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Research Paper

A COMPARATIVE STUDY OF POLYPROPYLENE FIBRE REINFORCED SILICA FUME CONCRETE WITH PLAIN CEMENT CONCRETE

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Concrete is the most widely used construction material because of its mould ability into any required structural form and shape due to its fluid behavior at early ages. The objective of this research is to investigate the workability and flexural strength of cement concrete containing silica fume and polypropylene fibers. Properties studied include workability of the fresh mix and flexural strength of hardened concrete. Silica fume content used was 0%, 5%, 10% and 15% by replacement of equal weight of cement in concrete. Polypropylene fibers were added in 0%, 0.20%, 0.40% and 0.60% by volume fraction of concrete. The experimental test results demonstrated that addition of polypropylene fibers at 0.4% Volume fraction showed considerable gain of flexural strength of 4.95 MPa and 7.32 MPa at 7 and 28 days respectively. The behavior of concrete under flexural loads was found to be consistently improved compared with reference mix design. Results show that the use of 10% silica fume combined with 0.40% fiber volume fraction results in optimum mixture design for applications from the standpoints of workability and flexural strength. Further, flexural strength at the ages of 7 and 28 was also determined and results are included here.

Keywords: Concrete, Flexural strength, Fiber reinforced concrete, Polypropylene fiber, Silica fume, Workability

INTRODUCTION

The inclusion of various types of fibers to improve or modify the mechanical properties of Portland Cement Concrete (PCC) called Fiber Reinforced Concrete (FRC). Fiber reinforced concrete is a most widely used solution for improving tensile and flexural strength of concrete. The reinforcing fibers are randomly distributed in the PCC matrix. Improvement in the mechanical properties of concrete like flexural, compressive strength, ductility, toughness can be attributed to the presence of fiber in concrete matrix.

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The commonly used fibers are steel, glass, polymeric, carbon, asbestos, and natural fibers. The polymeric fiber viz., polypropylene, polyethylene, polyester, acrylic, and aramid fibers are becoming popular these days. Polypropylene fibers, produced by the fibrillation of polypropylene films, have been used in Portland cement concrete since the late 1960s (Bentur and Mindess, 1990). With nominal lengths of 6, 12 or 18 mm, polypropylene fiber is the ideal solution for concrete mixtures susceptible to plastic shrinkage, cracking and crazing. The failure mode of conventional concrete is mainly due to spalling, while the failure mode of fiber reinforced concrete is bulging in transverse direction. Mydin, Roohollah studied the flexural behavior of Light weight Foamed Concrete (LFC) exposed to high temperatures with different PF percentages in range of 0.2 to 0.6% of mix volume and showed improved results (Md Azree *et al.*, 2012; and Roohollah *et al.*, 2012). Peng-Zhang investigated in their work that inclusion of polypropylene fiber greatly improves fracture toughness, decrease crack length and maximum mid-span deflection of the three-point bending beam specimens of concrete composite containing 15% fly ash and 6% silica fume (Peng and Qingfu, 2013). Effect of polypropylene was more pronounced in tension than compression due to the adhesive and friction forces between concrete and Polypropylene fibers. Aly concluded that the overall total shrinkage strain of concrete increases slowly but consistently with increase in volume of PP added (Aly *et al.*, 2008). Samir Shihada concluded that the superiority of RC beams containing polypropylene fibers over those without polypropylene fibers in terms of increased ultimate residual strengths (Samir and Mohammed, 2012). The effects of polypropylene fibers on flexural, compressive and ten-sile strength as well as on toughness and elastic modu-lus is not quite clear (Houssam, 1998). Researchers have studied cement concrete and polypropylene fiber reinforced concrete, however considering reinforcing fibers and silica fume is an innovative approach however considering reinforcing fibers and silica fume is an innovative approach.

Materials: Materials used in whole experimental work included Ordinary Portland cement (43 grade) of Japyee brand, crushed coarse aggregate of size of 20 mm and 10 mm, river sand, silica fume, tap water, Conplast SP430G8 High-Range Water-Reducing Admixture (HRWRA) and polypropylene fibers. The short description of the materials used in the study is given below.

