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EXPERIMENTAL INVESTIGATION ON HIGH PERFORMANCE REINFORCED CONCRETE COLUMN WITH SILICA FUME AND FLY ASH AS ADMIXTURES

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ABSTRACT

The purpose of this experimental investigation is to study the behavior of short columns produced from High Performance Concrete (HPC). In this investigation HPC was manufactured by usual ingredients such as cement, fine aggregate, coarse aggregate, water and mineral admixtures such as Silica Fume (SF) and Fly ash at various replacement levels and the Super Plasticizer used was CERAPLAST-300. The water binder ratio (w/b) adopted is 0.30. The concrete used in this investigation was proportioned to target a mean strength of 60 MPa. Specimens such as cubes, cylinders and prism beams were cast and tested for various mixes viz. Seven mixes M1 to M7 are cast with 0%, 5%, 7.5% and 10% replacement of SF and another set of specimens with 0%, 5%, 7.5% and 10% replacement of SF along with 10% constant replacement of Fly ash to study the mechanical properties such as compressive strength, split tensile strength and flexural strength at different ages of concrete such as 3, 7, 28, 56 and 90 days. The result shows that the optimum replacement of silica fume is 7.5%. If 10% of Fly ash is added the optimum replacement of silica fume is 5%. Totally 7 columns were cast for mixes M1 to M7. The column specimens were tested in 1000kN loading frame at 28 days. From this, Load-Mid height deflection (P-Δ) curves were drawn and compared. The same failed columns were rehabilitated with GFRP sheets with one or two layers and again tested in 1000kN loading frame. The results were then compared with the initial results.

Keywords: High performance concrete; fly ash; silica fume; load-deflection curve; GFRP

1. INTRODUCTION

High Performance Concrete (HPC) has been developed over the last two decades, and was

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primarily introduced through private sector architectural design and construction such as high rises and parking garages. Public agencies tend to be more conservative than the private sector when it comes to changing specifications, but the public sector now is committed to incorporate this technology in the field.

HPC is used for concrete mixtures, which possess high workability, high strength, and high modulus of elasticity, high density, high dimensional stability, low permeability and resistance to chemical attack. HPC is also, a high strength concrete but it has a few more attributes specifically designed as mentioned above. HPC is often called "durable" concrete because its strength and impermeability to chloride penetration makes it last much longer than conventional concrete. It's an engineered concrete made up of the classic elements of water, Portland cement and fine and coarse aggregates, but with added admixtures. According to ACI “High Performance Concrete is defined as concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using conventional materials and normal mixing, placing and curing practices”.

2. OBJECTIVES

- The main objective of the present investigation is to study the behavior of high performance reinforced concrete columns (replacement of cement with silica fume and fly ash). Silica fume and fly ash are used as a partial replacement of cement and super plasticizer is used to achieve require workability.
- The ultimate load carrying capacity of short columns for axial compression.
- To determine properties such as Stiffness and Compressive strength indices for HPC short columns.
- The effectiveness of Glass Fiber Reinforced Polymer Composites to enhance the Performance.
- Load – axial deformation characteristics & evaluation of ductility parameters of Short column.
- To rehabilitate the failure short column using GFRP sheet.
- To determine the ultimate load carrying capacity of the Rehabilitated Columns.
- Comparison between high performance reinforced concrete columns and Rehabilitated columns using GFRP.

2.1 Materials used

- Cement: Ordinary Portland cement, 43 Grade conforming to IS: 12269 – 1987.
- Fine aggregate: Locally available river sand conforming to Grading zone II of IS: 383 – 1970.
- Coarse aggregate: Locally available crushed blue granite stones conforming to graded aggregate of nominal size 20 mm as per IS: 383 – 1970.
- Fly ash: Obtained from Mettur Thermal Power Plant, mettur. Confirming to IS: 3812 – Part 1 – 2003 as mineral admixture in dry powder form.
- Silica fume: Obtained from ELKEM India (P) Ltd., Navi Mumbai conforming to ASTMC 1240 as mineral admixture in dry densified form.

- Super plasticizer: CERAPLAST 300 was used as chemical admixture to enhance the workability of the concrete.
- Water: Potable water.
- GFRP: Woven roving (360gms/sqm) used for wrapping of columns.

2.2 Experimental methodology

2.2.1 Mix proportioning details

The concrete used in this study was proportioned to attain strength of 60 MPa. ACI committee recommendation has been used for M60 design The mixes M1, M2, M3 and M4 were obtained by replacing 0, 5, 7.5 and 10 percent of the mass of cement by silica fume, Then mix M5, M6 and M7 were obtained by replacing the mass of cement by the above percentage of silica fume and with 10% of fly ash. The water binder ratio (w/b) is taken as 0.30**.** The description of mixes used in this study is given in Table 1.

Table 1: Description of mixes

Mix	% of silica fume	% of flyash
M1	0	0
M2	5	0
M3	7.5	0
M4	10	0
M5	5	10
M6	7.5	10
M7	10	10

2.2.2 Mix design-by weight basis (Aci 211.4r – 93)

Aggregate size as = 20mm

Specific gravity of cement = 3.15

Specific gravity of sand = 2.67

Specific gravity of coarse aggregate =2.81

Bulk density of fine aggregate =1721 kg/m^3

Bulk density of coarse aggregate = 1674 kg/m^3

Average design strength = f_{ck} =60MPa

Volume of coarse aggregate in concrete = 0.70

Step 1:

Average design strength = 60 Mpa

Step 2:

Weight of coarse aggregate = Bulk density × volume of coarse aggregate
= 1674 × 0.70
=1171.80 kg/m^3

Step 3:

Water content and cement content
Consider as no air entrained concrete
Using W/C ratio chart, for 60MPa
W/C ratio = 0.30.
W/B ratio = 0.30.
Assume slump value as 25mm to 50mm.
Coarse aggregate as 20mm

As per ACI 211.4R – 93 (Table 4.3.4)

Volume of voids = 1.5%
Water = 169 liters
Void content = (1- ((bulk density of C.A)/(specific gravity of F.A))×1000)×100
Void content V = 35.54%
Mixing water adjustment = (V- 35) ×8×0.592 = 2.47 lit
Total water content = 171.47 lit (169+2.47)
Weight of cement = (total water content /water binder ratio)
= (171.47/ 0.30)
= 571.57 kg/m^3

Step 4:

Volume of ingredients
Total volume of material = 1.000m^3
Volume of cement = 0.181 m^3
Volume of water = 0.171 m^3
Volume of coarse aggregate = 0.417 m^3
Volume of void = 0.0015 m^3
Total volume of material except F.A = 0.771 m^3
Volume of fine aggregate = 0.229 m^3
Weight of fine aggregate = (volume of F.A × specific gravity of F.A)
= 610.275 kg/m^3

Step 5:

Weight of cement = 571.57 kg/m^3
Weight of fine aggregate = 610.275 kg/m^3
Weight of coarse aggregate =1171.80 kg/m^3
Water content = 171.47 lit

Cement	F.A	C.A	W/C
1	1.07	2.05	0.3

Step 6:

Proportion mix using cement, Silica fume and fly ash

Specific gravity of fly ash = 2.15
Specific gravity of Silica fume = 2.20
Replacement of fly ash = 10%
Weight of fly ash replaced = 57.16kg/m^3
Replacement of Silica fume = 5%
Weight of Silica fume replaced = 28.58kg/m^3
Weight of cement = (571.57-57.16-28.58)
=485.83 kg/m^3

Step 7:

Proportion adjusted
Total volume of material = 1.000m^3
Volume of cement = 0.154 m^3
Volume of water = 0.171 m^3
Volume of coarse aggregate = 0.417 m^3
Volume of void = 0.0015 m^3
Volume of Silica fume =0.013 m^3
Volume of Flyash =0.027 m^3
Total volume of material except F.A = 0.784 m^3
Volume of fine aggregate = 0.216 m^3
Weight of fine aggregate = (volume of F.A × specific gravity of F.A)
= 577.28 kg/m^3

Step 8: (Ratio)

Weight of cement = 485.83 kg/m^3
Weight of fly ash replaced = 57.16kg/m^3
Weight of Silica fume replaced = 28.58kg/m^3
Weight of fine aggregate = 577.28 kg/m^3
Weight of coarse aggregate =1171.80 kg/m^3
Water content = 171.47 lit

Binder	F.A	C.A	W/B
1	1.01	2.05	0.3

2.3 Experimental investigation on behaviour of HPC columns

2.3.1 Test specimens

The experimental work consisted of testing of seven columns. All short columns cast were of size 100x100x1000mm and square in cross section. The axial load capacity of these column specimens and details of the specimens were arrived based on the procedure given in IS-456-2000. The description of the specimens is given in Table 2. The end condition of columns was hinged and it was achieved by resting the columns over neoprene pad. The reinforcement details of column specimens are shown in Figures 1-2.

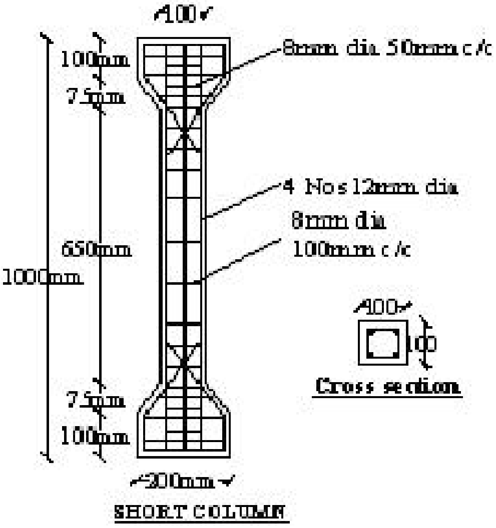

Figure 1. Reinforcement details of column test specimen

Figure 2. Reinforcement cage for short column

Table 2: Mix proportions ratio

Mix	SF (%)	Fly ash (%)	Ratio
M1	0	0	1:1.07:2.05:0.30
M2	5	0	1:1.05:2.05:0.30
M3	7.5	0	1:1.04:2.05:0.30
M4	10	0	1:1.03:2.05:0.30
M5	5	10	1:1.01:2.05:0.30
M6	7.5	10	1:1.00:2.05:0.30
M7	10	10	1:0.99:2.05:0.30

2.3.2 Materials

HPC column specimens were provided with M60 mix, water binder ratio of 0.3. OPC 43 Grade cement, natural river sand and crushed graded aggregate of size 20mm were used. Fe415 grade steel was used as main reinforcement. For both long and short columns, the main bar reinforcement was 12mm in diameter lateral ties of 8 mm diameter @ 100mm spacing were used and 50mm spacing used for header portion.

2.3.3 Casting of test specimens

All the reinforced column specimens were cast at the structural Engineering Laboratory. The wooden mould were prepared and lubricated with oil before the concrete was poured. Concrete was mixed using a rotary-type laboratory mixer and was poured into the moulds in layers. A mixing time of 3 to 5 minutes was given to ensure uniform mixing. The specimens were demoulded after 24 hours and cured for 28 days using gunny bags and then the columns were kept for 24 hours in a dry state. To facilitate easy loading all the columns were provided with head at top. After drying they were cleaned with a sand paper to remove all girt and dirt. The column specimens after casting and curing were white washed and as shown in Figure 4. White washing facilitates easy detection of crack propagation. Control cube specimens of size 100x100x100mm size were cast with every specimen. Figure 3 shows casting of test specimen.

