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INVESTIGATIONS ON MECHANICAL PROPERTIES OF HIGH STRENGTH SILICA FUME CONCRETE

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ABSTRACT

Now a days high strength and high performance concrete are being widely used all over the world. Most applications of high strength concrete have been in high rise buildings, long span bridges and in some special applications in structures. In developed countries, using high strength concrete in structures today would result in both technical and economical advantage. In high strength concrete, it is necessary to reduce the water/cement ratio and which in general increases the cement content. To overcome low workability problem, different kinds of pozzolanic mineral admixtures (fly ash, rice husk ash, metakaoline, etc. and chemical admixtures are used to achieve the required workability.

In the present experimental investigation, the mechanical properties of high-strength concrete of grades M40 and M50, at 28 days characteristic strength with different replacement levels of cement with silica fume or micro silica of grade 920-D are considered. Standard cubes (150mm x 150mm x 150mm), standard cylinders (150mm dia x 300mm height) and standard prisms (100mm x 100mm x500mm) were considered in the investigation. In all, 144 specimens were cast with and with out silica fume. The mechanical properties viz., compressive strength, flexural strength and splitting tensile strength, and stress-strain characteristics of high strength concrete with various replacement of silica fume viz., 3%, 6%, 9%, 12% and 15%, has been considered. The investigations revealed that the use of waste material like silica fume improved the mechanical properties of high strength concrete witch is other wise hazardous to the environment and thus may be used as a partial replacement of cement.

Keywords: High performance; admixtures; workability; silica fume; stress-strain characteristics and partial replacement

1. INTRODUCTION

High-strength concrete refers to concrete that has a uniaxial compressive strength greater

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than the normal strength concrete obtained in a particular region. This definition does not include a numerical value for compressive strength indicating a transfer from a normal strength concrete to high strength concrete. In 1950's, concrete with a compressive strength of M35 MPa was considered as high strength concrete. In the 1990's concrete with a compressive strength greater than 110MPa was used in developed countries. However this numerical value (110MPa) could be considerably lower depending on the characteristics of the local materials used for these concrete products. Report of ACI committee 363 in 1979 defined high-strength concrete as having compressive strength more than 41.37 MPa (6000 Psi).

High-strength and High-performance concrete are being widely used throughout the world and to produce them it is necessary to reduce the water/binder ratio and increase the binder content. High-strength concrete means good abrasion, impact and cavitation resistance. Using High-strength concrete in structures today would result in economical advantages. Most applications of high strength concrete to date have been in high-rise buildings, long span bridges and some special structures. Major application of high strength concrete in tall structures have been in columns and shear walls, which resulted in decreased dead weight of the structures and increase in the amount of the rental floor space in the lower stories.

In future, high range water reducing admixtures (super plasticiser) will open up new possibilities for use of these materials as a part of cementing materials in concrete to produce very high strengths, as some of them are more finer than cement. The brief literature on the study has been presented in following text.

Hooton [1] investigated on influence of silica fume replacement of cement on physical properties and resistance to sulphate attack, freezing and thawing, and alkali-silica reactivity. He reported that the maximum 28-day compressive strength was obtained at 15% silica fume replacement level at a w/b ratio of 0.35 with variable dosages of HRWRA. Prasad et al. [2] has undertaken an investigation to study the effect of cement replacement with micro silica in the production of High-strength concrete.Yogendran et al.[3] investigated on silica fume in High-strength concrete at a constant water-binder ratio (w/b) of 0.34 and replacement percentages of 0 to 25, with varying dosages of HRWRA.The maximum 28-day compressive strength was obtained at 15% replacement level. Lewis [4] presented a broad overview on the production of micro silica, effects of standardization of micro silica concrete-both in the fresh and hardened state. Bhanja., and Gupta [5] reported and directed towards developing a better understanding of the isolated contributions of silica fume concrete and determining its optimum content. Their study intended to determine the contribution of silica fume on concrete over a wide range of w/c ratio ranging from 0.26 to 0.42 and cement replacement percentages from 0 to 30. Tiwari and Momin [6] presented a research study carried out to improve the early age compressive strength of Portland slag cement (PSC) with the help of silica fume. Silica fume from three sources- one imported and two indigenous were used in various proportions to study their effect on various properties of PSC.Venkatesh Babu and Natesan [7] Investigated on physico-mechanical properties of High-performance concrete (HPC) mixes, with different replacement levels of cement with condensed silica fume (CSF) of grade 960-D. Keeping some of the important points of literature

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reviewing to consideration, the investigation has been designed.

