engineering practices. Most applications of high strength concrete have been in high rise buildings, long span bridges and some special structural applications. The use of high strength concrete would result in both technical and economical advantage. In high strength concrete it is necessary to reduce the water binder ratio, which in turn will increase the binder content. Superplasticizers are used to achieve the desired workability. There are two types of mineral admixtures which are commonly mixed into the Portland clinker. They can be categorized as crystalline, which are also known as hydraulically inactive additions and pozzolanic which are hydraulically active additions. Silica fume is one of the popular pozzolans used in concrete to get improved properties. The use of silica fume in conjunction with superplasticizers has become the backbone of high strength and high performance concrete. Silica fume is very reactive pozzolan, which is used in concrete because of its fine particles, large surface area and high SiO_2 content. A detailed experimental investigation has been carried out to study the effect of silica fume in conjunction with superplasticizers on some of the properties of fresh concrete. The investigation revealed that by maintaning a constant dosage of high performance superplasticizer along with silica fume, it is possible to maintain a optimum slump value i.e. workability, thereby satisfying most of the modern structural applications.*
Also the isolated effects of silica fume on the different strength parameters of silica fume concrete over a wide range of water cementitious material ratio ranging from 0.30 to 0.42 has been studied. The results indicate that there is a remarkable increase in the compressive strength of concrete with respect to control on replacement of cement by silica fume.

Keywords*: High strength concrete, silica fume, water binder ratio, compressive strength, mix proportions etc.*

1. INTRODUCTION

Concrete production exists around the globe and is one of the leading construction material, essentially man made stone that has become a most versatile and universally recognised tool to build with. Concrete is a widely used structural material which essentially consists of a binder and a mineral filler. It has the unique distinction of being the only construction material which is manufactured actually on the site, whereas other materials are merely shaped and fabricated and eventually assembled at site. Ever since the time of Romans, there has been a continuous effort by the research workers in the field of cement and concrete technology to produce better quality cement resulting in concretes of overall improved quality. The introduction of reinforced concrete as an alternative to steel construction, in the beginning of 20th century, necessitated the developement and use of low and medium strength concretes. In keeping with the demands of the nuclear age, high density concrete has been successfully used for the radiation shielding of highly active nuclear reactors. Considerable progress has been achieved in the design and use of structural light weight concretes, which have the dual advantage of reduced density coupled with increased thermal insulation. With the present state of knowledge in the field of concrete mix design, it is possible to select and design concrete capable of resisting heat, sea water, frost and chemical attack arising out of industrial effluents.

Nowadays silica fume is almost invariably used in the production of High Performance Concretes. In future, high range water reducing admixtures (Superplasticizers) will open up new possibilities for the use of such material as partial replacement of cement to produce and develop high strength concrete, as some of them are much finer than cement. The existing literature is rich in information on silica fume concrete and after performing a detail review of the research papers published over the last two decades, the objective of the present study was framed. The present investigation is an effort towards developing a better insight into the isolated effect of silica fume on the different strength parameters of silica fume concrete over a wide range of water cementitious material ratio ranging from 0.30 to 0.42 and silica fume replacement percentages of 0, 5, 10 and 15 by weight of total binder with high range water reducing admixtures for optimizing its effect on concrete.

The results indicate that there is a remarkable increase in the compressive strength of concrete with respect to control on replacement of cement by silica fume. The optimum level of replacement depended on the water cement ratio and age of testing and it was obtained in the range of 10-12%.

2. AIMS AND OBJECTIVES

The use of silica fume in combination with a superplasticizer is nowadays a usual way to obtain high strength concrete. The effect of silica fume in concrete have attracted the attention of researchers throughout the world.