Cement: Ordinary Portland cement of 43 grade of 28 days compressive strength of 44 MPa, satisfying the requirements of IS: 8112 (IS: 8112-1989). The different laboratory tests were conducted on cement to determine fineness, soundness, specific gravity, standard consistency, initial and final setting time and

Table 1: Physical Properties of Ordinary Portland Cement

Physical Property	Results Obtained	IS: 8112-1989 Specifications
Normal consistency	28%	–
Vicat initial setting time (minutes)	75	30 min
Vicat final setting time (minutes)	215	600 max
Compressive strength 7 days (MPa)	36.5	33.0 min
Compressive strength 28 days (MPa)	44	43.0 min

Table 2: Sieve Analysis of Coarse Aggregate (20 mm)

Weight of Sample 2000 gm IS 383-1970				
IS sieve (mm)	**Weight Retained (gm)**	**Cumulative Weight Retained (gm)**	**Cumulative % Weight Retained**	**% Passing**
40	0	0	0	100
20	82.60	82.60	4.13	95.87
10	1866	1948.6	97.43	2.57
4.75	34.60	1983.20	99.16	0.84

Note: Fineness modulus = 7.00.

Table 3: Sieve Analysis of Coarse Aggregate (10 mm)

Weight of Sample 2000 gm IS 383-1970				
IS sieve (mm)	**Weight Retained (gm)**	**Cumulative Weight Retained (gm)**	**Cumulative % Weight Retained**	**% Passing**
20	0	0	0	100
10	86.20	82.60	4.31	95.61
4.75	1823	1909.20	95.46	4.54
2.36	74.20	1983.40	99.17	0.83

Note: Fineness modulus = 5.98.

compressive strength (IS: 4031 (Part-iv,v) 1988). The results conforms to the IS recommendations.

Coarse Aggregate: Grading (IS: 383-1970) of all aggregate should be closely and continuously monitored and must be taken in account in order to produce concrete of constant quality. Coarse aggregates used in this study are crushed aggregate of maximum size 20 mm and 10 mm obtained from Raipur quarry of Rewa. Specific gravity (IS: 2386 (Part-iii) 1963) of coarse aggregates used was 2.754 and 2.705 for 20mm and 10 mm aggregates respectively. Water absorption (Houssam, 1998) value at 24 hours of coarse aggregate and sand are 0.52% and 0.70% respectively (IS: 2386 (Part-iii) 1963).

Table 4: Sieve Analysis of Fine Aggregate

Weight of sample 1000 gm IS 383-1970				
IS sieve (mm)	**Weight Retained (gm)**	**Cumulative Weight Retained (gm)**	**Cumulative % Weight Retained**	**% Passing**
10.0	0	0	0	100
4.75	29.8	29.80	2.98	97.02
2.36	18.8	48.60	4.86	95.14
1.18	67.0	115.60	11.546	88.44
0.6	207.70	323.30	32.33	67.67
0.3	463.8	787.10	78.7	21.29
0.15	196.70	983.80	98.38	1.62

Note: Fineness modulus = 2.29.

Table 5: Combined Sieve Analysis of Coarse Aggregate

Weight of Aample 1000 gm IS: 383-1970

IS sieve (mm)	Aggregate % Passing		Blending Proportion		Total 100%	Mid Point
	20 mm	10 mm	59% 20 mm	41% 10 mm		
40	100	100	59	41.00	100%	100
20	95.87	100	56.56	41.00	97.56	97.56
10	2.57	95.61	1.52	39.20	40.72	40.72
4.75	0.84	4.54	0.50	1.86	2.36	2.36

Fine Aggregates: Fine aggregate used in the study is river sand which was obtained from Gopad River at Barpan (Sidhi) and confirms to zone III (IS: 383-1970). Specific gravity and water absorption value (IS: 2386 (Part-iii) 1963) of sand used was 2.553 and 0.8% of wt. respectively.