Figure 3. Casting of test specimen

Figure 4. Short column specimens before testing

2.4 Experimental set up and instrumentation

The columns were tested by placing the columns inside a slab footing. The end conditions of columns were hinged and it was achieved by resting the columns over neoprene pad within the pit. The pit was filled with sand after placing the columns under the loading point, so that the column does not slip during the loading process. The verticality of the column specimens was checked with a plumb bob.

All the short columns were tested for uniaxial compression under a loading frame of capacity of 1000 KN. LVDTs were placed at middle in short columns to measure the lateral deflection of the column. A demountable mechanical strain gauge having a gauge length of 100mm with a least count of 0.002mm was used to measure the axial deformation. Figure 5 shows the test set up.

Figure 5. Test set up

Figure 6. Wrapped short columns

2.4.1 Test procedure
The load was applied by using a load cell of 500 kN capacity. An initial set of 5kN was applied to seat the specimen in position in each test and then the instruments were normalized and initial readings were observed. For short columns, the loads were applied as axial and the axial deformations were measured at mid span of the specimen on all four faces. The average value was used to plot the load versus axial deformation curves. Deflections were measured at mid height using linear variable differential transducers (LVDT).

The load was applied gradually and the deflection was measured at various load stages at regular intervals, at the same time strain values were also measured and observations of initiation of crack and propagation of cracks at different stages of loading, ultimate load to failure and mode of failure were taken.

2.5 Experimental investigation on wrapped columns
The tested columns are wrapped with GFRP wrapping after straightening and filling the cracks.

2.5.1 Procedure for affixing sheets:

- The outer surface of the column is well cleaned and the cracks are filled with either resin when the cracks are relatively small or with cement mortar when cracks are large.
- In Isopthalic resin, catalyst (6%) and accelerator (2%) is added and care has been taken that it has to be stirred well to get appropriate mix.
- Initially this mix fills minor cracks also.
- Resin is applied over the column and is allowed to dry for 10 min.
- When the resin is at the hardening stage, the woven rings GFRP 300gms/Sq.m is wrapped around the column. Roller weights are used to fix the mat firmly over the column.
- After two minutes again a second coat of the mix is applied over the mat for header portion of column and allowed to set.

The GFRP sheets are applied over the long and short column. The Figure 6 shows wrapped short column.

The same testing procedure is followed for wrapped column testing also. The schematic diagram of loading set-up arrangement and LVDT for deflection measurement for short column is shown in the Figure 7.

Figure 7. Experimental set up for wrapped short column

Figure 8. Specimen after testing

2.6 Results and discussion

The cube Compressive Strength results at the various ages such as 3,7,28,56 and 90 days, for the water binder ratio of 0.3 and at the replacement levels such as 0%,5%,7.5% and 10% of silica fume and the same % of replacement with 10% constant replacement with fly ash are presented in Table 5. The development of compressive strength with age for different percentages of silica fume and fly ash were plotted in the form of graphs in Figures 11 (a) & (b).

Table 3: Mix proportions quantities in kg/m^3

Mix	Cement (kg/m^3)	SF (kg/m^3)	FA (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	SP (Lit/m^3)
M1	571.57	0	0	610.27	1171.8	6.97 (1.5%)
M2	542.99	28.58	0	599.81	1171.8	8.83 (1.9%)
M3	528.7	42.87	0	594.58	1171.8	9.23 (2%)
M4	514.41	57.16	0	589.35	1171.8	9.75 (2.1%)
M5	485.83	28.58	57.16	577.28	1171.8	16.72 (3.6%)
M6	471.55	42.87	57.16	572.05	1171.8	17.19 (3.7%)
M7	457.26	57.16	57.16	566.82	1171.8	17.19 (3.7%)

Figure 9. Specimen after testing

Figure 10. Specimen after testing

From the results it was observed that the maximum compressive strength is obtained for mixes with 7.5% silica fume and 5% silica fume with 10% fly ash at all ages and for the water binder ratio of 0.3.

Table 4: Description of specimens for short columns.

Description of specimen	Description	% of SF	% of FA
SC	Short Column	0%	0%
SSC1	Short SF Column1	5%	0%
SSC2	Short SF column2	7.5%	0%
SSC3	Short SF, Column3	10%	0%
SSFC1	Short SF, FA Column1	5%	10%
SSFC2	Short SF, FA Column2	7.5%	10%
SSFC3	Short SF, FA Column3	10%	10%

For the w/b ratio of 0.3, at all ages, the optimum replacement level of silica fume was found to be 7.5% and silica fume and fly ash was found to be 5 % and 10% respectively. For the same w/b ratio 10% SF and 10% fly ash gives high result at later ages.C-S-H gel is the sources of hardened concrete, as it is the binder, which binds the aggregates together. If the silica fume percentage in the concrete is increased gradually, it reaches a point called an optimum point, where silica fume content is exactly what is required for reaching with the calcium hydroxide present or it may be the reason because of more and dense C-S-H gel act as an impervious layer which may prevent the water to enter through it and thereby preventing further hydration. Therefore excess silica fume added beyond this limit remains as it is, since there would not be any calcium hydroxide to react with free silica fume in concrete does not act as binder and hence will cause a reduction in strength.

