Effect of Cement Replacement by Silica Fume on Compressive Strength of Glass Fiber Reinforced Concrete

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Abstract—**The present study focuses on the preparation of high performance concrete by employing industrial waste to preserve the natural raw ingredients of concrete. In this regard, an attempt was made to investigate the combined effects of incorporating glass fibers and silica fume on compressive strength of concrete. Glass fibers were added in ratio of 0%, 0.5%, 1.0% and 1.5%. Also, cement was partially replaced with silica fume by 0%, 5%, 10% and 15% by weight of cement. Compressive strength test was carried out on standard specimens cast by composite mixes prepared in this way. Slump test was also carried out on all mixes before casting test specimens to ascertain workability of fresh concrete. It was found that compressive strength of GFRC increased with the increase in percentage of SF replacement and glass fiber content. Maximum compressive strength of GFRC was obtained at 15% replacement of cement with SF. Furthermore, it was also found that addition of silica fume facilitated the early high strength of GFRC.**

***Index Terms*—Pozzolana, Replacement level, Mix ratio, GFRC, Workability, Silica fume, Water binder ratio.**

I. Introduction

Portland cement is the most significant constituent of concrete. Its massive production is triggering the environmental problems as well as the depletion of natural resources. Rapid advancement in environmental awareness and its probable hazardous effects has led the researchers to use industrial by-products as supplementary cementitious material to produce concrete. Among these by-products silica fume is used for increasing compressive strength of concrete by partly substituting cement with it.

Silica fume is derivative of the smelting phenomena in silicon and ferrosilicon industry. It is considered as a pozzolanic admixture and is very effective in improving the mechanical properties. Ref. [1] Compressive strengths of 100 MPa to 150 Mpa can be easily obtained in laboratory by using silica fume with different super plasticizers. Ref. [2] Concrete has a brittle character and weak tensile behavior. Strength and ductility of concrete can be increased by the use of reinforcement in concrete, but it requires careful placement by skilled labor. Alternatively, better solution may be provided by intrusion of fibers to concrete. Concrete becomes homogeneous and isotropic material after the addition of fibers. When concrete fails, the haphazardly distributed fibers facilitate in halting crack development and propagation, and therefore improving strength and ductility.

Ref. [3, 4] Fiber reinforced concrete consists of hydraulic cement, aggregates and reinforcing fibers. It is somewhat new material and has high tensile strength. It consists of composite and uneven scattered fibers. Uniform distribution of fibers increases the cracking strength of concrete. GFRC is significant cement based compound which employs fine sand, cement, water, admixtures and alkali-resistant glass fibers. Glass fibers are similar in role as steel reinforcement and are principal tensile-load carrying members.

Ref. [5, 6] Ghorpade studied the behavior of glass fibers in High Performance Concrete by using silica fume in different percentages and found that performance of concrete was improved at 1% fiber volume. On comparison between metakaolin and silica fume it was found that for a specific mixture metakaolin showed better workability than the silica fume. Also, the strength of MK amended concrete showed an increase in strength at all ages with the increase in replacement.

Ref. [7, 8] Compressive strength of concrete reinforced with steel fibers having 8% silica fume by weight of cement was found to be increased up to 32.4% at 1% fiber volume along with increase in tensile strength up to 74% at 1% steel fiber content. 0.5% polypropylene fiber in the silica fume mix enhances compressive strength, split tensile strength, flexural strength, and mainly the behavior of concrete in terms of impact loading.

Ref. [9] Impact of joint action of silica fume as well as limestone on strength improvement, porosity, pore-structure and organizational features of the system have been studied and it was recognized that total porosity of mortars was significantly increased when cement was replaced with finely ground limestone equal to 15%. Limestone reduces the porosity, if silica fume is replaced up to 8%. Increase in porosity is observed if silica fume is added more than 8 %. Ref. [10, 11] Polypropylene fibers had no significant effect on the modulus of elasticity and

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compressive strength of lightweight self-compacting concrete. However, by adding these fibers durability, tensile and flexural characteristics are improved. Ref. [12] Sadrmomtazia et. al., investigated the effects of silica fume on mechanical strength and microstructure of basalt fiber reinforced cementitious composites (BFRCC) and found favorable results.

II. EXPERIMENTAL PROGRAM

The aim of experimental program was to find out the effect of addition of silica fume as partial replacement of cement on overall improve the performance of concrete as well as to utilize industrial waste in concrete to preserve the natural raw ingredients of concrete.