Based on the guidelines of the previous work and need for further research to explore the ever expanding field of silica fume concrete, the following objectives are outlined:

- To study the isolated effect of silica fume in concrete keeping other mix design factors almost constant. Cement will be replaced by silica fume over a wide range of water/binder ratios and replacement percentages. As the mix design factors remains almost unchanged, the changes in concrete properties will occur primarily due to silica fume replacements. Since the SP contents of all the mix will be kept constant, to eliminate the interference of workability, the compaction energy will be varied for obtaining proper compaction. The time of compaction will vary, more for stiff concretes and less for flowing concretes.
- To determine the influence of microsilica on the compressive strength of concrete, rate of evolution of strength and percentage gains with respect to control concrete.

3. SIGNIFICANCE OF THE PRESENT RESEARCH WORK

There are many important parameters which needs to be explored in detail. The isolated effect of silica fume in concrete and the optimum silica fume replacement percentage still calls for detailed investigations to ensure the maximum utilization of silica fume in concrete. The present work aims at a deeper insight into the effect of cement replacement by silica fume in concrete over a wide range of water-cementitious material ratios and silica fume replacement percentages.

4. EXPERIMENTAL PROCEDURE

The present research is aimed at investigating the effect of silica fume on the properties of concrete in the fresh and hardened state. Concrete at diffferent water/binder ratio ranging from 0.30 to 0.42 will be prepared. At each water/binder ratio, cement will be replaced by silica fume @0 to 15%. All the concretes will be tested in the fresh states as per relevant Indian Standards and their properties will be determined. Accordingly the effect of silica fume on cement replacements will be determined. The workability of the silica fume concretes depends on a host of parameters. The present investigation is aimed to determine the isolated effect of silica fume on concrete as a result of which the mix variables like quality of ingredients, mix proportions, curing conditions, dosage of SP etc. have been kept constant. The fundamentals of the present investigation is not to arrive at a particular strength or workability but to study the effect of silica fume on the rheological properties of concrete and also the strength parameters of hardened concrete and to determine the optimum silica fume replacement percentage to maintain the desired workability, so as to satisfy most of the modern structural applications. Therefore the effect of cement replacement by silica fume was studied over a wide range of water/binder ratio (0.30 to 0.42) and over a wide range of cement replacements (0-15%).

5. MIX PROPORTION

According to Shah and Ahmad (1994) for proportioning of high strength concretes, mostly purely empirical procedures based on trial mixtures are used and the trial mix approach is best for proportioning high strength concretes. Any mix proportioning method for High Strength Concrete is yet to be universally accepted. The Indian Standard- "Recommended Guidelines for Concrete Mix Design"(IS-10262) is meant for the design of low to medium strength concretes but does not include the design of concrete mixes when pozzolans and admixtures are used. Therefore for arriving at the reference mix, the basic principles on which high strength concrete mix should be based were considered and the proportions of a number of mixes incorporating silica fume as reported in the literature were reviewed. Since the strength of silica fume concretes depend on a host of parameters, in order to study the effect of silica fume only, the others were to be kept constant. Hence the mix proportion as well as the dosage of SP were to be kept constant as in the reference mix. For High Strength Concrete the content of cementitious material is higher ranging from 500-650 kg/m^3 (Shah and Ahmad,1994). For the present investigation the binder content will be maintained at 525 kg/m^3. Coarse aggregate and fine aggregate were maintained at a ratio of 60:40 for obtaining the maximum packing density. The detailed mix proportion is presented in the table 01:

Table 1: Detailed Mix Proportion

Mixes	W/B	Cement (Kg/m^3)	Silica Fume		Aggregates (Kg/m^3)		Water (Kg/m^3)
			%	(Kg/m^3)	Fine	Coarse	
SFC 01	.30	525	0	0	724	1086	157
SFC 02		498	5	26.2	720	1080	
SFC 03		472	10	52.5	716	1075	
SFC 04		446	15	78.7	712	1069	
SFC 05	.34	525	0	0	701	1052	178
SFC 06		498	5	26.2	698	1047	
SFC 07		472	10	52.5	694	1041	