Table 5: Compressive strength of concrete mixes with and with out mineral admixtures with water bonder ratio of 0.3 at various ages

Age in days	Compressive strength for 0.3 w/b (MPa)						
	NC	**SF 5%**	**SF 7.5%**	**SF 10%**	**SF 5% FA 10%**	**SF 7.5% FA 10%**	**SF 10% FA 10%**
3	31.67	32	34.33	32.67	33.67	31.33	29
7	42.33	40.67	44.67	40.33	42.33	41	39.33
28	54.67	55	61.33	56.33	58.67	57.33	55.33
56	61.33	61.67	69.67	65.67	68.67	68.33	60.33
90	66.67	67.67	76.33	71.67	74.33	73.67	67.33

Table 6: Splitting tensile strength of concrete mixes with different replacement level of SF, SF & FA, MK and MK&FA at 28 days

w/b	Tensile strength (MPa)						
	NC	**SF 5%**	**SF 7.5%**	**SF 10%**	**SF 5% FA 10%**	**SF 7.5% FA 10%**	**SF 10% FA 10%**
0.3	4.99	5.03	5.83	5.09	5.62	5.19	5.01

Flexural Strength

Table 7: Flexural strength of Concrete mixes with different replacement level of SF,SF & FA, MK and MK&FA at 28 days

w/b	Flexural strength (MPa)						
	NC	**SF 5%**	**SF 7.5%**	**SF 10%**	**SF 5% FA 10%**	**S 7.5% FA 10%**	**SF 10% FA 10%**
0.3	4.59	5.13	5.96	5.23	5.71	5.36	5.9

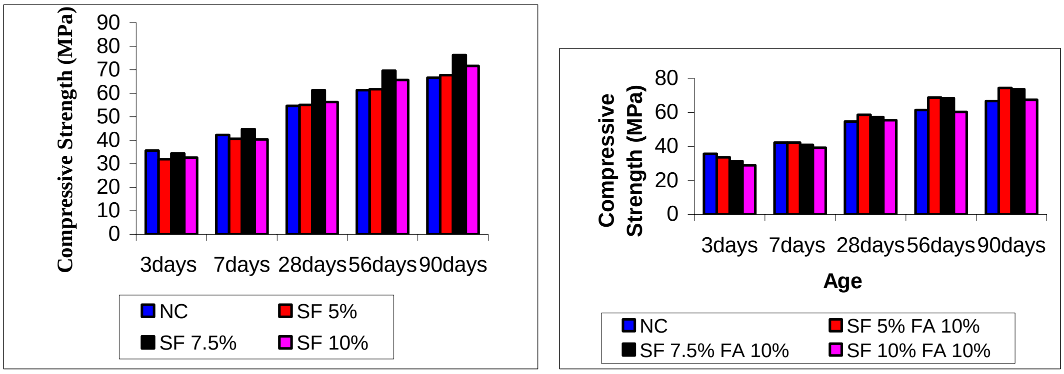

Figure 11. Compressive strength of concrete mixes with w/b ratio of 0.3 Silica fume (b) silica fume with fly ash

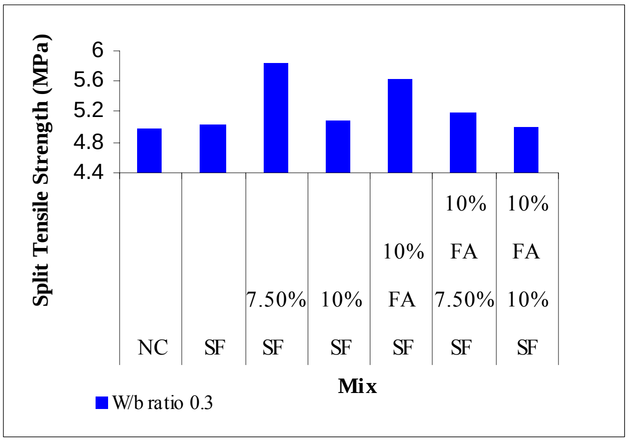

Figure 12. Split tensile strength of concrete mix for a w/b ratio 0.3

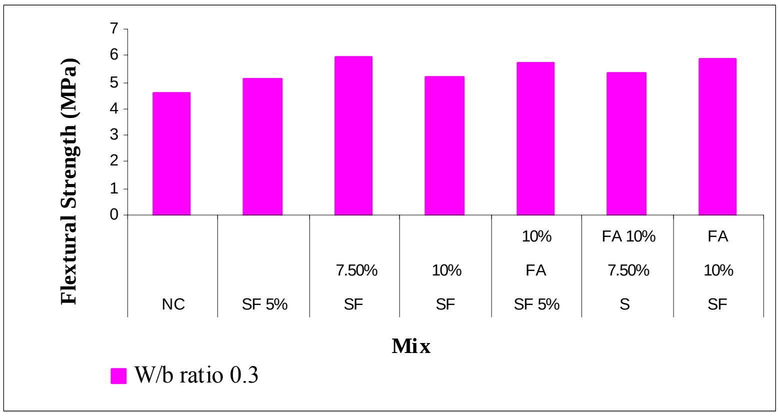

Figure 13. Flexural strength of concrete mix for a w/b ratio 0.3

The summary of test data of short column is given in Table 8. Generally, when a column is subjected to axial load, it fails either due to buckling, depending on the slenderness effect, material properties, eccentricity of the applied load and its end conditions. If a column is perfectly straight and short and subjected to axial load, it does not develop any appreciable bending, fails by crushing. In such failures, concrete fails by crushing and shearing outwards along the inclined planes in addition to the vertical cracks due to the tensile stress developed in outward direction. The Compressive stress and Ductility indices are shown in Table 9.

