Evaluation of Mechanical Properties of Concrete using Silica fume and Steel fibers

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Abstract — The present investigation carried out on concrete due to the effect of silica fume with and without steel fibers on 53-Grade Portland cement. In this study we used concrete mixes with silica fume of 0%, 5%, 10% and 15% by the volume of concrete for M35 garde concrete. The optimum percentage of silica fume to give maximum compressive strength was found to be 10%. With the addition of crimped steel fibers of diameter 0.5mm and length 12mm with aspect ratio 24, the various percentages as 0.2%, 0.4%, 0.8%, 1.0% and 2% to the optimized percentage of silica fume (i.e., 10%). The effects of mineral admixture as cement replacement material with and without steel fibers on mechanical properties were analyzed and compared with normal concrete.

Key words — Silicafume (SF), Steel fibers (STF), Superplastisizer (SP), Steel fiber reinforced concrete (SFRC) Compressive strength, split tensile strength, Flexural strength, and Cement type: OPC 53 grade.

1 Introduction

There are many kinds of fibers, both metallic and polymeric, which have been used in concrete to improve specific engineering properties of the material. Steel fibers are used in a wide range of structural applications, in general, when the control of concrete cracking is important such as industrial pavements precast structural elements and tunnel linings. Steel fibers have high elastic modulus and stiffness and produce improvements in compressive strength and toughness of concrete. Improvements in flexural strength of the material are also obtained by the use of steel fibers in concrete. Increase in flexural strength is achieved with increasing fiber aspect ratio (length to diameter ratio) and fiber volume fraction; significant improvements are obtained at high volume fractions. In general, addition of steel fibers influences the compressive strain at ultimate load and ductility in flexure more significantly than the improvements in strength. Steel fibers, however, increase structure weight of concrete and exhibit balling effect during mixing, which lowers the workability of the mix. In addition, steel fibers easily basset and rust, and it also has the problem of conductive electric and magnetic fields.

Synthetic fibres are less stiff than steel fibres and are most typically used in industrial pavements to reduce the cracking induced by shrinkage. Synthetic fibres are mainly effective in reducing crack formation, particularly at an early stage of the cast and in severe weather conditions (e.g. in dry climatic zones), when hygrometric shrinkage brings along some weak tensile stress which is yet too high for the fresh mixture to withstand. Synthetic fibers made using nylon Polypropylene and acrylic are available commercially. Polypropylene fibers are available in two different forms; Monofilaments and Fibrillated. Monofilament fibers are single strand of fibers having uniform cross-sectional. Fibrillated fibers are manufactured in the form of films or tapes that are slit in such a way that they have net like physical structure. Polypropylene fibers have good ductility, fineness, and dispersion so they can restrain the plastic cracks.

Here steel fibre and silica fume is common additive that can improve concrete performance. In this present investigation a study has been carried out to determine the compressive strength, flexural strength and split tensile strength of steel fiber reinforced concrete (SFRC) at the grade of M35. Crimped steel fibers with aspect ratio 24 are used in this experimental investigation in different fractions ranging from 0.2%, 0.4%, 0.8%, 1.0% and 2% by addition to weight of cement. Replacement of Portland cement is made with silica fume at the rate 10% by mass of cementing materials. The optimum content of silica fume is achieved by performing experimental investigation with the percentage of silica fume by weight of cement is to be from 5%, 10%, and 15%.

2 Literature Review

The effects of silica fume on tensile, compressive and flexure strengths on high strength lightweight concrete was done by H. Katkhuda, B. Hanayneh and N. Shatarat [2]. They carried out by replacing cement with different percentages of silica fume at different constant water-binder ratio keeping other mix design variables constant. The silica fume was replaced by 0%, 5%, 10%, 15%, 20% and 25% for a water-binder ratios ranging from 0.26 to 0.42. For all mixes, split tensile, compressive and flexure strengths were determined at 28 days. The results showed that the tensile, compressive and flexure strengths increased with silica fume incorporation but the optimum replacement percentage is not constant because it depends on the water–cementitious material (w/cm) ratio of the mix. Based on the results, a relationship between split tensile, compressive and flexure strengths of silica fume concrete was developed using statistical methods.