2. AIMS AND OBJECTIVES OF THE PRESENT INVESTIGATION

To investigate the mechanical properties i.e., compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of concrete at different replacement levels of cement with silica fume for the selected grades of concrete.

3. SCOPE OF THE PRESENT WORK

High-strength concrete of grades M40 and M50, the replacement levels of cement by silica fume are selected as 0%, 3%, 6%, 9%, 12% and 15% for standard sizes of cubes, cylinders and prisms for testing.

4. EXPERIMENTAL PROGRAMME

The experimental program was designed to compare the mechanical properties i.e, compressive strength, flexural strength and splitting tensile strength of high strength concrete with M40 and M50 grade of concrete and with different replacement levels of ordinary Portland cement (ultra tech cement 53 grade) with silica fume or micro silica of 920-D.

The program consists of casting and testing a total of 144 specimens. The specimens of standard cubes (150mmX150mmX150mm), standard cylinders of (150mm Dia X 300mm height) and standard prisms of (100mmX100mmX500mm) were cast with and with out silica fume. Universal testing machine was used to test all the specimens. In first series the specimens were cast with M40 grade concrete with different replacement levels of cement as 0%, 3%, 6%, 9%, 12% and 15% with silica fume. And in the second series the same levels of replacement with M50 grade of concrete were cast.

4.1 Materials Used

Ordinary Portland cement (Ultra tech cement) of 53 grade conforming to IS: 12269 and locally available natural sand were used. Specific gravity and fineness modulus were found to be 2.53 and 2.73 respectively. Crushed granite stone chips (angular) of maximum size 20mm were used. Specific gravity and fineness modulus were found to be 2.60 and 7.61 respectively. Potable water was used for mixing and curing.

Silica fume (Grade 920-D) was obtained from “Elkem India private limited”, Mumbai, India.

Super plasticizer by trade name Conplast SP-430 manufactured at Bangalore was used as water reducing agent to achieve the required workability. It is available in brown liquid instantly dispensable in water.

Physical properties of cement as per IS 4031 (Part-II)-1988, and silica fume as per IS 4031 (Part-II)-1999, tested at National Council for Cement and Building Materials

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Hyderabad India, are presented in Table 1.

Table 1. Physical properties of cement and silica fume

Designation	Specific gravity	Fineness (Blaine's) m^2/kg
Cement	3.15	290
Silica fume	2.27	-

Chemical properties of cement (as per IS 12269) and silica fume (as per ASTMC-99) tested at Indian Institute of Chemical Technology, Hyderabad, India are presented in Table 2 and Table 3, respectively.

Table 2. Chemical properties of cement

Characteristics	Result (%by mass)
Loss on ignition	1.95
Silica as (SiO_2)	23.50
Alumina as (Al_2O_3)	4.42
Iron as (Fe_2O_3)	11.38
Calcium as (CaO)	58.51

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Table 3. Chemical properties of silica fume

Characteristics	Specifications	Result (%by mass)
SiO_2	% min 85.0	88.7
Moisture content	% max 3.0	0.7
Loss on ignition 975c	% max 6.0	1.8
Carbon	% max 2.5	0.9
>45 micron	% max 10	0.2
Bulk density	500-700 Kg/m^3	670

Two concrete mixes were designed to a compressive strengths of 40MPa and 50MPa with a water-cementitious ratio of 0.36 and 0.30 respectively, as per IS code. In both the cases, the Portland cement was replaced with silica fume by 0%, 3%,6%, 9%, 12%, and 15%. The water reducing agent Conplast SP-430, 600 ml per 50kg of cement was added, to get the desired workability. The proportions of constituent materials i.e., cementitious material (cement and silica fume), aggregates (coarse and fine), water and chemical admixture (super plasticizer) for two mixes are presented in Table 4.