Table 8: Test results of short columns

Specimen details	% of SF/MK	% of Flyash	First crack load (kN)	Ultimate load (kN)	Deflection at ultimate load (mm)
SC	0	0	164	196	0.86
SSC1	5	0	147	192	0.90
SSC2	7.5	0	192	238	1.5
SSC3	10	0	168	225	1.01
SSFC1	5	10	187	230	1.34
SSFC2	7.5	10	170	223	1.05
SSFC3	10	10	156	189	0.65

The short column with 7.5% of Silica Fume (SSC2) had the maximum ultimate load carrying capacity of 238 kN. This is 1.21 times higher than the load carrying capacity of control Column (SC). The deflection at ultimate load is also 1.74 times higher when compared with control Column (SC). The column SSFC1 had the ultimate load carrying capacity of 230kN. This is 1.17 times higher than the control column. It was observed that the columns cast with Silica Fume and Silica Fume with Fly Ash shows higher load carrying capacity compared to control column except SSC1 and SSFC3. The increase in ultimate load carrying capacity for other columns when compared to the control column is 0.97%, 21.42%, 14.79%, 17.34%, 13.77% and 0.96% of SSC1, SSC2, SSC3, SSFC1, SSFC2, SSFC3 respectively compared with SC. The deflection values are increasing for SSC2 and SSFC1.

2.7 Load axial deformation curves

Short columns with axial load did not show appreciable deflection before failure and failed suddenly when the load reached the ultimate load.

The axial deformation varies from 0.0065D to 0.015D. This may be due the initial imperfections and the proportions of the admixtures. The maximum axial deformations were observed as 1.5mm with SSC2. The Axial deformations of column SSC2, SSFC1 were higher than SSC3. This shows the brittle nature of SF.

(Malathy and Subramanian et al. the workability of SF concrete decreases with increase in the SF content. The concrete mix becomes harsh, dry, cohesive and strongly stiff at SF content more than 10%).

The maximum axial deformation was observed as 1.5mm with SSC2. It shows that along with SF the column becomes flexible and axial deformation of SSFC1 is 1.34mm. (The workability of concrete mix is increased with flyash). The specimens with both SF and FA show higher deformations compared with control mix column.

The column with 7.5% SF (SSC2) has the highest load carrying capacity. This is 1.21 times higher than the load carrying capacity of control column. The load carrying capacity of SF column shows higher values compared with control and other mix of silica fume columns. The reason for improvement in the properties is due to filler-effect and pozzolanic reaction achieved due to micro-silica.

In general, all columns, failed at column head and base at column support i.e. premature failure. Sudden explosive sound was observed during failure for all the columns. This is due to brittle nature i.e. the columns are stiffer. The brittle nature of HSC can be controlled by suitably confining the column in compression zone.

SC shows head failure, cracks observed at column head for a length of 0.21D from top.

SSC1 column developed a crack along the length of the column for a length of 0.35L from the head at top support. Crack observed at base for about 0.13L length from base.

SSC2 column developed a crack along the length of the column for a length of 0.26L from the head at top support. Spalling of concrete cover observed at base.

SSC3 shows column head failure, crack developed for a length of 0.17L from column head. Spalling of concrete observed at base.

SSFC1 shows column head failure, crack developed for a length of 0.91 from column head. Spalling of concrete observed at base.

SSFC2 shows column head failure, crack developed for a length of 0.0.39L from column head. Cracks were observed at base.

SSFC3 shows column base failure, crack developed for a length of 0.24L from column head.

2.8 Ductility

Although columns under axial compression usually behave in a brittle manner, the specimens tested in this study did show some ductility. The column ductility was obtained form the Load- axial deformation curves. The Ductility index (μ) was defined as Au / Ap. Where Au is the area under the load-deformation curve before the load drops to 25% of the maximum load, and Ap is the area under the load-deformation curve up to peak load. The values for μ are shown in Table 9. Each column had a large μ value than control mix column. Maximum value was observed with SSC3, SSC2 and SSFC1 higher than the control mix. Since ductility is the requirement of earthquake resistant structures, concrete with silica fume and flyash or silica fume can be used for construction of seismic resistant structures. Figure 14 shows the load versus axial deformation curves of short column.

Table 9: Compressive strength and ductility index

Description of test specimens	Compressive strength of column (MPa)	Compressive strength of cube (MPa)	Compressive strength index	Ductility index (μ)
SC	19.6	54.67	0.358	0.358
SSC1	19.2	54.33	0.35	0.35
SSC2	23.8	61.33	0.39	0.39
SSC3	22.5	56.33	0.40	0.40
SSFC1	23.0	58.67	0.39	0.39
SSFC2	22.3	57.33	0.388	0.388
SSFC3	18.9	51.33	0.36	0.36

