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A Study of the Stress - Strain Behaviour of Silica Fume Concrete under Axial Compression

Seshu.D.R.* & Sai L.V.A.S.**

The production of high performance concrete that consistently meets the requirements for strength and durability places more stringent requirements on materials selection. The enforcement of specifications leads to the higher cost of materials. This necessitates the use of chemical and mineral admixtures. Also the present research aimed at energy conservation in the cement and concrete industry has in part focused on the use of less energy intensive materials such as fly ash, slags, and pozzolans. Recently some attention has been given to the use of condensed silica fume (CSF) as a partial replacement for cement. Silica fume is a by product resulting from the reduction of high purity quartz with coal in electric arc furnaces in the production of silicon and ferrosilicon alloys. The material which contains more than 80 percent of silica in non crystalline state in the form of extreme fine particles is highly pozzolanic and is useful in the cement and concrete industries. The main problem in using this material is associated with its extreme fineness and high water requirement. However, the availability of high range water reduction admixtures (superplasticizers) has opened new possibilities for use of silica fume as a part of cementing material in concrete to produce very high strength and durable concrete. The increased demand for high strength concrete has also increased the use of silica fume in the concrete mix and such concrete is known as Silica Fume Concrete (SFC). Whether incorporation of silica fume in the concrete mix brings about any fundamental changes in the stress-strain behaviour of concrete is yet to be established fully. Several investigations (1-6) on SFC indicated that the cement-CSF blends can be used for production of low density high strength concrete for structural use.

Notations

f	=	stress
ε	=	strain
f_o	=	ultimate strength of ordinary concrete
ε_o	=	strain at ultimate of ordinary concrete
μ	=	ductility of concrete
f_{sf}	=	ultimate strength of silica fume concrete (SFC)
ε_{sf}	=	strain at ultimate of SFC
$\varepsilon_{0.90a}$	=	strain at 90% of ultimate in the ascending portion of stress- strain curve
$\varepsilon_{0.90d}$	=	strain at 90% of ultimate in the descending portion of stress-strain curve

This paper presents an experimental investigation on the behaviour of silica fume concrete under axial compression by varying the percentage of silica fume replacing the cement in the strength range of 40 to 60 MPa.

Experimental investigation

The experimental programme consisted of casting and testing of 36 prisms of size 100x100x400 mm. Specimens were divided into three batches A, B and C representing M40, M50 and M60 grades of concrete. In each batch the percentage of silica fume replacing the cement was varied from 0 to 15 in intervals of 5 which gave four different types of mixes P, Q, R and S respectively. Each specimen was designated by the grade of concrete and percentage of silica fume replacing cement. Thus the specimen with designation AQ stands for M40 grade concrete having 5 percent of cement replaced with silica fume. For each mix three identical specimens were cast and tested and the average behaviour was taken to represent the behaviour of that set of three specimens.

Materials used

Cement: The cement used was 43 grade ordinary portland cement.

Fine Aggregate: River sand procured locally confirming to zone II as per IS 383.

Coarse Aggregate: Crushed granite aggregate having maximum size of 12.5 mm was used throughout the work.

Silica Fume: The properties of the silica fume used are as follows:

Specific gravity	: 1.84
Fineness by wet sieving on 45 micron sieve	: 5.04
Lime reactivity	: 2.34
Loss on ignition	: 10%

Superplasticizer: A superplasticizer known as CONPLAST 430 was used in the work.

Mix Proportion: The mix proportion adopted in the study was 1:1:2.2. Water cement ratio was varied to obtain different grades of concrete.

Testing

All prisms were tested under compression in Tinius Olsen Testing Machine (TOTM) of capacity 2000kN. Specially fabricated compressometers, consisting of four dial guages, which enables the measurement of strains even during spalling of concrete near ultimate load, were used. Strain rate control of 0.00025 mm/mm/minute was adopted to get the complete stress-strain diagram including descending portion.

Discussion of results

Behaviour of test specimens under load

The load increased rapidly in the initial stages upto about 60-65 percent of peak load and increased at a slower rate until the peak load was reached. Test was continued until the peak loads dropped to about 0.85 times the peak load. Beyond the peak load the strains were increased at a rapid rate and were accompanied with decrease in the load carrying capacity of the specimen. The spalling of con-

* Asst. Prof. Dept. of Civil Engg. REC, Warangal
** Prof., Dept. of Civil Engg., Osmania University College of Engg., Hyderabad

crete was noticed before the peak load was reached. The average strain at the maximum stress for ordinary concrete specimens ranged between 0.17 percent and 0.18 percent.