Besides that, intrusion of glass fibers was also done in the mix to improve the tensile properties and ductility of concrete. Typical concrete mix ratio (1:2:4), being widely used in Pakistan, have been worked out at different cement replacement levels with SF. Silica fume (SF) was used in 0%, 5%, 10%, and 15% replacement ratios whereas glass fibers were used in 0%, 0.5%, 1% and 1.5% by weight of cement. Water binder ratio used was 0.6. To determine the compressive strength of the matrix, 144 cube samples were cast. After casting, test specimens were de-molded after 24 hours and kept in the curing tanks up to their specified time of testing.

Out of 144 cube samples (150x150x150 mm size), 48 specimens were tested for “3 day’s compressive strength”, 48 samples for “7 day’s compressive strength” and remaining 48 samples were tested to find out “28 day’s compressive strength”.

A. Mixing Schedule

The concrete mixes with different percentages of glass fibers and fixed percentages of silica fume are detailed in Table 1. A total no of 16 different mixes were prepared. SF was used as cement replacement material while GF was additionally mixed.

III. RESULTS & DISCUSSION

A. Compressive Strength

1) Compressive strength at constant SF content

The results of compressive strength test carried out on samples having normal mix ratio 1:2:4 and w/b ratio of 0.6, with different percentages of cement replacement by SF in GFRC are given in Figs. 1–4. These figures indicate variation in compressive strength of glass fibered reinforced concrete at different replacement levels of silica fume.

Fig. 1 shows 3, 7, and 28 day’s compressive strength of GFRC at 0% replacement of silica fume. It is evidently clear that improvement in compressive strength is not related to subsequent increase in fiber content. Maximum strength was achieved at 1.5% fiber content for 3, 7 and 28 days. Compressive strength at 1.5% glass fibers was 19.3%, 19.6% and 10.4 % more as compared to control mix for 3, 7, and 28 day’s respectively. Thus, it can be inferred that increase in strength was more pronounced for 3 and 7 day’s strength.

TABLE I. MIXING SCHEDULE

Sr No.	Mix designation	Mix details
1	$S_0 G_0$	OPC (Control Mix)
2	$S_0G_{0.5}$	OPC + 0.5% GF
3	$S_0G_{1.0}$	OPC + 1.0% GF
4	$S_0G_{1.5}$	OPC + 1.5% GF
5	$S_5 G_0$	5% SF + 0% GF
6	$S_5G_{0.5}$	5% SF + 0.5% GF
7	$S_5G_{1.0}$	5% SF + 1.0% GF
8	$S_5G_{1.5}$	5% SF + 1.5% GF
9	$S_{10} G_0$	10% SF + 0% GF
10	$S_{10}G_{0.5}$	10% SF + 0.5% GF
11	$S_{10}G_{1.0}$	10% SF + 1.0% GF
12	$S_{10}G_{1.5}$	10% SF + 1.5% GF
13	$S_{15} G_0$	15% SF + 0% GF
14	$S_{15}G_{0.5}$	15% SF + 0.5% GF
15	$S_{15}G_{1.0}$	15% SF + 1.0% GF
16	$S_{15}G_{1.5}$	15% SF + 1.5% GF

The compressive strength of GFRC is shown in Figure 2 at different ages for 5% replacement of silica fume. Graphical representation shows a notable improvement in compressive strength at all ages for different fiber contents.

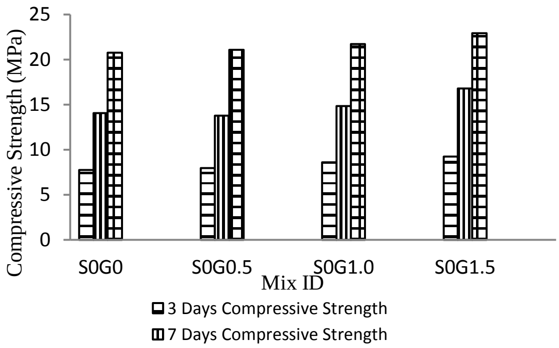

Figure 1. Fiber content versus compressive strength without SF replacement

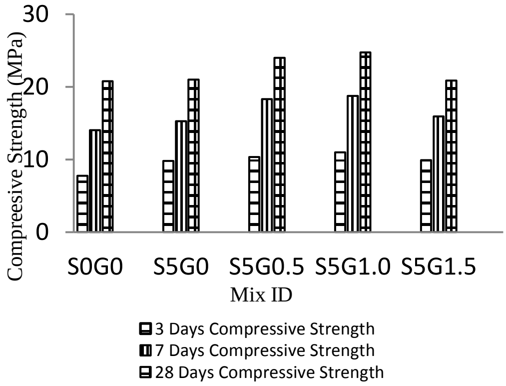

Figure 2. Fiber content versus compressive strength at 5% SF replacement

Maximum compressive strength was achieved at 1% glass fibers for the same percentage of silica fume i.e. 5%. 3, 7 and 28 day’s strength of the mix containing 1% GF is