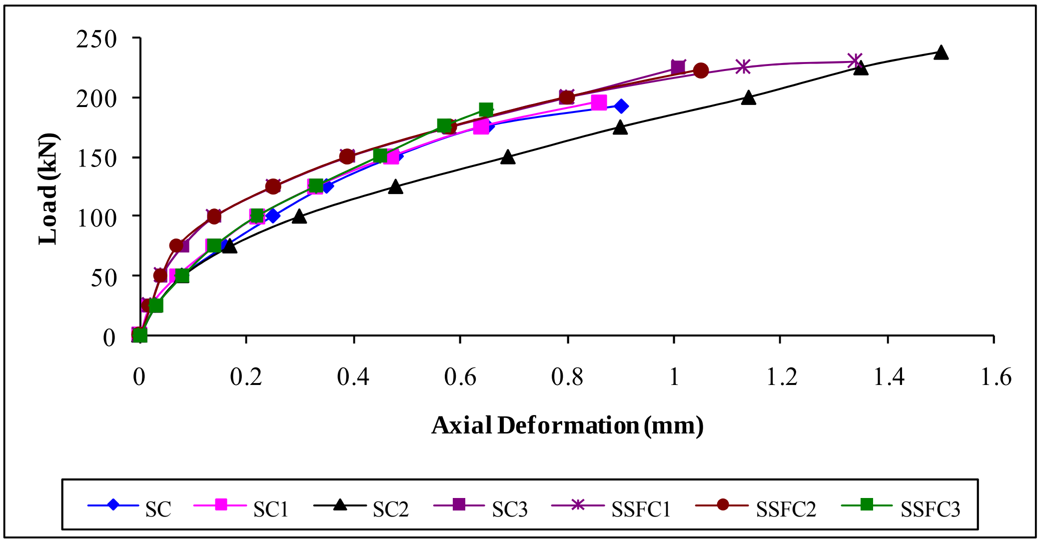

Figure 14. Load Vs axial deformation curve for short column with w/b ratio of 0.3

2.9 Rehabilitated short column

Testing of rehabilitated column was carried out as per the procedure of short column and the experimental set up stated in Figure 5. The mode of failure of GFRP-Wrapping for rehabilitated short column is shown Figure 13.

Figure 15. Specimen after testing

2.10 Test results and discussion

The summary of the GFRP wrapping for short column test results are tabulated in Table 10.

Even though the GFRP and R.C column combination is a composite action, the most of the load is carried by the GFRP alone. After the failure of GFRP the ultimate load is reached. The Ultimate load carrying capacities of wrapped columns are almost equal to unwrapped column in some cases. In some columns the load carrying capacity has been enchanced compared with unwrapped columns.

Table 10: Failure of GFRP wrapping for short column

Description	**Ultimate load (kN)**	**Deflection at ultimate load (mm)**	**Notifications**
SC	183	0.76	Tearing of fibers with bursting sound and sudden failure at header portion of column.
SSC1	198	0.87	Crushing of concrete at ultimate load at column head.
SSC2	243	1.56	Snatching of fiber, no sudden failure. Cracks developed at head and base.
SSC3	230	1.10	Tearing of fibers at column head.
SSFC1	238	1.40	Tearing of fibers at the column head and base.
SSFC2	229	1.08	Sudden failure of column base with tearing of fibers with bursting sound.
SSFC3	195	0.72	Snatching of fiber, concrete crushed at head and base of column.

2.11 Comparison between conventional and rehabilitated short column

The comparison of ultimate load carrying capacity of and deflection between conventional and wrapped columns are shown in the Table 12.

Table 12: Comparison between conventional and rehabilitated short columns

Specimen	Conventional columns		Rehabilitated columns	
	Ultimate load (kN)	**Deflection (mm)**	**Ultimate Load (kN)**	**Deflection (mm)**
SC	196	0.86	183	0.76
SSC1	192	0.90	198	0.87
SSC2	238	1.50	243	1.56
SSC3	225	1.01	230	1.10
SSFC1	230	1.34	238	1.40
SSFC2	223	1.05	229	1.08
SSFC3	189	0.65	195	0.72

2.12 Load versus deflection curves for wrapped short column

Load versus Deflection curves for the rehabilitation short column specimen tested are shown in Figure 16 to 22. Table 8 shows axial deformation of rehabilitated short column specimens SC, SSC1, SSC2, SSC3, SSFC1, SSFC2 and SSFC3.

Table 10: Test Results of rehabilitated short columns

Description of test specimens	**Ultimate load (kN)**	**Axial deformation (mm)**	**Stiffnessx10^5 (N/mm)**
SC	183	0.76	2.40
SSC1	198	0.87	2.27
SSC2	243	1.56	1.56
SSC3	230	1.10	2.10
SSFC1	238	1.40	1.70
SSFC2	229	1.08	2.10
SSFC3	195	0.72	2.70

Table 11: Compressive strength and ductility index

Description of test specimens	Compressive strength of column (MPa)	Compressive strength of cube (MPa)	Compressive strength index	Ductility index (μ)
SC	18.3	54.67	0.334	0.334
SSC1	19.8	54.33	0.36	0.36
SSC2	24.3	61.33	0.396	0.396
SSC3	23.0	56.33	0.41	0.41
SSFC1	23.8	58.67	0.40	0.40
SSFC2	22.9	57.33	0.39	0.39
SSFC3	19.5	51.33	0.37	0.37

Table 12: Comparison between Conventional and Rehabilitated Short Columns

Specimen	Conventional Columns		Rehabilitated Columns	
	Ultimate Load (kN)	Deflection (mm)	Ultimate Load (kN)	Deflection (mm)
SC	196	0.86	183	0.76
SSC1	192	0.90	198	0.87
SSC2	238	1.50	243	1.56
SSC3	225	1.01	230	1.10
SSFC1	230	1.34	238	1.40
SSFC2	223	1.05	229	1.08
SSFC3	189	0.65	195	0.72

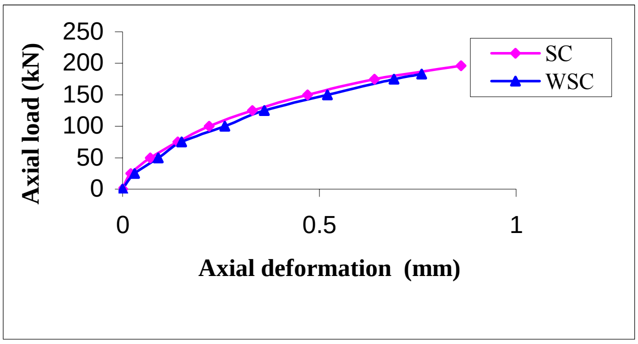

Figure 16. Comparison of load vs axial deformation curve for wrapped and unwrapped control column