Polypropylene Fiber: Polypropylene fibers used in this study are Walia Fibercon-CF and purchased from Walia International Machines Corporation, Janakpuri, New Delhi. Specification of polypropylene fiber are given in Table 6.

Table 6: Polypropylene Fiber – Specifications

Parameters	Specifications
Size	12 mm
Shape of fiber	Special for improved holding of cement aggregates
Tensile strength	4000-6000 kg/cm^2
Specific gravity	0.91

Silica Fume: Silica fume imparts improvement to rheological, mechanical and chemical properties. It improves the durability of the concrete by reinforcing the microstructure through filler effect and thus reduces segregation and bleeding. Silica fumes of specific gravity 2.34 used in powder form in the study. Silica fume was purchased from Oriental Trexim Pvt. Ltd., Navi Mumbai. The chemical composition of Silica fume is given in Table 7.

Table 7: Chemical Compositions of Silica Fume

S. No.	Constituents	Quantity (%)
1.	SiO_2	92
2.	Al_2O_3	2.0
3.	Fe_2O_3	1.0
4.	CaO	1.2
5.	LOI	3.0

Water: The water used in the mix design was potable water from the water supply network system so it was free from the suspended solids and organic material, which might have affected the properties of the fresh and hardened concrete.

Chemical Admixtures: Superplasticizers or high range water reducing admixtures are an essential component of concrete. Conplast SP430G8 was used as superplasticiser. It complies with IS: 9103:1999 and BS: 5075 Part 3-1985, and ASTM-C494M-99a, 1999 Type 'G' as a high range water reducing admixture.Conplast SP430 G8 is based on Sulphonated Napthelene Polymers and is supplied as a brown liquid instantly dispersible in water.

METHODOLOGY

Theoretical proportion of different ingredient of plain cement concrete of grade M-40 is determined following the guidelines of IS 10262-2007 and 2009. The mix design proportion obtained for cement: fine aggregate: coarse aggregate: water was in ratio of 1: 1.71:2.778:0.36 by weight. In trial mix water cement ratio is kept 0.36 and dosages of superplasticizer are fixed @1.6% of weight of cement.

Sixteen mixtures that contained different fiber volume fractions (0, 0.2, 0.4, and 0.6) and silica-fume percentages (0, 5, 10, and 15) were fabricated and tested in order to assess fresh and hardened properties of concrete. In first series plain concrete of M40 grade was prepared as per mix design proportion. In second, third and fourth series of concrete 0.2%, 0.4%, and 0.6% polypropylene fiber by volume fraction of concrete is added respectively. In all four series silica fume content is kept nil. Polypropylene Fiber Reinforced Silica Fume Concrete (PFRSFC) of first to fourth series are designated as PF_0S_0, $PF_{0.2}S_5$, $P_{0.4}S_{10}$ and $P_{0.6}S_{15}$ respectively.

In fifth, sixth, seventh and eighth series of concrete, 5% of cement is replaced by equal weight of silica fume. In all these four series polypropylene fiber content in concrete 0%, 0.2%, 0.4% and 0.6% by volume fraction of concrete is added.

In ninth, tenth, eleventh and twelfth series of concrete 10% of cement by weight is replaced by equal weight of silica fume. In all these four series polypropylene fiber content in concrete 0%, 0.2%, 0.4% and 0.6% by volume fraction of concrete is added.

At last thirteenth, fourteenth, fifteenth and sixteenth series of concrete 15% of cement by weight is replaced by equal weight of silica fume. In all these four series polypropylene fiber content in concrete 0%, 0.2%, 0.4% and 0.6% by volume fraction of concrete is added.

The concrete mixtures were mixed using a 30 liters capacity of container with tilting drum type mixer and specimens were casted using steel mould in the standard beam of size 150 x 150 x 700 mm. The fresh concrete mixtures in moulds were compacted and the specimens were demoulded after 24 hours after casting and water cured at 27 ± 3 °C until the age of testing at 7 and 28 days. All mixes were prepared in a portable drum mixer. Upon completion of mixing, place the fresh concrete into the moulds and vibrate simultaneously. Then the specimens were kept in laboratory conditions until they were tested at the age of 7 and 28 days in order to measure the flexural strength of hardened concrete (IS 516-1959 (Reaffirmed 1999)).