SFC 08		**446**	**15**	**78.7**	**690**	**1035**	
SFC 09	**.38**	**525**	**0**	**0**	**679**	**1019**	**199**
SFC 10		**498**	**5**	**26.2**	**675**	**1013**	
SFC 11		**472**	**10**	**52.5**	**672**	**1008**	
SFC 12		**446**	**15**	**78.7**	**667**	**1001**	
SFC 13	**.42**	**525**	**0**	**0**	**656**	**985**	**220**
SFC 14		**498**	**5**	**26.2**	**653**	**979**	
SFC 15		**472**	**10**	**52.5**	**649**	**973**	
SFC 16		**446**	**15**	**78.7**	**645**	**968**	

6. RESULTS AND DISCUSSIONS

In the present study, a detailed investigation was performed on the strength parameters of concrete over a range of water binder ratio. Silica Fume was used as a partial replacement of cement at different levels varying from 0 to 15%. Compressive strength test was carried out to investigate the mechanical properties of high strength concrete.

7. A. FRESH CONCRETE:

In the fresh state, the mixes were closely examined by visual observations and consistency of the mixes were determined. Since silica fume concretes are sticky and the investigation was carried out for a wide range of water cementitious materials ratio and binder contents, workability of the mixes varied over a wide range, from highly flowing concrete to concrete suffering from segregation and bleeding. Hence to get a better idea of concrete consistency both slump and compacting factor tests were performed as per IS:1199. The slump was measured in mm and its type was also noted. The C.F. values have been calculated according to the following formula:

$$\text{C.F.} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of fully compacted concrete}}$$

The fresh concrete density was also determined for all the mixes.

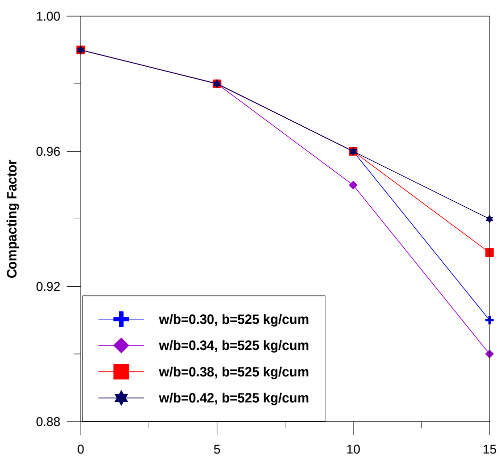


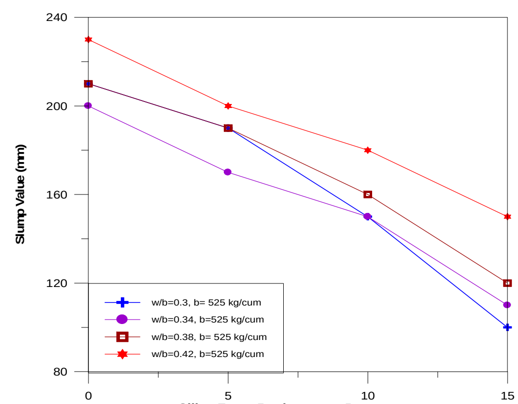
Fig: Variation of Compacting Factor With Silica Fume Replacement Percentage For Different w/b ratios.

VI:A.1. DISCUSSIONS

The aim of the present study was to investigate the concrete properties on the effect of cement replacement by silica fume over a wide range of water binder ratios. In the following sections a detailed study of the effect of these variable on the fresh concrete properties are presented.