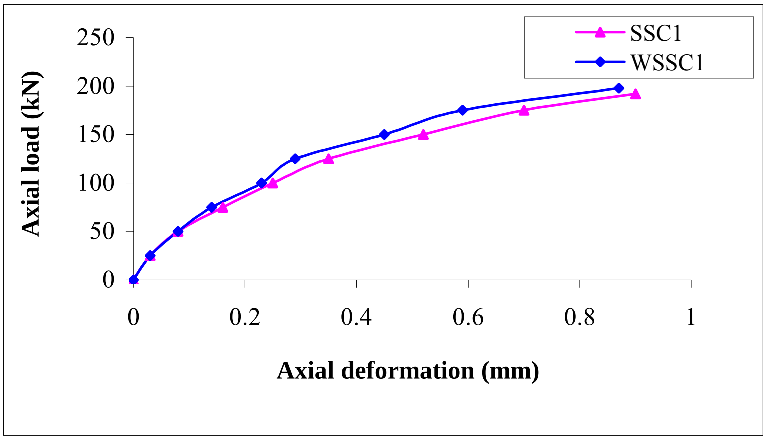

Figure 17. Comparison of load vs axial deformation curve for SSC1 & WSSC1

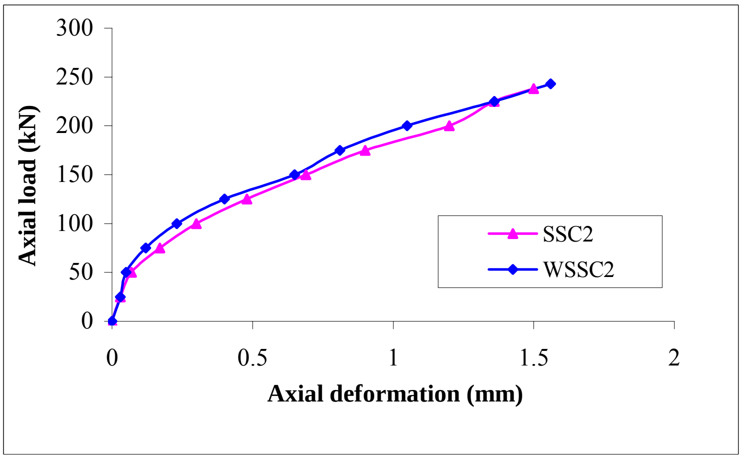

Figure 18. Comparison of load Vs axial deformation curve for SSC2 & WSSC2

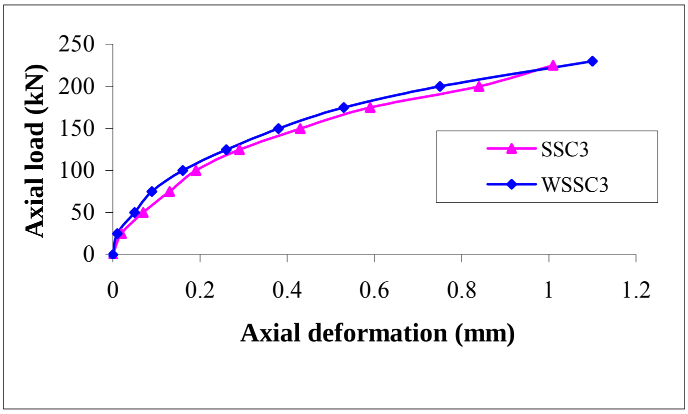

Figure 19. Comparison of load vs axial deformation curve for SSC3 & WSSC3

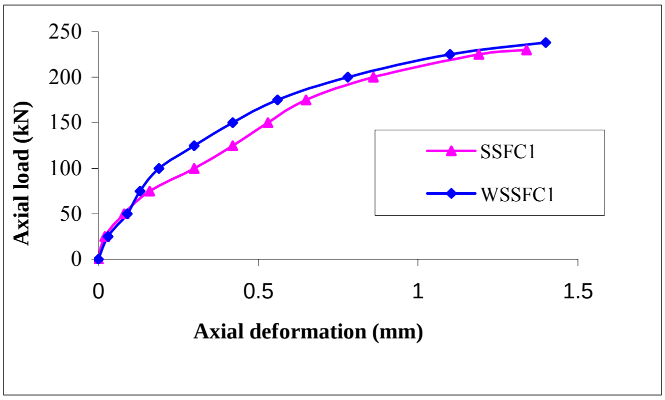

Figure 20. Comparison of load vs axial deformation curve for SSFC1 & WSSFC1

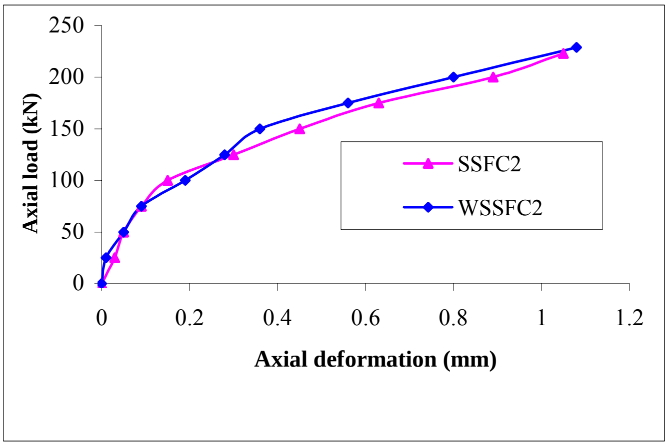

Figure 21. Comparison of load vs axial deformation curve for SSFC2 & WSSFC2

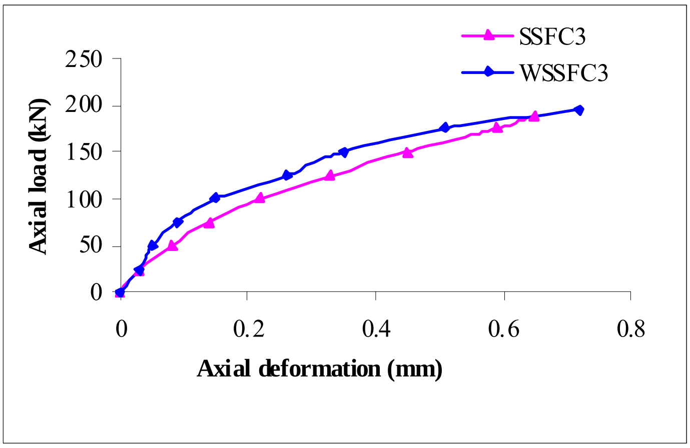

Figure 22. Comparison of load vs axial deformation curve for SSFC3 & WSSFC3

3. CONCLUSIONS

- The super plasticizer demand of concrete containing fly ash and silica fume increases with increasing amount of fly ash and silica fume. The increase is primarily due to the high surface area of the fly ash and silica fume.
- Fresh concrete containing fly ash and silica fume is more cohesive and less prone to segregation.
- SF and FA column undergoes more deformation than that of control columns of same area of steel, which shows that along with fly ash and silica fume shows the ductile behavior.
- The short column with (SSC2) 7.5% SF shows higher value of ultimate capacity which is 21.4% higher than the control column (SC) and also it shows the ductile behavior.
- The short column with (SSFC1) 5% SF and 10% FA shows higher value of ultimate capacity which is 14.7% higher than the control column (SC).
- The stiffness was observed higher for short column (SSFC3) with 10% SF and 10% FA.
- Mode of failure observed for short columns were due to the lack of lateral confinement.
- The Ultimate load carrying capacity of wrapped columns is slightly increased when compared to unwrapped columns.
- Hence GFRP sheets can play a major role in the field of repairing of damaged columns and buildings.

REFERENCES

1. Andrew Maas PE, Jason H, Ideker, Juenger MCG. Alkali silica reactivity of agglomerated silica fume, *Cement and Concrete Research*, **37**(2007) 166-74.
2. Andrea Prota, Gaetano Manfredi, Edoardo Cosenza. Ultimate behaviour of axially loaded RC wall like columns confined with GFRP, *Journal of Composites,* Part B, **37** (2006) 670-8.
3. ACI committee 363. Guide for the silica fume in concrete. Detroit: American Concrete Institute; 1994.