MIX PROPERTIES

Workability Test

Slump Test: slump test is the most well-known and widely used test method to characterize the workability of fresh concrete. The apparatus consists of a mold in the shape of a frustum of a cone with a base diameter of 20 cm, a top diameter of 10 cm, and a height of 30 cm. A graduated steel tamping rod 16 mm diameter and 600 mm long rounded at one end graduated in mm is used for tamping of concrete. The mold is filled with concrete in three layers of equal volume. Each layer is compacted with 25 strokes of a tamping rod. The slump cone mold is lifted vertically upward and the change in height of the concrete is measured. Initial slump is measured after just lifting of cone and final slump is recorded after 45 minute of lifting of cone.

Flexural Strength

The standard beam specimen of size 150 x 150 x 700 mm is tested in flexural testing machine. The bearing surfaces of the supporting and

Table 8: Mix Proportions

Mix Id	Cement	Fine Aggregate	Coarse Aggregate	Water	F/C	w/b	Polypropylene Fiber (%)	Silica Fume (%)
	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3				
PF_0S_0	422	723.5	1172.5	152	0.62	0.36	0	0
$PF_{0.2}S_0$	422	723.5	1172.5	152	0.62	0.36	0.2	0
$PF_{0.4}S_0$	422	723.5	1172.5	152	0.62	0.36	0.4	0
$PF_{0.6}S_0$	422	723.5	1172.5	152	0.62	0.36	0.6	0
PF_0S_5	401	723.5	1172.5	152	0.62	0.36	0	5
$PF_{0.2}S_5$	401	723.5	1172.5	152	0.62	0.36	0.2	5
$PF_{0.4}S_5$	401	723.5	1172.5	152	0.62	0.36	0.4	5
$PF_{0.6}S_5$	401	723.5	1172.5	152	0.62	0.36	0.6	5
PF_0S_{10}	380	723.5	1172.5	152	0.62	0.36	0	10
$PF_{0.2}S_{10}$	380	723.5	1172.5	152	0.62	0.36	0.2	10
$PF_{0.4}S_{10}$	380	723.5	1172.5	152	0.62	0.36	0.4	10
$PF_{0.6}S_{10}$	380	723.5	1172.5	152	0.62	0.36	0.6	10
PF_0S_{15}	359	723.5	1172.5	152	0.62	0.36	0	15
$PF_{0.2}S_{15}$	359	723.5	1172.5	152	0.62	0.36	0.2	15
$PF_{0.4}S_{15}$	359	723.5	1172.5	152	0.62	0.36	0.4	15
$PF_{0.6}S_{15}$	359	723.5	1172.5	152	0.62	0.36	0.6	15

loading rollers shall be wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers. The specimen shall then be placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould, at centre of the specimen. The axis of the specimen shall be carefully aligned with the axis of the loading device. The load shall be applied without shock and increasing continuously at a rate such that the extreme fiber stress increases at approximately 7 kg/sq cm/min, that is, at a rate of loading of 400 kg/min for the 15.0 cm specimens. The load shall be increased until the specimen fails, and the maximum load applied to the specimen during the test shall be recorded. These specimens are tested for flexure strength after 7 days curing and 28 days curing.

RESULTS AND DISCUSSION

Workability

Workability of fresh mix of FRSFC was determined which is based on slump cone method. The slump test results for various mixes (PF_0S_0 to $PF_{0.6}S_{15}$) is given in Table 9. The addition of polypropylenes fiber and silica fume showed adverse effect on workability of concrete. Concrete having 0.2% of polypropylene fiber ($PF_{0.2}S_0$, $PF_{0.2}S_5$, $PF_{0.2}S_{10}$ and $PF_{0.2}S_{15}$) show is rapid decrease rate (45-36%) in workability in comparison to concrete having nil content of polypropylene fiber (PF_0S_0, PF_0S_5, PF_0S_{10} and PF_0S_{15}) respectively. However, as the dosage of PP fibers increase, i.e., for mixes $PF_{0.4}S_0$, $PF_{0.4}S_5$, $PF_{0.4}S_{10}$ and $PF_{0.4}S_{15}$ and $PF_{0.6}S_0$, $PF_{0.6}S_5$, $PF_{0.6}S_{10}$ and $PF_{0.6}S_{15}$ showed a lesser reduction in rate of decrease in workability compared to reference concrete.