Table 4. Proportions of Constituent materials of M40 and M50 Grade Concrete

Grade of mix	w/c ratio	Proportions of constituent materials		
		C	F.A	C.A
M40	0.36	1	0.92	2.82
M50	0.30	1	0.65	1.90

4.2 Casting and Curing of Test Specimens

The specimens of Standard cubes (150mm×150mm×150mm) 6 No.s, Standard prisms (100mmX100mmX500mm) 6No.s and Standard cylinders (150mm diameterX300mm height) 6 No.s were cast per a day, for 6 days. In all 72 specimens, cement was replaced by silica fume (RS-0, RS-3, RS-6, RS-9, RS-12 and RS-15) with M40 mix case and 72 specimens with M50 mix case were cast.

Measured quantities of coarse aggregate and fine aggregate were spread out over an

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impervious concrete floor. The dry ordinary Portland cement (ultra tech) and silica fume were spread out on the aggregate and mixed thoroughly in dry state turning the mixture over and over until uniformity of color was achieved. Water was measured exactly by weight, and super plasticiser Conplast SP-430 (600ml per 50kg) was added to the water, 75% quantity of water was added to the dry mix and it was thoroughly mixed to obtain homogeneous concrete. The time of mixing shall be in 10-15 minutes.

5. DISCUSSIONS OF TEST RESULTS

The present investigation reports a part of a comprehensive study intended to determine the contribution of silica fume on concrete mixes M40 and M50 with a w/c ratio of 0.36 and 0.30 and cement replacement levels from 0 to 15.

The optimum silica fume replacement level and strength improvement of high strength concrete have been determined. The workability tests are presented in Table 5.

Table 5. Slump and compaction factor values of M40 and M50 grade concrete

Silica fume%	M40		M50	
	Slump (mm)	Compaction factor	Slump (mm)	Compaction factor
RS-0	50	0.87	43	0.87
RS-3	45	0.86	40	0.83
RS-6	43	0.82	38	0.81
RS-9	41	0.80	37	0.80
RS-12	38	0.76	35	0.78
RS-15	35	0.73	32	0.73

5.1 Compressive Strength of Concrete

The test was carried out conforming to IS 516-1959 to obtain compressive strength of M40 and M50 grade of concrete. The compressive strength of High-strength concrete with OPC and silica fume concrete at the age of 28 days is presented in Table 6.

There is a significant improvement in the strength of concrete because of the high pozzolanic nature of the silica fume and its void filling ability. The compressive strength of the two mixes M40 and M50 at 28-days age, with replacement of cement by silica fume (920-D) was increased gradually up to an optimum replacement level of 12% and then decreased. The maximum 28-day cube compressive strength of M40 grade with 12% of silica fume was 61.20MPa, and of M50 grade with 12% silica fume was 68.66MPa.

The compressive strength of M40 grade concrete with partial replacement of 12% cement by silica fume shows 16.37% greater, and of M50 grade with 12% replacement shows 20%

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greater, than the controlled concrete.

The maximum compressive strength of concrete in combination with silica fume depends on three parameters namely the replacement level, water cement ratio and chemical admixture. The chemical admixture dosage plays a vital role in concrete to achieve the required workability at lower w/c ratio.

Table 6. Twenty eight days compressive strength of concrete

Silica fume %	**Compressive strength (MPa)**	
	M40	**M50**
RS-0	52.59	57.18
RS-3	54.18	57.63
RS-6	58.22	62.08
RS-9	60.74	62.81
RS-12	61.20	68.66
RS-15	58.50	63.50

Note: RS-Replacement of silica fume by weight of cement

5.2 Splitting Tensile Strength of Concrete

The test was carried out according to IS 5816- 1999 to obtain the splitting tensile strength of M40 and M50 grade concrete. The test results of both the mixes were presented in the Table 7.

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Table 7. Twenty eight days splitting tensile strength of concrete

Silica fume %	**Splitting tensile strength (MPa)**	
	M40	**M50**
RS-0	3.05	3.15
RS-3	3.57	3.62
RS-6	3.84	3.68
RS-9	4.15	3.76
RS-12	4.17	3.80

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RS15	3.86	3.68

As replacement level increases there is an increase in splitting tensile strength for both M40 and M50 grades of concrete up to 12% replacement level, and beyond that level there is a decrease in splitting tensile strength.