Effect of steel fiber on the mechanical properties of cement-based composites containing silica fume was done by Wei-Ting Lin, Ran Huang, Chin-Lai Lee, and Hui-Mi Hsu [3]. They carried out to evaluate the mechanical properties of cement-based composites. Test variables included water to cementitious ratio, dosage of silica fume and volume fraction of steel fiber. Compressive strength test, direct tensile strength test, splitting tensile strength test, abrasion resistance test and drop weight test were performed and the results were analyzed statistically. According to the results of this study, the designed direct tensile testing method was a suitable method to estimate the tensile strength of fiber cement- based composites. Addition of fibers provided better performance for the cement-based composites, while silica fume in the composites would help obtaining uniform fiber dispersion in the matrix and improve strength and the bonding between fiber and matrix resulting from extra dense calcium- silicate-hydrate gel. The combination of steel fibers and silica fume can greatly increase the mechanical properties of cement- based composites. Besides, a multiple regression analysis was conducted to correlate compressive strength, direct tensile strength, abrasion coefficient and impact number with w/cm ratio, silica fume content and steel fiber content and a fairly agreement between test data and estimated values was found.

The effect of steel fibers on the mechanical properties of high performance concrete was carried out by ShakirA.SalihSaeed K. Rejeb Khalid B. Najem [4]. They said the effect of steel fibers content and the combined effect of rice husk ash (RHA) and high range water reducing agent (HRWRA) on the mechanical properties of the produced matrix. The experimental results showed the using steel fibers in High-performance concrete led to a considerable improvement in mechanical properties of concrete. The results exhibited that the addition of steel fibers to high performance concrete up to 1% with 6% (HRWRA) and 8% (RHA) as a partial replacement by weight of cement, increases the compressive strength significantly. Also, the results showed that the addition of 1.5% steel fibers with 6% (HRWRA) and 8% (RHA) increases the splitting and flexural strengths significant. At 28 days, the compressive, splitting and flexural strengths were increased to 11.57%, 63.86%, and 32.93% more than High performance concrete without steel fibers, respectively.

“Influence of Silica fume in enhancement of compressive strength, flexural strength of steel fibers concrete and their relationship” was carried out by PawadePrashant.Y, Nagarnaik P.B and PandeA.M [5], they investigated on concrete due to the effect of silica fume with and without steel fibers on Portland Pozzolona cement. In this study we used concrete mixes with Silica Fume of 0%, 4%, 8%and 12% with addition of crimped steel fibers of two diameters 0.5 mm Ø and 1.0 mm Ø with a constant aspect ratio of 60, at various percentages as 0%, 0.5 %, 1.0 % and 1.5 % by the volume of concrete on M30 grade of concrete. In comparison, with control concrete the replacement of 4%,8%,12% and 16% cement by silica fume showed 7.46%, 11.17%,11.91%and 9.83% increase in compressive strength at 28 days of curing. The optimum combined effect at 8% silica fume and 1.5% steel fiber with normal concrete the maximum compressive strength increase at 0.5 mm Ø and 1.0 mm Ø steel fiber at 28 days of curing were 15.38% and 18.69%, the maximum flexural strength increase were 17.13% and 24.02%.The combined effect of silica fume at 4% & 12% with steel fiber at 0.5%, 1.0% & 1.5% of both diameters 0.5 mm Ø and 1.0 mm Ø at different ages of curing are presented.

Fibers have been used as discrete randomly distributed reinforcement to strengthen a material weak in tension. Fibers have been shown to improve the toughness and the post crack ductility in tension, which is achieved by the reinforcement effect across a crack in the material matrix. The use of fibers results in an enhancement in the load carrying ability which is achieved due to stress transfer after cracking. The earliest documented use of fibers has been the incorporation of chopped hay and camel hair in adobe bricks by the Egyptians. Since then different types of fibers have been developed, which can broadly be classified as metallic, synthetic, glass, and mineral. Properties of the different fibers commonly available today are listed in Table 1.