Table 9: Initial and Final Slump

S. No.	Name of Polypropylene Fiber Reinforced Concrete with Silica Fume	Percentage of Polypropylene Fiber	Percentage of Silica Fume	Initial Slump (mm)	Final Slump (mm)
1.	PF_0S_0	0	0	160	120
2.	$PF_{0.2}S_0$	0.2	0	85	60
3.	$PF_{0.4}S_0$	0.4	0	65	45
4.	$PF_{0.6}S_0$	0.6	0	45	30
5.	PF_0S_5	0	5	100	75
6.	$PF_{0.2}S_5$	0.2	5	55	35
7.	$PF_{0.4}S_5$	0.4	5	45	25
8.	$PF_{0.6}S_5$	0.6	5	30	20
9.	PF_0S_{10}	0	10	65	45
10.	$PF_{0.2}S_{10}$	0.2	10	40	30
11.	$PF_{0.4}S_{10}$	0.4	10	30	20
12.	$PF_{0.6}S_{10}$	0.6	10	20	10
13.	PF_0S_{15}	0	15	55	35
14.	$PF_{0.2}S_{15}$	0.2	15	35	25
15.	$PF_{0.4}S_{15}$	0.4	15	25	10
16.	$PF_{0.6}S_{15}$	0.6	15	15	0

Concrete having 5% of silica fume (PF_0S_5, $PF_{0.2}S_5$, $PF_{0.4}S_5$ and $PF_{0.6}S_5$) show is rapid decrease rate (40-30%) in workability in comparison to concrete having nil content of silica fume (PF_0S_0, $PF_{0.2}S_0$, $PF_{0.4}S_0$ and $PF_{0.6}S_0$) respectively. However, as the dosage of silica fume increase, i.e., for mixes PF_0S_{10}, $PF_{0.2}S_{10}$, $PF_{0.4}S_{10}$, and $PF_{0.6}S_{10}$ and PF_0S_{15}, $PF_{0.2}S_{15}$, $PF_{0.4}S_{15}$, and $PF_{0.6}S_{15}$ showed lesser reduction in rate of decrease in workability compared to reference concrete.

Flexural Strength

The test results for various mixes (PF_0S_0 to polypropylene fiber 0%, 0.2%, 0.4%, 0.6%) on beam specimens at the ages of 7 and 28 days in the flexural testing machine is given in Table 10 and shown graphically in Figure 1. The average flexural strength achieved at 7 days and 28 days for reference mix (PF_0S_0) is 3.65 MPa, and 5.19 MPa respectively and an addition of polypropylene 0.6% and replacement of cement by silica fume by 10% in concrete ($PF_{0.6}S_{15}$) showed an improvement up to 4.95 MPa at 7 days and 7.32 MPa at 28 days.

Addition of polypropylene fiber 0%, 0.2%, 0.4%, 0.6% showed that continuous enhancement of flexural strength in all mixes. However, with the higher dosage of polypropylene fiber 0.6%, i.e., for mixes ($PF_{0.6}S_0$, $PF_{0.6}S_5$, $PF_{0.6}S_{10}$ and $PF_{0.6}S_{15}$) there is ($PF_{0.4}S_0$, $PF_{0.4}S_5$, $PF_{0.4}S_{10}$ and $PF_{0.4}S_{15}$) slight increase in the flexural strength.