The splitting tensile strength at 28-days age of curing of M40 and M50grade of concrete was 4.17MPa and 3.80MPa respectively. The splitting tensile strength of both grades at 12% replacement, increased by about 36.06% and 20.63% respectively, when compared to that of conventional concrete.

5.3 Flexural Strength of Concrete

The tests were carried out conforming to IS 516-1959 to obtain the flexural strength of M40 and M50 grade concrete. Three standard prism specimens were cast for each replacement level and tested under two-point loading. The experimental results of flexural strength with OPC for both the mix cases are shown in Table 8.

Table 8. Twenty eight days flexural strength of concrete

Silica fume %	**Flexural strength (MPa)**	
	M40	**M50**
RS-0	5.00	5.06
RS-3	5.11	5.14
RS-6	5.41	5.39
RS-9	5.78	5.70
RS-12	5.82	5.85
RS15	5.58	5.68

The flexural strength at the age of 28- days of silica fume concrete continuously increased with respect to controlled concrete and reached a maximum value of 12% replacement level for both M40 and M50 grades concrete respectively.

The maximum 28-day flexural strength of M40 and M50 grades of concrete with 12% replacement of silica fume was 5.82MPa and 5.85MPa respectively.

It can be concluded that the ultra-fine silica fume particles, which consist mainly of amorphous silica, enhance the concrete strength by both pozzolanic and physical actions.

The results of the present investigation indicate that the percentage of silica fume contributing to the mechanical properties is comparable or even more significant than that of control concrete.

5.4 Modulus of Elasticity

The test was carried out conforming to IS 516-1959 to obtain the stress-strain curve and modulus of elasticity of the concrete. From this, it can be confirmed that as the load increases, strain increases steadily up to15.79MPa. At that stress, strain was $0.628x10^{-3}$, and stress is directly proportional to strain. At that limit it has a Young's modulus of 25.13GPa. Beyond 15.79MPa of stress there is a constant stress where stress is not directly proportional

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to strain.Table 9 shows the modulus of elasticity increases up to 12%, beyond that strain is increased, at constant stress.

Table 9. Modulus of elasticity of concrete

Silica fume %	**M40 grade of concrete (GPa)**	**M50 grade of concrete (GPa)**
RS-0	25.13	23.33
RS-3	26.08	23.73
RS-6	26.22	27.26
RS-9	28.23	29.31
RS-12	32.19	30.15
RS-15	31.31	29.41

The material used silica fume, slump and testing setup are presented in plates 1-5. Typical stress-strain curves for M40 and M50 grades of concrete are presented in Figure 1-2.

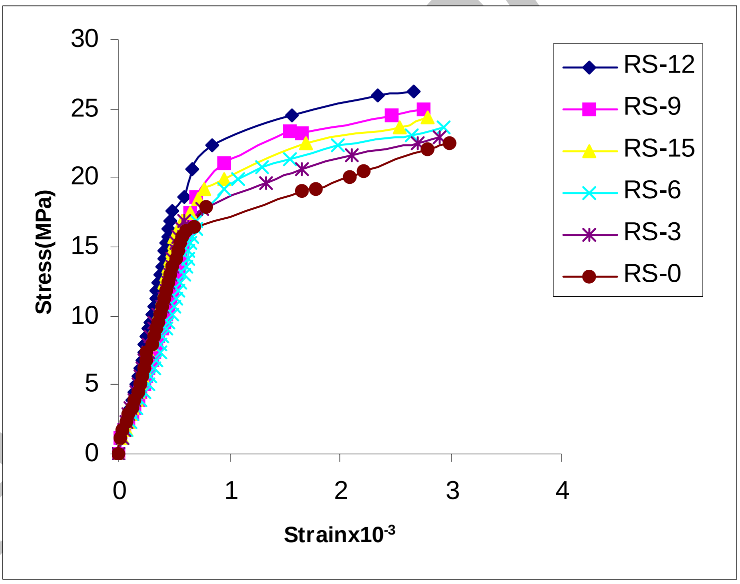

Figure 1. Combined stress-strain curve of M40 grade concrete (RS-0, RS-3,RS-6,RS-9,RS-12 and RS-15)