Experimental stress-strain curves

From the observed data for a given specimen the longitudinal deformations were calculated from the average readings of the four dial gauges of the compressometer. The stresses and strains were obtained by dividing the load with the gross area of cross section and deformation with the gauge length respectively. The stress strain curves drawn for each set on a single graph and average

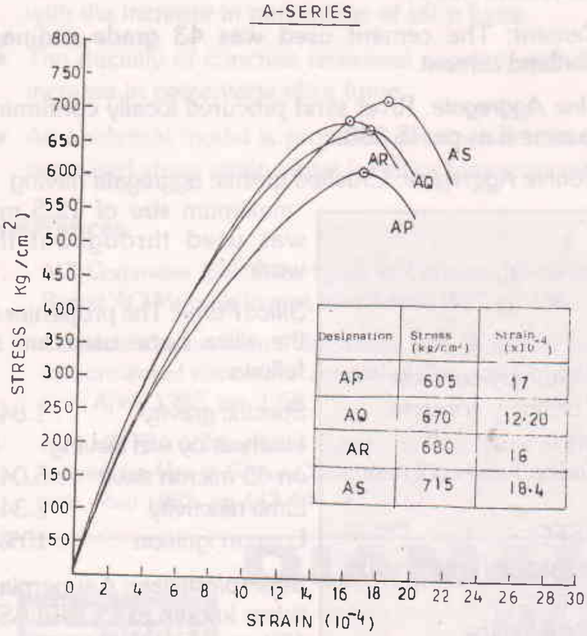

Fig.1 STRESS VS STRAIN CURVES

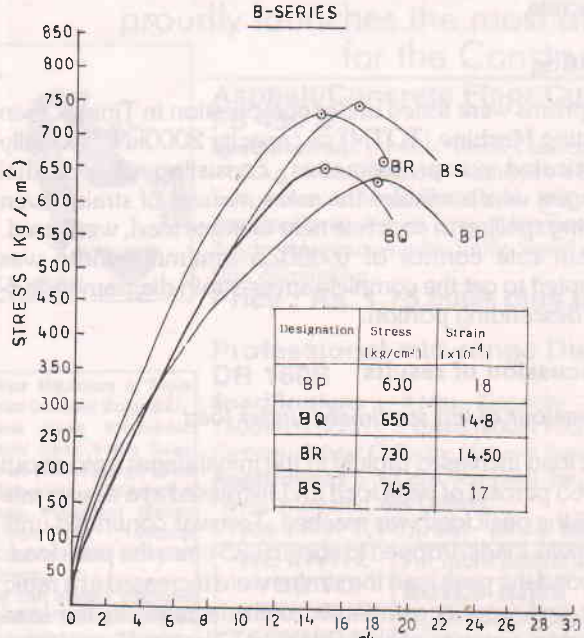

Fig. 2 STRESS VS STRAIN CURVES

curve was drawn. The stress strain curve for all mixes in one grade were drawn on the same sheet with the same scale for the purpose of comparison. Such curves are shown in Fig. 1, 2 and 3 respectively for M40, M50 and

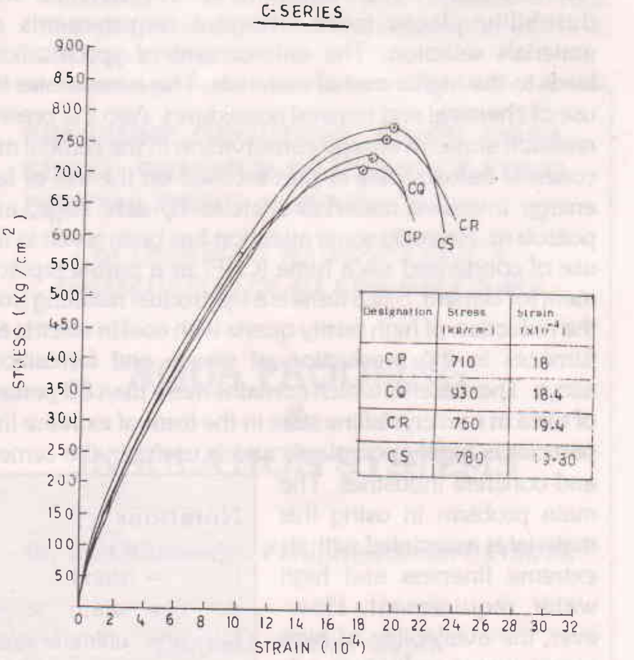

Fig.3 STRESS VS STRAIN CURVES

M60 grades of concrete.