12%, 22.5% and 17.96% greater than the mix with 0% fiber content and 5% replacement level of silica fume. Similarly, when compared with the control mix, increase in 28 day's compressive strength was 19.2%. Graphical representation also shows that increase in strength was more for 3 and 7 day's age. Increase in early strength is due to fineness of silica fume particles. Larger surface area of silica fume leads to rapid pozzolanic reaction and hence early high strength is achieved. Fig. 3 describes the effect of 10% replacement of silica fume with different ratios of fiber content. Results show that cube compressive strength increases with the increase in GF up to 1% and then decreases for the same replacement level. Maximum increase in 28 day's strength is 34.6% as compared to control mix. There is no change in 3 day's strength when glass fiber percentage increases from 0.5% to 1% while 7 day's and 28 day's strength shows a slight increase. Maximum increase in strength as compared to mix ratio with 0% fiber and 10% silica fume is 29.2% which is shown at the age of 7 days.

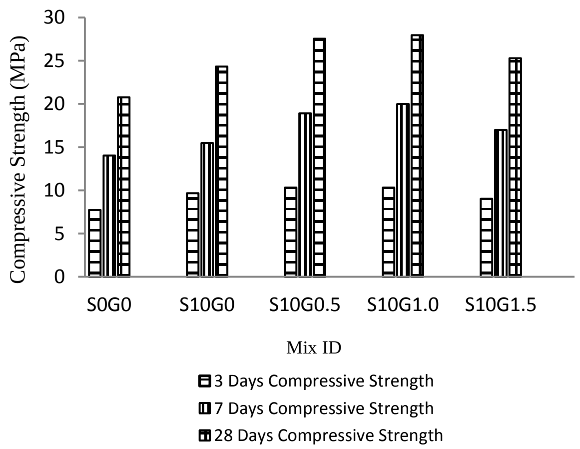

Figure 3. Fiber content versus compressive strength at 10% SF replacement

Fig. 4 illustrates cube compressive strength of the mix having 15% replacement level of SF at the age of 3, 7 and 28 days. Graphical representation show that overall maximum strength is obtained at 15% replacement with SF. Increase in strength is greater from 5% to 10 % replacement whereas lesser gain in strength is observed from 10% to 15% replacement. Similarly, the values at 3, 7 and 28 day's age for 1% fiber content are 9.75%, 36.7% and 6.5% greater than the mix containing 0% fiber and 15% SF. Results show that cube compressive strength increases with the increase in GF up to 1% and then decreases for the same replacement level. Increase in 28 day's compressive strength is 35.8% w.r.t control mix for 1% fiber content. The reason behind increase in compressive strength as per increase in replacement level may be due to silica fume which contains nearly 85% highly reactive SiO_2. Calcium silicate was produced as result of reaction with $Ca(OH)_2$, which has high cementitious properties leading to the high compressive strength.

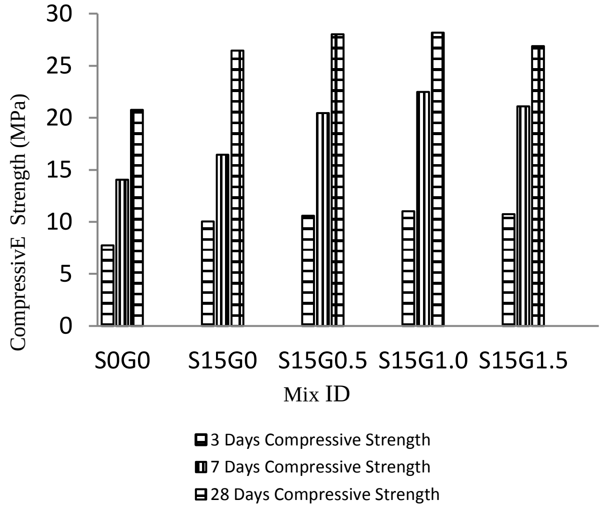

Figure 4. Fiber content versus compressive strength at 15% SF replacement

2) Compressive strength at constant GF content

Results of compressive strength of concrete at constant fiber content with variable silica fume percentage are shown in Figs. 5-8. The increase in compressive strength of concrete compared to different percentages of silica fume without addition of glass fibers shown in Fig. 5. Maximum increase in 3, and 28 day's strength is 29.7% and 27.5% respectively with respect to control specimen. Increase in early strength may be due to the fineness of silica fume particles. Higher surface area of silica fume leads to rapid pozzolanic reaction and hence early high strength is achieved.