TABLE 1: TYPICA PROPRTIES OF FIBER

Fiber	Diameter	Specific gravity	Tensile strength	Elastic Modulus
	(um)		(GPa)	(GPa)
Steel	5-500	7.84	0.5-2.0	210
glass	9-15	2.6	2.0-4.0	70-80
Fibrillated Polypropylene	20-200	0.9	0.5-0.75	5-77
Cellulose	-	1.2	0.3-0.5	10
Carbon (high strength)	9	1.9	2.6	230
Cement matrix	-	2.5	3.7×10-3	10-45

Fiber volume content is the primary variable which influences the response of the fiber reinforced composite in tension as shown in Fig 2.1 1. For small volume fraction, after first crack there is drop in the load. There are a small number of fibers bridging the crack that sustain the load. The capacity provided by the number of fibers crossing the crack is significantly less than the first crack load and load carrying capacity decreases rapidly with increasing deformation. For intermediate volume fraction, after the drop in load associated with the formation of a crack, the load carrying capacity provided by the fibers produces a progressive yet gradual decrease in the load carrying capacity. For high volume fraction, after first crack, there are a large number of fibers bridging the crack and the resistance to crack opening provided by the fibers is larger than the first crack load. As the load increases, more cracks form along the length of specimen.

2.1 Steel Fibers

Steel fibers have a relatively high strength and modulus and are available in aspect ratios ranging from 20 to100 and length ranging from 6.4mm to 75mm. The process of manufacture varies from cut sheets, cold drawn wires or hot melt extraction and is available in different cross-sections and shapes depending on the method of manufacture and use. While steel fibers improve the strength of concrete under all load actions, their effectiveness in improving strength varies among compression, tension and flexure. There an insignificant change in the ultimate compressive strength upon the addition of steel fibers; There is an increase of up to 15 percent for volume of fibers up to 1.5 percent by volume [12] [13]. There is a significant improvement in strength in tension with an increase of the order of 30 to 40 percent reported for the addition of 1.5 percent by volume of fibers in mortar or concrete [14]. Strength data [15] shows that the flexural strength of SFRC is about 50 to 70 percent more than that of the unreinforced concrete matrix in the normal third-point bending test [15] [16].

The ability of steel fibers to serve as reinforcement is determined by the resistance of the fibers to pullout from the matrix resulting from the breakdown of the fiber-matrix interfacial bond. Improvements in ductility depend on the on the type and volume percentage of fibers present [17] [18]. In conventionally mixed SFRC, high aspect ratio fibers are more effective in improving the post-peak performance because of their high resistance to pullout from the matrix. However, at high aspect ratio there is a potential for balling of the fibers during mixing [19]. Techniques such as enlarging or hooking of ends, roughening their surface texture, or crimping to produce a wavy rather than straight fiber profile allow for retaining high pullout resistance while reducing fiber aspect ratio. These types are more effective than equivalent straight uniform fibers of the same length and diameter. Consequently, the amount of these fibers required achieving a given level of improvement in strength and ductility is usually less than the amount of equivalent straight uniform fibers [19] [20].

Improvements in post-crack ductility under tension result in significant improvements in flexural response. Ductile behaviour of the SFRC on the tension side of a beam alters the normally elastic distribution of stress and strain over the member depth. The altered stress distribution is essentially plastic in the tension zone and elastic in the compression zone, resulting in a shift of the neutral axis toward the compression zone [21].

3 Materials and Methods

3.1 Introduction

This section presents the details of materials and experimental methods used in the study. The types of specimens, mix proportions and test methods employed are presented.

3.1.1 Cement

In the present investigation, commercially available 53 Grade ordinary Portland cement was supplied by PENNA Cement with Specific Gravity of 3.1 and Fineness modulus of 325m²/kg was used for all concrete mixtures.

