

Comparative Study on Effects of Fly Ash, Nano Silica and Silica Fume on Properties of Glass Fiber Reinforced Self Compacting Concrete

M. Yagita Sarada¹, V.K. Visweswara Rao²

M. Tech Student, Department of Civil Engineering, G. Pulla Reddy Engineering College, Kurnool, A.P, India¹

Assistant Professor, Department of Civil Engineering, G. Pulla Reddy Engineering College, Kurnool, A.P, India²

ABSTRACT: Self Compacting concrete (SCC) is a flowing concrete that is able to consolidate under its own weight without any need for vibration. The high fluid nature of SCC makes it suitable for placing it in difficult conditions and in sections with congested reinforcement. Use of SCC overcomes the difficulties pertaining to casting conditions and reduces the man power required. Self compacting concrete and glass fibers were combined together to obtain glass fiber reinforced self compacting concrete (GFRSCC). The present work deals with the studies on workability and strength properties of glass fiber reinforced self compacting concrete of grade M30 with partial replacement of cement with mineral admixtures like fly ash, nano silica and silica fume. The glass fiber percentage was varied from 0 to 0.1% by the volume of the mix. To reduce the cement content, Portland cement was replaced with different proportions of pozzolanic admixtures. The rheological properties of fresh concrete were observed through workability tests given for SCC. Also mechanical properties such as compressive strength, flexural strength and split tensile strength of GFRSCC were studied.

KEYWORDS: Glass fibers , compressive strength, split tensile strength, flexural strength, fly ash, silica fume, nano silica.

I. INTRODUCTION

Self compacting concrete (SCC) is a concrete which shows less resistance to flow so that it can be placed and compacted under its own weight with no vibration effort, even though it has enough viscosity to handle without segregation or bleeding. SCC demands a large amount of powder content compared to conventional vibrated concrete to produce a homogeneous, cohesive and flowable mix. The common practice to obtain self compactibility in SCC is to limit the coarse aggregate content and maximum size of coarse aggregate and also to use lower water – powder ratio. Also new generation super plasticisers (SP) and viscosity modifying admixtures are used to achieve required properties of SCC . During the transportation and placement of SCC the increased flowability may cause segregation and bleeding which can be reduced by the addition of fibers like glass fibers with in limited fractions. One of the disadvantages of SCC is its cost, associated with the use of chemical admixtures and use of high volume of Portland cement. So one alternative to reduce the cost of SCC is making use of pozzolanic materials such as fly ash(FA) , silica fume(SF) , nano silica(NS) etc.,

Fiber reinforced concrete is relatively new generation concrete developed through extensive research. It had already found a huge range of practical applications and found to have superior performance characteristics compared to conventional concrete. Incorporation of fibers in concrete has found to improve its several mechanical properties. Many fibers like asbestos, steel, nylon, coir etc., were used in the past. Further development in the field of fiber reinforced concrete was due to introduction of high strength fibers like glass and carbon fibers. The initial studies have shown the

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deterioration of glass fibers due to corrosive alkaline environment of cement paste. The alkali resistant glass fiber, which are developed recently has overcome this defect and can effectively be used in the concrete. These alkali resistant glass fibers can even reduce the bleeding and segregation occurring in SCC. In the 1970's alkali resistant (AR) glass fibers were perfected by Owens-Corning and by Nippon Electric Glass (NEG) leading to a rapid increase in its applications.

AR glass fibers helps in controlling and preventing the cracks in fresh and hardened concrete. They even provide the overall enhancement of durability and mechanical properties of concrete. Fibers are added not only to improve the strength properties itself, but also mainly to control the cracking, prevent coalescence of cracks and to change the behaviour of material by bridging of fibers across the cracks. Hence simultaneously, ductility is provided with fiber reinforced cementitious composites because fibers bridge crack surfaces and delay the onset of extension of localised cracks. The use of fibers might extend the possible fields of application of SCC. Fibers have a long shape and compared with aggregates of same volume a higher specific surface. The degree to which workability decreases depends on the type and content of fibers used in the matrix in which they are embedded and the properties of the constituents of the matrix on their own. A high content of fibers is difficult to distribute uniformly, a good distribution however is required to achieve optimum benefits of the fibers. Hence using the appropriate fiber volume fraction and a good matrix can dramatically improve the performance of the fiber reinforced concrete. High cement content used in SCC, usually liberates high hydration heat, high autogenous shrinkage and high cost. Reduction of energy usage can be taken place even by design methods or using waste materials.