EFFECT OF CEMENT REPLACEMENT BY SILICA FUME ON CONSISTENCY

The relative proportion of the concrete mixes including the SP content was kept almost constant, only cement was replaced by silica fume. Hence the mix character varied over a wide spectrum- from flowing concrete to concrete suffering from high bleeding and segregation. But the concrete suffering from bleeding and segregation improved drastically with silica fume incorporation. The workability of the concrete mixes decreased tremendously with the increasing percentage of silica fume replacement, starting from 5% of cement replacement. At water cement ratio of 0.34, the control concrete was a flowing one. At 5% silica fume replacement, the cohesiveness of the mix increased. But at 10% there was a considerable reduction in workability, which got reduced at even higher percentage of silica fume i.e.15%. At water cement ratio of 0.34, the slump values at 0% (control), 5%, 10% and 15% silica fumes were 200, 170, 150 and 110 respectively. Incorporation of silica fume turns the concrete sticky and hence there is a change in workability. At water cement ratio of 0.38, the control concrete was a highly flowing one. But with the addition of 5% silica fume the mix character improved considerably and with even higher percentages of silica fume replacement a very cohesive concrete mix was obtained. Concrete with a very high percentage of silica fume exhibited a bluish ash colour. At water cement ratio of 0.42 the control concrete suffered from segregation and bleeding. But as a result of the incorporation of the silica fume a stable mix was obtained at 15% silica fume replacement.



Variation Of Slump With Silica Fume Replacement Percentage For Different w/b ratios.

GENERAL OBSERVATIONS

Slump test is very sensitive for flowing mixes, Most of the concrete mixes were cohesive, flowable and free from segregation. The slump values of all the mixes lies between 100-210 mm indicating a very high degree of workability as per IS 456-2000. The slump values of 5% silica fume replacement was very close to control but the slump value of 10% silica fume was reduced considerably. Again with the addition of high percentage of silica fume i.e.15%, the slump value was dramatically reduced.

The values of the fresh density of concrete indicate that as the silica fume content increases, the fresh density of concrete decreases. On calculation it is observed that average density of control and silica fume concretes are about 2550 kg/m^3 and 2475 kg/m^3 respectively.

Control concrete at water cement ratio of 0.38 and 0.42 have exhibited high bleeding, but with the incorporation of silica fume the mix character improved considerably and highly stable and cohesive mix was obtained with reduced bleeding.

CONCLUSIONS FOR FRESH CONCRETE:

From the above observation it can be concluded that silica fume affects a number of properties of fresh concrete.

1. For all water cement and binder content, the workability of the concrete mix reduced dramatically with the increase in the silica fume replacement percentage.
2. As the amount of silica fume used in a mix increases, the cohesiveness of the mix increases and the mix becomes sticky.
3. Superplasticizer dosage was kept constant (2.5%). Hence no effect of SP dosage on slump variation.

VI:B. HARDENED CONCRETE

In the present investigation compressive strength test were performed on silica fume concrete. For determination of strength at any particular age at least three specimens were tested. A total of 144 specimens were tested for the present experimental investigation spanning over 4 water-binder ratios (0.30, 0.34, 0.38 and 0.42). The database thus generated was analyzed to develop a better insight in to the effects of microsilica on concrete over a wide range of water cementitious material ratios and silica fume replacements.

Table 2: Compressive Strength Results

W/B Ratio	Binder (Kg/m^3)	Silica Fume %	Compressive Strength (MPa)		
			7 Days	28 Days	90 Days
0.30	525	0	43	60	63
		5	46	66	70
		10	54	76	81
		15	45	65	68
0.34	525	0	38	53	60
		5	40	62	66
		10	48	68	71
		15	40	61	65
0.38	525	0	32	45	53
		5	35	53	58
		10	38	60	64
		15	35	58	62
0.42	525	0	28	42	48
		5	33	46	53
		10	37	52	59
		15	36	49	57

VI:B.1. DISCUSSIONS

In order to explore the various aspects of silica fume concrete, the results of the present investigations will be analyzed in different sections as follows:

- Rate of gain in compressive strength.
- Optimum silica fume replacement percentage.