Replacement of cement by silica fume by 0%, 5% and 10% showed that continuous enhancement of flexural strength in all mixes. However, with the higher 15% replacement of cement by silica fume, i.e., for mixes (PF_0S_{15}, $PF_{0.2}S_{15}$, $PF_{0.4}S_{15}$ and $PF_{0.6}S_{15}$)

Table 10: Flexural Strength (7 Days)

PF Vf% → SF% ↓	0.00%	0.20%	0.40%	0.60%
0%	3.65	4.15	4.47	4.56
5%	3.85	4.36	4.71	4.74
10%	4.03	4.53	4.89	4.95
15%	3.50	3.91	4.27	4.30

Table 11: Flexural Strength (28 Days)

PF Vf% → SF% ↓	0.00%	0.20%	0.40%	0.60%
0%	5.19	6.10	6.49	6.70
5%	5.60	6.40	6.90	7.11
10%	5.81	6.64	7.14	7.32
15%	5.45	6.22	6.70	6.81

there is slight decrease in strength compared to 10% replacement of cement by silica fume, i.e., for mixes (PF_0S_{10}, $PF_{0.2}S_{10}$, $PF_{0.4}S_{10}$ and $PF_{0.6}S_{10}$). The increase in flexural strength was found to be around 41% with the use of polypropylene and silica fume compared to the reference concrete. Flexural strength was found out to be optimum for a mix containing 0.4% polypropylene fiber and 10% Silica fume.

Figure 1: Showing Flexural Strength of Beams (7 Days)