Nowadays, most industrial wastes are being used without taking full advantages of their characteristics or disposed rather than used. Among these materials, fly ash (FA), a by-product of thermal power plants and ground granulated blast furnace slag (GGBS) have been reported to improve the mechanical properties and durability of concrete when used as a cement replacement material.

Silica fume, also known as micro silica is an amorphous (non crystalline) polymorph of silicon dioxide. It is an ultra fine powder collected as a by product of the silicon and ferrosilicon alloy production and consists of spherical particles. Silica fume is added to Portland cement to improve its compressive strength, bond strength and abrasion resistance. The improvement in the mechanical properties results from addition of a very fine powder to the cement paste mix, as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste. Silica fume reduces workability to certain extent due to the large surface area of silica fume particles, it even acts as anti-bleed agents.

There are some works on incorporating nano particles into concrete specimens to achieve improved physical and mechanical properties which most of them have focused on using SiO₂ nano particles in normal concrete, SCC and high performance self compacting concrete. This paper investigates the effects of silica nano particles, silica fume and fly ash on rheological and mechanical properties of GFRSCC. The mechanical properties were assessed by compressive strength, split tensile strength and flexural strength.

II. LITERATURE REVIEW

Published literature on self compacting concrete first appeared in 1989, and has been increasing significantly since that time, reflecting the amount of research and practical applications taking place. A vast research is going on the various waste materials that can replace cement in self compacting concrete. This chapter summarizes the most important published information of direct relevance to the experimental work reported in this project. As the present investigation deals with the study on effects of fly ash, silica fume and nano silica on GFRSCC. An attempt has been made to reveal briefly the available literature.

P. Srinivasa Rao, et al had studied the strength behaviour of fiber reinforced SCC subjected to flexure for various grades of concrete mixes and had used glass fibers of Cem-fill Anticrack HD of length 12mm, by varying percentages of 0 to 0.1%, and also replaced cement by fly ash for different percentages of 30, 40, 50. Reduction in bleeding was observed by addition of glass fibers in SCC. Study shown that the load carrying capacity of glass fiber reinforced SCC beams at 0.03% are higher side when compared with other beams with 0.05, 0.06% and 0.1%.

K. Rajesh Kumar, Dr. N. Mahendran has conducted experimental studies on strength, durability behaviour of beams using SCC with E-glass fiber strands. They made use of 6mm length E-glass fiber chopped strands with partial replacement of cement by fly ash and properties were fine tuned by using Okamura's guidelines. Fibers were added in

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range of 0%, 0.03%, 0.06%. The mix with 0.06% glass fibers , containing the mineral admixture of fly ash (45%) has shown higher compressive strength than other mixes.

Shahana Sheril P.T had made investigations on SCC using fly ash and glass fibers and made a comparative study on fresh and hardened properties of M20 and M30 grades of concrete mixes of SCC and GFRSCC. Glass fibers are added in the range of 0.05%, 0.1%, 0.15% & 0.2%. M30 mix with fibers of 0.1% shown a comparative good results regarding strength.

Morteza H. Beigi et al had made their study on the combined effects of fibers and nano silica on the mechanical , rheological and durability properties if SCC, with different fibers as steel, polypropylene and glass . Increasing the nano silica content to 4% increases the tensile and flexural strengths more significantly. Evaluating the results of compressive assessments, it was concluded that increase in the number of fibers per unit volume of concrete, initially increases the strength and consequently formability of samples up to splitting point.