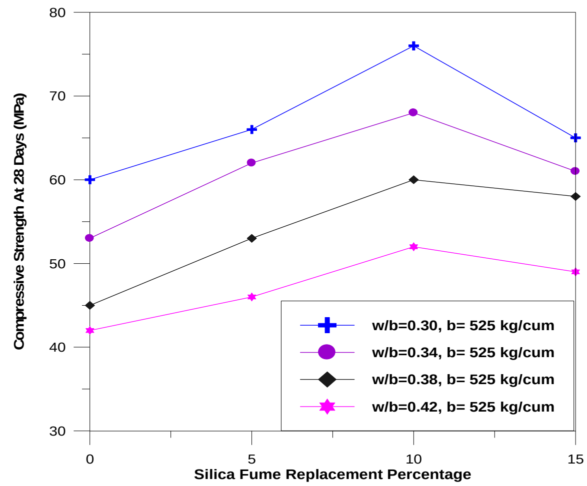


Figure: Compressive Strength at 28 days with Silica Fume Replacement %

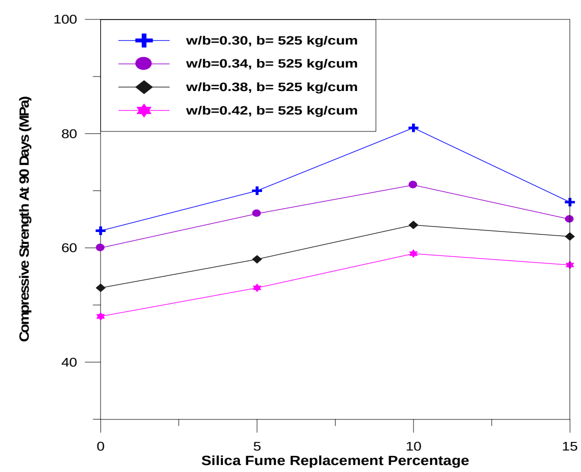


Figure: Compressive Strength at 90 days with Silica Fume Replacement %

RATE OF GAIN IN COMPRESSIVE STRENGTH

At any particular water-binder ratio, the percentage gain in strength at any age level at any silica fume content has been determined.

At water-binder ratio 0.30, in the present investigation, the rate of gain in compressive strength from 7 days to 28 days is maximum for 15% silica fume replacement level being around 45%. The 7 day and 28 day compressive strength for 15% silica fume replacement are 45 MPa and 65MPa respectively. Also it is observed that for control concretes the rate of gain in compressive strength from 7 days to 28 day is around 40%. The average rate of gain in compressive strength from 7 days to 28 days, for w/b ratio of 0.30 has been found to be 42%. However after 28 days, the rate of gain in strength up to 90 days is dramatically reduced, being maximum for 10% silica fume replacement i.e.7%.

OPTIMUM SILICA FUME REPLACEMENT PERCENTAGE

In the present investigation, it can be concluded that maximisation of concrete strength with silica fume incorporation has mostly occcurred for 10% silica fume replacement level. According to Neville (1994) superplasticizers do not alter fundamentally the strength of hydrated cement paste. The main effect is due to a better distribution of cement particles, and consequently their better hydration. To determine the optimum silica fume replacement percentage that causes maximisation of strength, the mix proportions and superplasticizer content were kept constant. Hence the variation in concrete properties occurred primarily due to variation in the silica fume replacement percentage.

CONCLUSIONS FOR HARDENED CONCRETE

It may be concluded that the use of silica fume is a necessity in the production of high strength concrete.

- From the study it has been observed that maximum compressive strength is noted for 10% replacement of cement with silica fume.
- Maximization of strength by incorporating silica fume has been obtained for the minimum water/binder ratio of 0.30. For 10% silica fume replacement percentage, the strength at 28 days is 27% higher with respect to control concrete.
- As the silica fume concrete is more compact and thereby more durable in nature and hence with some degree of quality control, it may be used in those places of construction where there is a chance of chemical attack, frost action etc.
- Lastly with good quality control, high early strength can be achieved in Silica Fume concrete which may be useful in various structural constructions such as high rise buildings, bridges etc

8. ACKNOWLEDGEMENT

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