Table 2: Physical Properties of Cement

S.NO	PARTICULARS	RESULTS
1	Specific Gravity	3.12
2	Initial setting time	30 min
3	Final setting time	600 min
4	Fineness modulus	225 m²/kg

3.1.2 Silica fume

Silica fume conforming to the requirements of IS15388supplied by ASTRRA chemicals with Specific gravity of 2.2 and fineness modulus of 380m²/kg was used as supplementary cementitiousmaterial in concrete mixtures.

Table 3.2 Physical properties of Silica fume

S.NO	*PARTICULARS*	*RESULTS*
1	Specific Gravity	2.2
2	pH	6.9
4	Fineness modulus	380 m²/kg

3.1.3 Aggregates

River sand with a specific gravity of 2.67 and fineness modulus of 2.83 was used as fine aggregate and crushed granite of specific gravity of 2.63 was used as coarse aggregate. Two different classes of coarse aggregate fractions were used: 10-4.75 mm and 20-10 mm.

3.1.4 Steel fibers

Crimped Steel fibresof 12 mm length and 0.5mm diameter with aspect ratio-24 manufactured by Bajaj Reinforcements Conforming to IS 13320: 2013 were used in this study. A photograph of fibers used in this study is shown Fig 3.1.1.

3.1.5 Admixure

Super plasticizer (Naphthalene based) was used to increase the workability of freshly prepared fiber reinforced concrete.

3.2 Experimental program and Mix Proportions

Concrete mix design for the mix design procedure given in IS: 10262 were followed with minor modification for M35 grade. For a target mean strength of 43 MPa, two different water/cement ratios equal to 0.48 was considered. Taking into considerations, the minimum requirements for cement content in kg/m3 of concrete for M35 as per IS 456-2000 as 300 kg/m3, cementitious content was fixed at 340 kg/m3. Using this, the water content was determined. In the concrete mixture fine aggregate were taken as 45% of the total aggregate volume fraction. The weights of fine and coarse aggregate were then calculated considering the specific gravities of coarse and fine aggregate.

The Concrete mixtures were produced at a constant water/Cement ratio of 0.48 and one control mixture and three different mixtures with different dosage of fiber were prepared. The control mixture contained no fiber. Concrete mixtures labelled SF-1, SF-2, SF-3 and SF-4 were produced with different dosage of steel fibers 0.68 kg/m3, 1.36 kg/m3, 2.72 kg/m3and 3.4 kg/m³by volume. The final batch weights of the different mixes for one cubic meter of concrete are presented in Table 3.1.

Table 3.3 Summary of weight proportion of the various mixes

Materials(kg/m³)	*C*	*SF*	*SF*	*SF*	*SF*	*SF*

	1	*1*	*2*	*3*	*4*	*5*
Steel fiber	-	0.68	1.36	2.72	3.4	6.8
OPC 53 grade cement	300	300	300	300	300	300
Silica fume	40	40	40	40	40	40
Water/Cement ratio	0.48	0.48	0.48	0.48	0.48	0.48
Admixture (%)	0.65	0.65	0.65	0.65	0.65	0.65
20 mm aggregates	508	508	508	508	508	508
10mm aggregates	508	508	508	508	508	508
Fine aggregates (River sand)	823	823	823	823	823	823
Water	163	163	163	163	163	163

3.2.1 Casting and Curing of Specimens

IS standard 150mm Cubes, 150mm X 300mm cylinder and 150 X 150 X 700 beams were cast from each mixture to evaluate compressive strength, Flexural strength and split tensile strength gain. Concrete was prepared using a drum mixer with a capacity of 0.25 m^3. The ingredients were put into the mixer in the decreasing order of their sizes staring from 20mm aggregate to cement. Dry mixing of the aggregates and cement was done for two minutes and then water was added gradually in the rotating mixer and allowed to mix for 15 minutes. During the mixing process, the walls and bottom of mixer were scraped well to avoid sticking of mortar. After mixing, the slump was checked and noted down to ascertain the effects of differently proportioned blends on workability of concrete. Finally the fresh concrete was placed in oiled moulds and compacted properly in three layers, each layer being tamped 35 times using a tamping rod. After the initial setting of concrete, the surface of the specimen was finished smooth using a trowel. Immediately after casting, all specimens were covered with plastic covers to minimize moisture loss. The specimens were stored at room temperature about $25^{o}C$. Specimens were demoulded 24 hours after casting and kept in curing water tank.