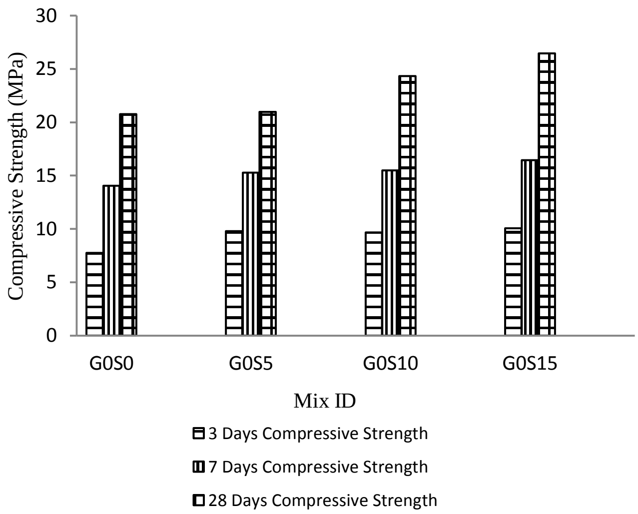

Figure 5. Replacement level versus compressive strength without fiber content

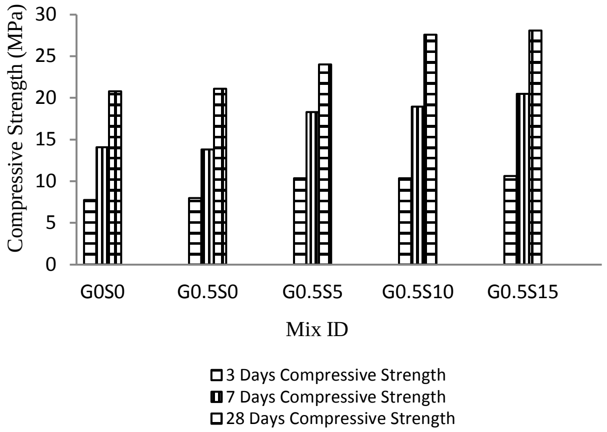

Figure 6. Replacement level versus compressive strength at 0.5 % fiber content

Fig. 6 shows the compressive strength at 0.5% fiber content with variable silica fume content .i.e. 5%, 10% and 15%. Increase in 3 and 7 day's strength from 5% to 10% SF is not much significant whereas maximum strength is achieved at 15% silica fume content.

Fig. 7 shows the compressive strength at 1.0% GF content with different SF ratios. Results show that strength increases by increasing the SF content. 3 day's strength decreases at 10% SF content and then again increases. Overall maximum strength was obtained at 1% fiber content. Increase in 28 day's strength is greater from 5% to 10% replacement whereas lesser gain in strength is observed from 10% to 15% replacement. Previous researches have shown that a decrease in strength is observed after 20% replacement level. (Ghorpade 2010). Fig. 8 shows the compressive strength with 1.5% glass fiber content at different SF replacement levels. It can be clearly seen that overall increase in strength is less than those obtained at 1.0% GF. Maximum strength is 29.6% greater than that of control mix which is obtained at 15% replacement.