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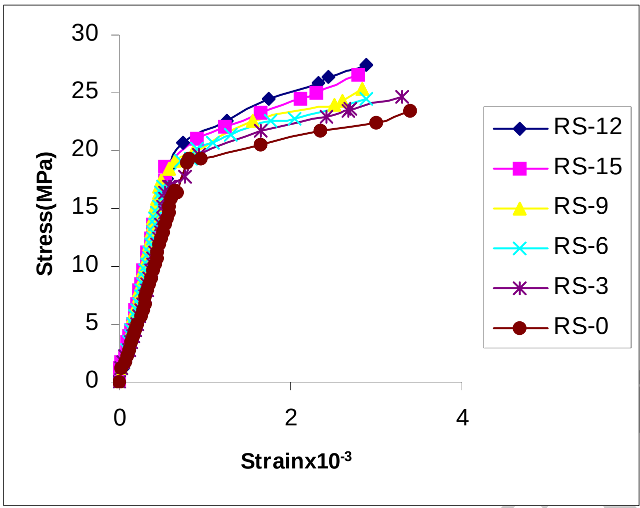

Figure 2. Combined stress-strain curve of M50 grade concrete (RS-0, RS-3,RS-6,RS-9,RS-12 and RS-15)

Plate 1. Silica fume

Plate 2. Slump Measurements

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Plate 3. Test for Compressive strength of Concrete

Plate 4. Test for flexural strength of Concrete

Plate 5. Test setup for Stress –Strain Curve of C

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6. CONCLUSIONS

1. Cement replacement up to 12% with silica fume leads to increase in compressive strength, splitting tensile strength and flexural strength, for both M40 and M50 grades. Beyond 12% there is a decrease in compressive strength, tensile strength and flexural strength for 28 days curing period.
2. It is observed that the compressive strength, splitting tensile strength and flexural strength of M40 grade concrete is increased by 16.37%, 36.06% and 16.40% respectively, and for M50 grade concrete 20.20%, 20.63% and 15.61% respectively over controlled concrete.
3. There is an increase in Young's modulus of concrete as silica fume content increases. This increase is again up to a replacement level of 12%. The Young's modulus at this replacement level is E_c=32.19GPa, for M40 grade concrete which is 28.06% higher than conventional concrete.
4. There is a decrease in workability as the replacement level increases, and hence water consumption will be more for higher replacements.
5. The ratio of cube strength to cylinder is found as 1.22 and 1.24 respectively for M40 and M50 grades, where as for the conventional concrete is1.20.
6. The maximum replacement level of silica fume is 12% for M40 and M50 grades of concrete.

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REFERENCES

1. Hooten RD. Influence of silica fume replacement of cement on physical properties and resistance to Sulphate attack, Freezing and Thawing, and alkali-silica reactivity, *ACI Material Journal*, No. 2, **90**(1993) 143-51.
2. Prasad AS, Santanam D, Krishna Rao SV. Effect of micro silica on high strength concrete, National conference-emerging trends in concrete construction, 22-24 Jan. 2003, CBIT, Hyderabad, India.
3. Yogendran V, Langan BW, Haque MN, Ward MA. Silica fume in High- strength concrete, *ACI Material Journal*, No. 2, **84**(1987) 124-9.
4. Lewis RC. Ensuring long term durability with high performance micro silica concrete, *The Indian Concrete Journal*, October 2001, pp. 621-26.
5. Bhanja S, Sengupta B. Optimum silica fume content and its mode of action on concrete, *ACI Materials Journal*, September- October 2003, pp. 407-712.
6. Tiwari A, Momin I. Improving early age strength of PSC with indigenous silica fume, *The Indian Concrete Journal*, October 2000, pp. 595-98.
7. Venkatesh Babu DL, Nateshan SC. Some investigations on silica fume concrete, The *Indian concrete Journal*, September 2004, pp. 57-60.

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