From the above curves the maximum stress of silica fume concrete (SFC) and the maximum stress for companion specimen made with ordinary concrete were obtained and are given in Table 1. The strains at maximum stress and those at 0.90 times the maximum stress on the ascending and descending portion of the stress strain curves were obtained for both SFC and ordinary concrete and are tabulated in Table 1.

Effect of silica fume on

Strength of concrete

The ultimate strength of concrete increased with increase in percentage of silica fume. Column 6 of Table 1 gives the ratio of the observed ultimate strength of SFC (f_{sf}) to that of ordinary concrete (f_o). A plot of percentage of silica

Table 1. Experimental values of strength and strain of SFC prisms.

Conc grade	Speci -men	Silica fume (%)	Ultimate comp. strength (f_{sf}) (kg/cm²)	Strain at ult. (ε_{sf}) 10^{-4}	f_{sf}/f_o	$\varepsilon_{sf}/\varepsilon_u$	$\varepsilon_{0.90a}$	$\varepsilon_{0.90d}$	μ
1	2	3	4	5	6	7	8	9	10
M 40	AP	0.0	605	17.0	1.000	1.000	13.0	20.0	1.538
	AQ	5.0	670	17.2	1.107	1.012	13.0	20.0	1.538
	AR	10.0	680	16.0	1.120	0.940	12.0	19.0	1.583
	AS	15.0	715	18.4	1.124	1.080	13.5	21.8	1.614
M50	BP	0.0	630	18.0	1.000	1.000	13.0	21.6	1.660
	BQ	5.0	650	14.8	1.031	0.820	11.4	18.6	1.630
	BR	10.0	730	14.5	1.158	0.800	10.8	18.0	1.670
	BS	15.0	745	17.0	1.182	0.940	12.6	20.4	1.620
M60	CP	0.0	710	18.0	1.000	1.000	13.5	21.6	1.600
	CQ	5.0	730	18.4	1.028	1.020	13.2	21.2	1.606
	CR	10.0	760	19.4	1.070	1.077	13.9	22.6	1.630
	CS	15.0	780	19.8	1.100	1.100	13.4	22.4	1.670

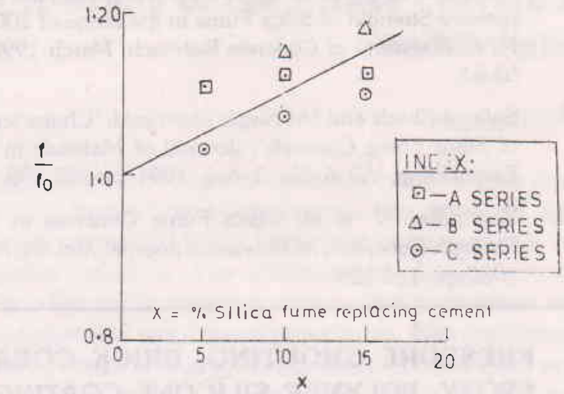

Fig. 4 % OF SILICA FUME VS IMPROVEMENT IN STRENGTH AT PEAK.

fume (S_f) versus the above ratio is given in Fig. 4. An examination of the plot shows that there is a linear relationship between the silica fume percentage and f_{sf} and f_o. A regression analysis conducted to fit a straight line between the above two parameters resulted in the following equation.

$$f_{sf}/f_o = 1.0 + 0.0088S_f \qquad (1)$$

Strain at ultimate strength

The strain at ultimate strength (ε_{sf}) increased at slower rate with an increase in percentage of silica fume. Column 7 of Table 1 gives the ratio of observed strain at ultimate stress of silica fume to that of ordinary concrete (ε_o). A