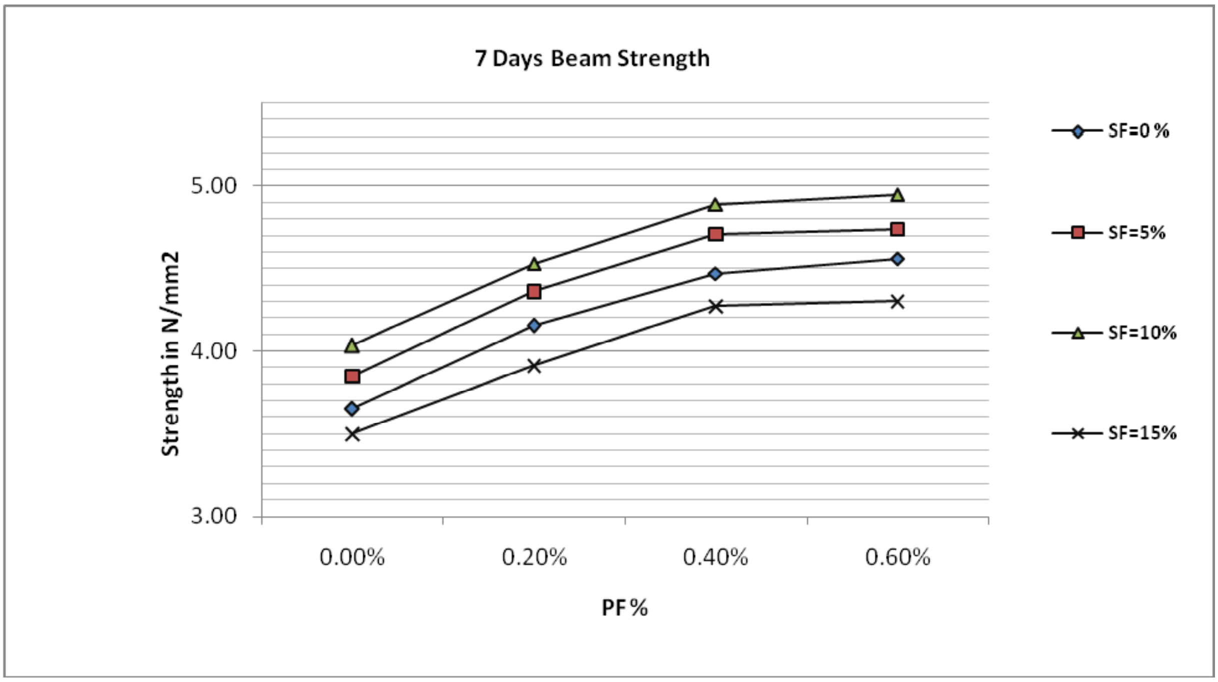
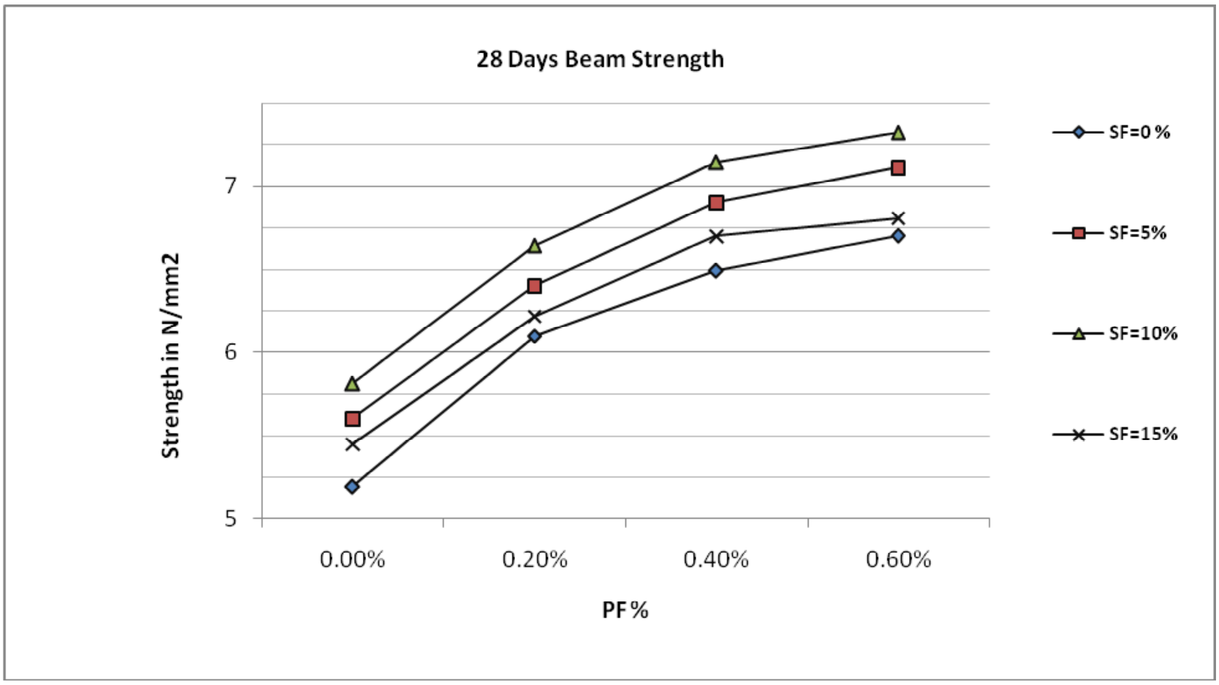


Figure 2: Showing Flexural Strength of Beams (28 Days)



CONCLUSION

On the basis of experimental studies the following conclusions can be drawn:

- Silica fume appeared to have an adverse effect on the workability of fiber concrete.
- Concretes PF_0S_0 to $PF_{0.6}S_{15}$ having different flexural strength could be prepared by different combination of cement, polypropylene fiber and silica fume with keeping the aggregate and super plasticizer content constant.
- It is observed from slump test results of PF_0S_0 to $PF_{0.6}S_{15}$ that there is continuous decrease in workability of concrete with increase in polypropylene fiber content.
- The increase in flexural strength was found to be around 40% with the use of polypropylene and silica fume compared to the reference concrete. Flexural strength was found out to be optimum for a mix of 0.4% PP and 10% SF.
- Silica fume has no significant effect on flexural strength of concrete.

Based on the test results presented in this research paper, it is concluded that a mixture design with 10% silica fume and 0.40% fiber volume fraction was optimum in flexural strength with maintaining an adequate workability.

Figure 3: Photographic View of Flexural Strength Test

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