A. Deepak Raj , et al carried out their research work on experimental methods on glass fiber reinforced self compacting concrete . They had studied the workability and mechanical properties of plain SCC and GFRSCC with the use of S-glass fibre content with 0%, 0.25%, 0.5%, 0.75%, 1% along with different lengths of fibers like 1.2m, 1.8mm, 2.4mm .They replaced 30% of fly ash for all the mixes Results showed that flow ability of GFRSCC is directly proportional to its length and quantity added. Mix with 1% of glass fibers with all different lengths was more flowable and also comparatively given higher compressive strength.

Arya P Nair, et al made a study on effects of nano silica on strength and durability properties of glass fiber reinforced SCC. Different GFRSCC mixes were made with constant glass fiber of 0.1% and by varying the nano silica content by the weight of cement. Workability of SCC decreased with addition of AR glass fibers and nano silica and mix with 2.5% nano silica has shown higher compressive strength.

Mostafa Jala, et al made a comparative study on effects of class F fly ash, nano silica and silica fume on properties oh high performance self compacting concrete. Results showed that the mixtures containing admixtures especially blend of silica nano particles and silica fume had improved mechanical and transport properties.

Manohar K N , et al , made their study on the strength characteristics of glass fiber reinforced SCC with fly ash and silica fume . In this study fly ash nd silica fume were kept constant and glass fibers were added as 0 to 0.8% by the weight of concrete. The compressive strength of SCC with glass fibers of 0.3% was maximum and the splitting tensile strength was maximum at fiber percentage of 0.04% and flexural strength was maximum at 0.7%.

III. MATERIAL PROPERTIES

The materials used in this work are cement, fine aggregate, coarse aggregate, water, super plasticizer, viscosity modifying agents, AR- glass fibers, Fly ash, silica fume, nano silica.

Cement: Ordinary Portland cement (OPC) of Ultra Tech brand and 53 grade confirming to IS: 12269-1987, specific gravity of cement is 3.1

Fine & Coarse aggregate: Fine aggregate used is natural river sand which is collected from the beds of river Tungabhadra. According to IS: 383-1970 the fine aggregate confirms to Zone II. Maximum nominal size of fine aggregate is 4.5mm, specific gravity is 2.66, bulk density of fine aggregate is 1453 Kg/m³.

Maximum nominal size of coarse aggregate used is 12.5mm, specific gravity is 2.85 and bulk density is 1300Kg/m³.

Water : Potable, fresh, colourless and clean municipal tap water free from organic matter is used .

Super plasticizer : Master Glenium Sky 8233 obtained from BASF company is used, this SP is based on modified polycarboxylic ether. Its properties are listed in table 1

Table 1 Physical properties of Super plasticizer

| Aspect | Light brown liquid |
|----------------------|--------------------|
| Relative Density | 1.08±0.01at 25°c |
| pH | ≥ 6 |
| Chloride ion content | <0.2% |

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Viscosity Modifying Admixture (VMA): VMA named Master Matrix 2, which is bought from BASF, Hyderabad is used. Its properties are listed in table 2

Table 2 Physical properties of VMA

| Aspect | Colourless free flowing liquid |
|----------------------|--------------------------------|
| Relative Density | 1.01±0.01 at 25° c |
| pH | ≥6 at 25°c |
| Chloride ion content | <0.02% |

Fly ash: Fly ash is a by product obtained during the process of combustion of pulverized coal in electric power generating plant. Fly ash produced from Raichur Thermal Power plant, Karnataka is used as partial replacement for cement. Its physical properties are listed in table 3.

Table 3 Physical properties of Fly ash

| Properties of Fly ash | Results |
|--|---------|
| Fineness modulus ash (passing through 75µ) | 7.5 |
| Specific surface area of particle | 372 |
| Specific gravity | 2.5 |

Silica Fume: Silica fume used here is obtained from Astrra Chemicals Ltd , Chennai, it is in white colour powder form and its properties are listed in table 4.