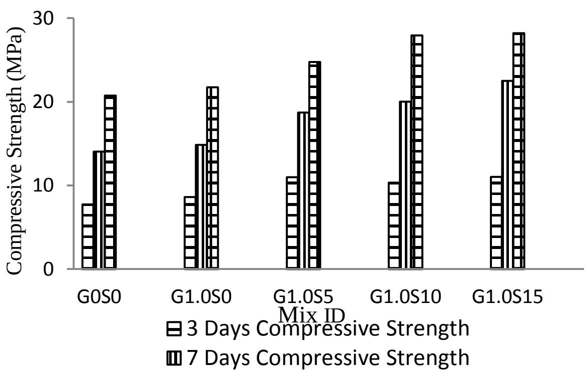

Figure 7. Replacement level versus compressive strength at 1.0 % fiber content

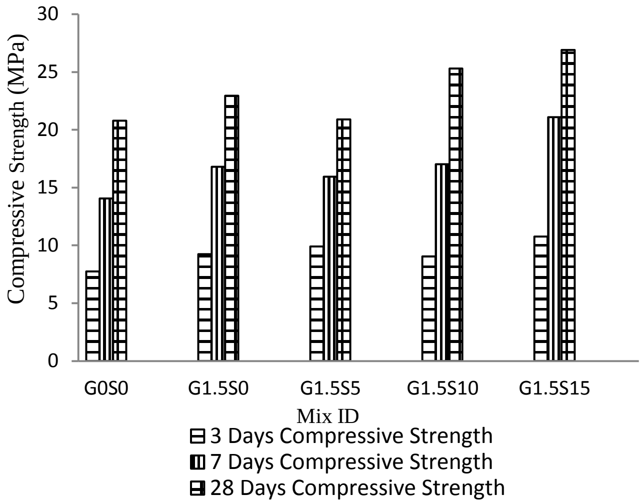

Figure 8. Replacement level versus compressive strength at 1.5 % fiber content

3) Maximum compressive strength results among different replacement levels

Figure 9 displays the graph between maximum compressive strength values from each replacement level with different fiber contents. Comparison between maximum strength for each replacement level is done to find out the optimum mix with maximum strength. Graphical description shows that overall maximum strength was achieved with 15% SF replacement and 1% fiber content but increase in strength was not so much significant from 10% to 15% replacement.

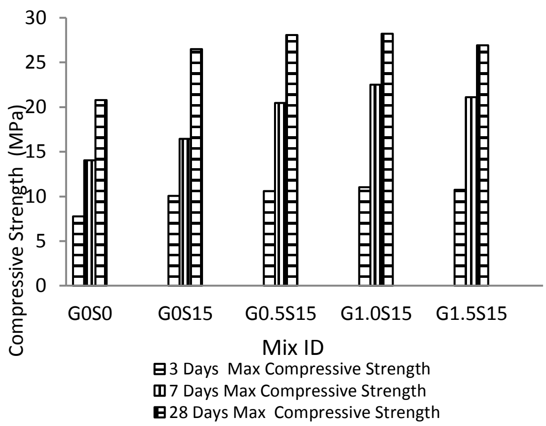

Figure 9. Maximum compressive strength from each replacement level with different fiber content

B. *Workability*

The workability of glass fibered reinforced concrete for different replacement levels of SF by weight of cement, at constant mix and w/c ratio was measured by slump test. Results are given in Table 2. Maximum workability is sown by the control mix while the other mixes show a gradual reduction in workability. It is quite clear that the need of super plasticizer/water reducing admixture cannot be ignored while using SF as cement replacement material in GFRC to achieve required workability.

TABLE II. SLUMP TEST RESULTS

Sr. No.	Mix designation	Avg. slump value (mm)
1	$S_0 G_0$	60
2	$S_0G_{0.5}$	54
3	$S_0G_{1.0}$	50
4	$S_0G_{1.5}$	48
5	$S_5 G_0$	57
6	$S_5G_{0.5}$	51
7	$S_5G_{1.0}$	40
8	$S_5G_{1.5}$	34
9	$S_{10} G_0$	40
10	$S_{10}G_{0.5}$	32
11	$S_{10}G_{1.0}$	22
12	$S_{10}G_{1.5}$	18
13	$S_{15} G_0$	21
14	$S_{15}G_{0.5}$	19
15	$S_{15}G_{1.0}$	17
16	$S_{15}G_{1.5}$	14

IV. CONCLUSIONS

Compressive strength of GFRC increases with the increase in percentage of SF replacement. Maximum compressive strength is obtained at 15% replacement with SF.

Compressive strength resulted increase with the increase in GF ratio up to 1% and then decreases for the same replacement level.

Maximum increase in 28 day's compressive strength is 35.8% w.r.t control mix for 1% fiber content at 15% SF replacement level.

Silica fume addition facilitates the early high strength of GFRC. Maximum workability is shown by the control mix while other mixes exhibit a gradual reduction in workability. The need of super plasticizer/water reducing admixture cannot be ignored while using SF as cement replacement material in GFRC to achieve required workability.

Impact of SF as cement replacement material on properties of GFRC could also be explored;

1. By using replacement levels higher than 15%.
2. By using different w/c ratios.
3. By using different mix ratios.
4. Effect of different additives and admixtures.
5. Modulus of elasticity of GFRC with SF as cement replacement material.
6. Study on High strength GFRC with SF as cement replacement material.
7. Shear behaviors of GFRC with SF as cement replacement material

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