3.3 Test Methods

An experimental program was designed to study the influence of fiber on the concrete. Each concrete mixture was evaluated with respect to Slump, compressive strength, and flexural tensile Strength of fiber reinforced concrete.

3.3.1 Slump

Slump was used to find the Workability of fresh concrete where the nominal maximum size of aggregate does not exceed 38 mm. slump cone was used to find the slump of the concrete as per the requirements of IS 1199-1959.

3.3.1.1 Procedure

Oil was applied on the base plate and interior surface of the slump cone. After that, Slump cone was attached to a base plate with screws and finally kept on the levelled surface. Immediately slump cone was filled with fresh concrete approximately one-quarter of height of the cone, each layer was tampered with the tampered rod 25 times. After compacting the top layer, mould and the base plate was cleaned with the clothes. Slump cone was Unscrewed from the base plate and removed immediately from the concrete by raising it slowly and carefully in a vertical direction. Finally slump cone of the base plate kept reverse position, height between the top of the mould and highest point of the concrete was measured with the scale. This height indicated the slump of the concrete.

3.3.2 Compression Strength

For cubes 40 tons digital compressive testing machine was used for determine the compressive strength and split tensile strength on hardened concrete as per the requirements of IS 516-1959

For cubes before starting the test the weight of the sample was recorded. The plates of the machine were cleaned and the specimen was kept centrally between the two plates. Load was applied gradually on the specimen at a load rate of 5.2 kN/s up to failure. Once the sample was failed, the failure pattern was recorded and the compressive strength was calculated from the maximum load recorded in the test.

3.3.3 Split tensile strength

Testing for split tensile strength of concrete is done as per IS 5816-1959[6]. The test is conducted on compression testing machine of capacity 40 tons. The cylinder is placed horizontally between the loading surfaces of compression testing machine and the load is applied till failure of the cylinder. Packing material such as plywood is used to avoid any sudden loading. During the test the platens of the testing machine should not be allowed to rotate in a plane perpendicular to the axis of cylinder.

Split tensile strength= $2P/(\Pi\ LD)$

Where P = load at failure

L = length of the cylinder and

D = diameter of the cylinder

3.3.4 Flexural strength testing (Three-point-bending test)

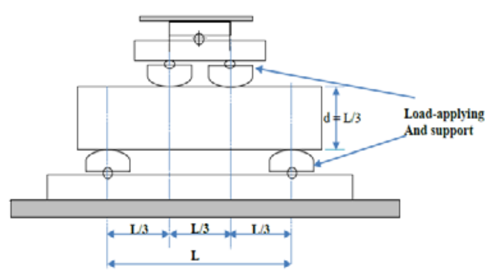


Fig 3.2 Diagrammatic view of flexure test of concrete by third-point loading Method

As per IS 516 the bed of the testing machine shall be provided with two steel rollers, 38 mm in diameter, on which the specimen is to be supported, and these rollers shall be so mounted that the distance from centre to centre is 60 cm for 15.0 cm specimens or 40 cm for 10.0 cm specimens. The load shall be applied through two similar rollers mounted at the third points of the supporting span that is, spaced at 20 or 13.3 cm centre to centre. The load shall be divided equally between the two loading rollers, and all rollers shall be mounted in such a manner that the load is applied axially and without subjecting the specimen to any torsional stresses or restraints.

$F_b = PL/(bd^2)$ when a is greater than 13.3 cm or

$F_b = 3Pa/(bd^2)$ when a is in between 11.0 cm and 13.3 cm

Wherea = the distance between the line of fracture and the nearest support

b = measured width in cm of the specimen,

d = measured depth in cm of the specimen was supported, and

P = maximum load in kg applied on the specimen.

If a is less than 11.0 cm the test result is discarded.