4. Bhanja S, Sengupta B. Influence of silica fume on the tensile strength of concrete, *Cement and Concrete Research Journal* **35**(2005)743-7.
5. Bilodeau A, Malhotra VM. High-volume fly ash system: concrete solution for sustainable development, *ACI Materials Journal* 97910(2000)41-9.
6. Chaallal O, Shahawy M. Performance of fiber reinforced polymer wraped reinforced concrete column under combined axial-flexural loading, *ACI Structural Journal*, No. 4, **97**(2000)659-69.
7. Ershad U. Chowdhury, Luke A. Bisby, Mark F. Green, Venkatesh K.R. Kodur. Investigation of insulated FRP-wrapped reinforced concrete columns in frie, *Fire Safety Journal* **42**(2007) 452-60.
8. Hadi MNS. Behabiour of FRP wrapped normal strength concrete columns under eccentric loading, *Journal of Composite Structures* ,72(2006) 503-11.
9. Halit Yazic. The effect of silica fume and high volume class C fly ash on mechanical

properties, chloride penetration and freeze-thaw resistance of self compacting concrete, *Construction and Building Materials Journal*, **22**(2008) 456-62.

10. Khedr SA, Abou-zeid Mn. Characteristics of silica fume concrete. *Journal of Materials in Civil Engineering ASCE*, No. 3, **6**(1994) 357-75.
11. Okan Ozcan, Baris Binici, Guney Ozcebe. Improving seismic performance of deficient reinforced concrete columns using carbon fiber –reinforced polymers, *Journal of Engineering Structures* **30**(2008) 1632-46.
12. Parvin A, Wang W. Behaviour of FRP jacketed concrete columns under eccentric loading. *Journal of Composites for Construction ASCE*, No. 3, **5**(2001) 146-52.
13. Sabir BB. High strength condensed silica fume concrete, *Magazine of Concrete Research* No. 172, **47**(1995) 219-26.
14. Toutanji HA, Bayasi Z. Effect of curing procedures on properties of silica fume concrete, *Cement and Concrete Research,* No. 4, **29**(1999) 497-501.
15. Yeginobali A, Sobolev KG, Soboleva SV, Kiyici B. Thermal resistance of blast furnace slag high strength concrete cement. In: *The 1st International Symposium on Mineral Aadmixtures in Cement. Turkey,Istanbu*l, 1997, pp. 106-117.
16. Yogendran V, Langan BW, Haque MN, Ward MA. Silica fume in high strength concrete, *ACI Materials Journal* No. 2, **84**(1982)124-9.
17. Yung-Chin Wang, Hsu K. Design of FRP-wrapped reinforced concrete columns for enhancing axial load carrying capacity. *Journal of Composite Structures*, **82** (2008)132-9.