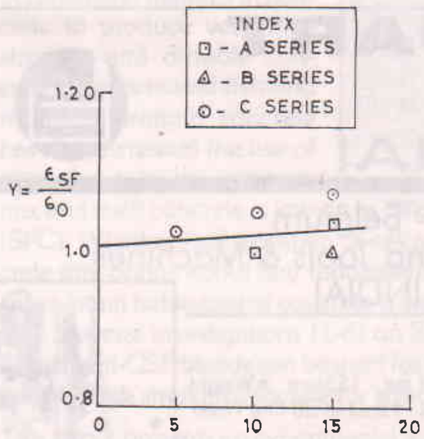

Fig. 5 % OF SILICA FUME VS IMPROVEMENT IN STRAIN AT PEAK

graph drawn between the above ratio and the percentage of silica fume is shown in Fig. 5. This indicates that the above two parameters are linearly related. A regression analysis is conducted and the following equation is obtained.

$$\varepsilon_{sf}/\varepsilon_o = 1.0 + 0.0055S_f \qquad (2)$$

Ductility

Ductility (μ) of the concrete as represented by the ratio of observed strain at 0.9 times the ultimate strength ($\varepsilon 0.90d$) in the descending portion of the stress - strain curve to that in the ascending portion ($\varepsilon 0.90a$) of stress-strain curve is remained constant with increase in percentage of silica fume. Fig. 6 shows the plot between the above ratio and percentage of silica fume.

Analytical model for the nondimensional stress strain curve of silica fume concrete

An examination of the stress strain diagrams from Fig. 1 to 3 for silica fume concrete indicates that the behaviour is similar for all the

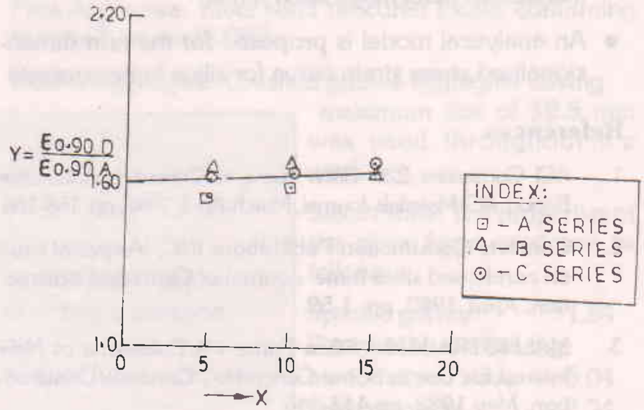

Fig. 6 % OF SILICA FUME VS DUCTILITY

specimens. The similarity leads to the conclusion that there is only a unique shape of the stress strain diagram, if expressed in non dimensional form along both the axes. The said form can be obtained by dividing stress at any level by peak stress and the strain at any stress level by the strain at peak stress. Thus all the stress strain diagrams will have the same point (1, 1) at peak stress. By non-dimensionalising the stress and strain as above, the in-

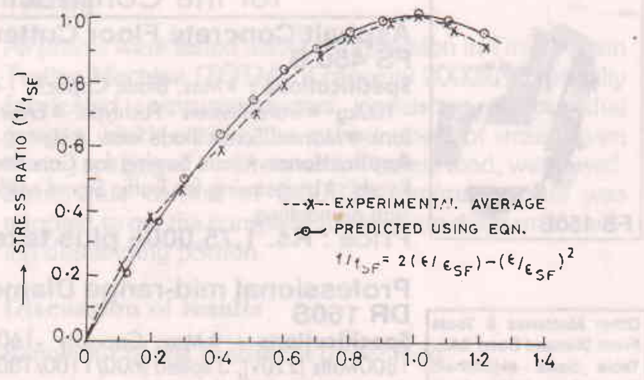

Fig. 7 NON-DIMENSIONALISED STRESS - STRAIN CURVE FOR SILICA FUME CONCRETE

fluence of the percentage of silica fume is eliminated for any specimen. Such non dimensionalised values of stress and strains are plotted on a graph (Fig. 7). The graph indicates that the stress strain behaviour of silica fume concrete can be represented by a general curve which functions as a stress block. The following equation is obtained for the non dimensionalised stress strain curve for silica fume.

$$f/f'_{sf} = 2(\varepsilon/\varepsilon_{sf}) - (\varepsilon/\varepsilon_{sf})^2 \qquad (3)$$

Conclusions

The following conclusions are drawn from the experimental investigation on the effect of percentage of silica fume replacing cement in high strength concrete.

- The replacement of cement with silica fume increases the ultimate strength of concrete and the increase in strength can be obtained using the equation 1.
- The strain at ultimate strength improved marginally with the increase in percentage of silica fume.
- The ductility of concrete remained constant with the increase in percentage silica fume.
- An analytical model is proposed for the non dimensionalised stress strain curve for silica fume concrete.

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