4 Experimental Results

The evaluation of the properties of FRC composites is of prime importance for these composites to be used effectively and economically in practice.The results of an investigation into the influence of the Steel fiber on the fresh and hardened properties of concrete are presented in this chapter. Results of compression tests of cube, Split tensile strength of cylinder and Flexural strength of beam at 28 days respectively are presented.

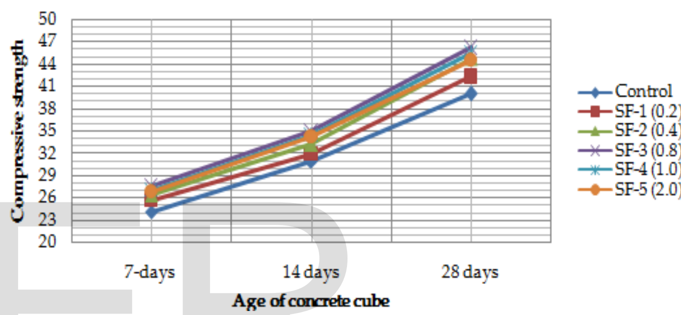
4.1 Compressive strength

The mean at 7, 14 and 28 day compressive strength from standard 150 mm cubes for control and SFRC obtained are tabulated in Table 4.1, respectively. The compressive strengths and weights of the individual cubes are listed in Annexure I. The observed standard deviation in the compressive strength values from the same batch are the expected variations produced by sample preparation, and to variations in the actual air contents of the hardened concrete and the differences in their unit weights. While there is an increase in the compressive strength, the variation of compressive strength with fiber content does not show a clear trend with fiber volume fraction. At 28 days of age, the compressive strengths obtained from SFRC at 0.68, 1.36 and 2.72 kg/m3 and control mixture are comparable and the variation in the compressive strength is within the range of experimental scatter evident within the batch. While the mean compressive strength at a fiber volume content of 2.72 kg/m3 is higher than the mean compressive strength of the control mix, the associated increase in the standard deviation at this fiber volume fraction does not permit for a making an inference about statistical significance of the observed increase in strength. Thus it may be concluded that there is no statistically significant change in the 28- day compressive strength in SPFRC for fibers at quantities up to 2.72 kg/m^3.

The effect of silica fume with and without steel fiber on compressive strength of concrete is shown in Table 4.1.and their graphical trends are shown in Graph 4.1.

Table 4.1. Compressive strength at 7, 14 and 28 - days of age at 0%, 0.2%, 0.4%, 0.8%, 1% and 2% of steel fiber to the optimum percentage of silica fume test results in N/mm^2.

Specimen	Mean Compressive Strength for 7-day (MPa)	Mean Compressive Strength for 14-day (MPa)	Mean Compressive Strength for 28-day (MPa)
Control	24.1	31	40
SF-1 (0.2)	25.7	31.9	42.3
SF-2 (0.4)	26.4	33.2	44.8
SF-3 (0.8)	27.6	34.9	46.2
SF-4 (1.0)	27.1	34.5	45.4
SF-5 (2.0)	26.9	s34.3	44.6



Graph 4.1 Compressive strength at 7, 14 and 28 - days of age at 0%, 0.2%, 0.4%, 0.8%, 1% and 2% of steel fiber to the optimum percentage of silica fume.

4.2. Split Tensile Strength

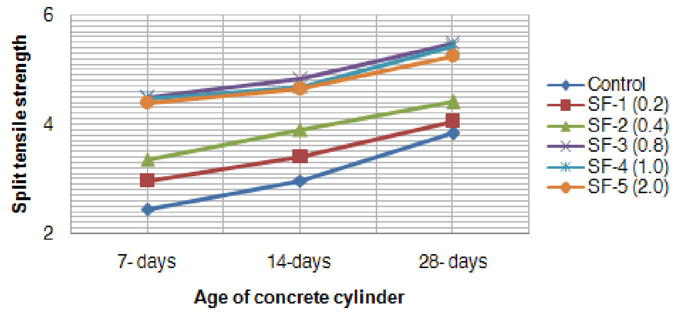
The test results for 7days, 14 days and 28 days of split tensile strength with various percentages replacement of steel fibers to optimum content of silica fume and their combination of both materials are represented below.

Table 4.2. Split tensile strength at 7, 14 and 28 - days of age at 0%, 0.2%, 0.4%, 0.8%, 1% and 2% of steel fiber to the optimum percentage of silica fume test results in N/mm^2.

Specimen	Mean Split tensile strength for 7 days (MPa)	Mean Split tensile strength for 14 days (MPa)	Mean Split tensile strength for 28 days (MPa)
Control	2.45	2.98	3.85
SF-1 (0.2)	2.97	3.42	4.07
SF-2 (0.4)	3.36	3.92	4.42
SF-3 (0.8)	4.51	4.83	5.50
SF-4 (1.0)	4.48	4.69	5.43

SF-5 (2.0)	4.41	4.67	5.27

FIGURE 4.2. SPLIT TENSILE STRENGTH AT 7, 14 AND 28 - DAYS OF AGE AT 0%, 0.2%, 0.4%, 0.8%, 1% AND 2% OF STEEL FIBER TO THE OPTIMUM PERCENTAGE OF SILICA FUME.



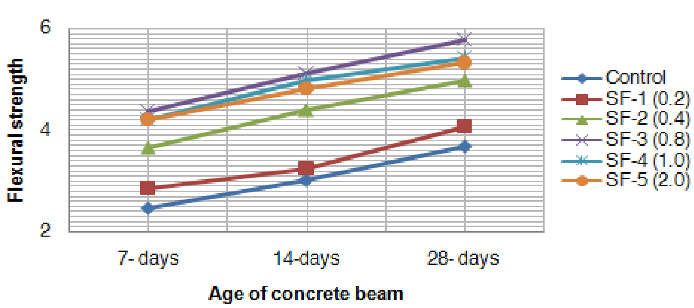
4.3. FLEXURAL STRENGTH

The test results for 7days, 14 days and 28 days of Flexural strength with various percentages replacement of steel fibers to optimum content of silica fume and their combination of both materials are presented in tabulated below.

TABLE 4.3. FLEXURAL STRENGTH AT 7, 14 AND 28 - DAYS OF AGE AT 0%, 0.2%, 0.4%, 0.8%, 1% AND 2% OF STEEL FIBER TO THE OPTIMUM PERCENTAGE OF SILICA FUME TEST RESULTS IN N/MM2.

Specimen	*Mean Flexural strength for 7 days (MPa)*	*Mean Flexural strength for 14 days (MPa)*	*Mean Flexural strength for 28 days (MPa)*
Control	2.47	3.01	3.68
SF-1 (0.2)	2.86	3.23	4.06
SF-2 (0.4)	3.65	4.40	4.98
SF-3 (0.8)	4.36	5.12	5.77
SF-4 (1.0)	4.21	4.98	5.41
SF-5 (2.0)	4.2	4.81	5.32

FIGURE 4.2: FLEXURAL STRENGTH AT 7,14 AND 28 - DAYS OF AGE AT 0%, 0.2%, 0.4%, 0.8%, 1% AND 2% OF STEEL FIBER TO THE OPTIMUM PERCENTAGE OF SILICA FUME.



5 CONCLUSION

In the present study the effect of steel fibers and silica fume on Mechanical properties of concrete is being studied and the following conclusions were obtained based on the experimental investigations.

1. The weight density of concrete increases with the increase in the steel fiber content.
2. Slump will lose at the higher percentage of steel fiber and lesser silica fume.
3. Workability of concrete improves when silica fume percentage increases.
4. The compressive strength increases significantly due to the addition of silica fume compared with normal concrete. The maximum increase in compressive strength was upto10% at 28 days.
5. The compressive strength increases with the addition of steel fiber for the optimum content of silica fume upto 13.4% at 28 days.
6. The Split tensile strength increases significantly due to the addition of steel fibersupto 30% at 28 days.
7. The flexural strength increases significantly due to the addition of steel fibersupto 36% at 28 days.
8. As the percentage of steel fibers increases, the percentage of tensile strength and flexural strength properties increases more than the compressive strength.

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