Table 4 Physical Properties of Silica fume

| Property | Result |
|------------------|-------------|
| Particle size | 0.5µm - 1µm |
| Pack density | 0.76 gm/cc |
| Moisture content | 0.058% |
| Specific gravity | 2.63 |

Nano Silica : Nano silica is obtained from Astrra Chemicals Ltd, Chennai, its properties are listed in table 5

Table 5 Physical properties of Nano silica

| Property | Result |
|--|---------|
| Specific surface area (m ² /gm) | 202 |
| SiO ₂ content (%) | 99.88 |
| Particle size | 17 nano |
| Density (g/l) | 44 |

AR Glass fibers : AR Glass fibers were obtained from Owens Corning Reinforcement, Hyderabad. Its properties are listed in table 6.

Table 6 Physical Properties of AR Glass fibers

| Property | Results |
|---------------------------------------|------------------------------|
| Length | 12mm |
| Filament diameter (ISO 1888: 2006) | 14µm |
| Specific gravity | 2.68 gm/cm ³ |
| Modulus of elasticity | 72GPa-10x10 ⁶ Psi |
| Tensile strength | 1000-1700 MPa |
| Loss on ignition(%) (ISO 1887 : 1995) | 0.60 |
| Moisture (%) (ISO 3344 :1997) | 0.50ax |

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IV. MIX PROPORTIONING

The mix proportioning is a key factor to achieve SCC. Though SCC was first developed in 1980's there is no standard method for mix design adopted or developed to achieve SCC. The European Federation of Specialist Construction Chemicals and Concrete systems (EFNARC) provide the guidelines for development of SCC, but no method of mix design specifies the grade of concrete in SCC except Nan Su et al method. In this work mix design is based upon the Nan Su et al method and confirming to the EFNARC guidelines. In the present work water to powder ratio of 0.4 is maintained constant throughout the experiment. Here SCC was achieved by trial mixes and then AR-Glass fibers were added in varying proportions of 0.05, 0.03%, 0.06%, 0.1%. The mix with glass fibers of 0.06% shown good workability conditions satisfying EFNARC guidelines and had higher compressive strength than other percentage of glass fibers. Keeping the percentage of glass fibers as constant as 0.06% through out the mixes, then cement was replaced by fly ash in percentages of 10%, 20%, 30%, 40%, 50%, fresh and hardened properties were checked. By taking the optimum mix, from the results and then keeping the percentage of fly ash constant, then again cement replacement is done by silica fume in percentages of 5%, 10%, 15% and for another set of mixes keeping the fly ash percentage and content of glass fibers as constant, cement is replaced by nano silica in percentages of 2%, 4%, 6%. The mix proportions were tabulated in table 7 and table 8.

Table 7 Mix Designation

| | |
|----|--|
| M0 | =100% CEMENT, 0% glass fibers |
| M1 | =100% CEMENT, 0.03% glass fibers |
| M2 | =100% CEMENT, 0.06% glass fibers |
| M3 | =100% CEMENT, 0.1% glass fibers |
| M4 | =10% FLY ASH, 90% CEMENT, 0.06% glass fibers |
| M5 | =20% FLY ASH, 80% CEMENT, 0.06% glass fibers |
| M6 | =30% FLY ASH, 70% CEMENT, 0.06% glass fibers |
| M7 | =40% FLY ASH, 60% CEMENT, 0.06% glass fibers |
| M8 | =50% FLY ASH, 50% CEMENT, 0.06% glass fibers |

| S.No | Mix designation | Cement (Kg) | F.A (Kg) | C.A (kg) | Fly ash (Kg) | Silica fume (Kg) | Nano Silica (Kg) | Glass fibers (%) | Water (lit) | SP (lit) | VMA (lit) |
|------|-----------------|-------------|----------|----------|--------------|------------------|------------------|------------------|-------------|----------|-----------|
| 1 | M0 | 500 | 879 | 688 | 0 | 0 | 0 | 0 | 200 | 4.62 | 0.25 |
| 2 | M1 | 500 | 879 | 688 | 0 | 0 | 0 | 0.03 | 200 | 4.62 | 0.25 |
| 3 | M2 | 500 | 879 | 688 | 0 | 0 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 4 | M3 | 500 | 879 | 688 | 0 | 0 | 0 | 0.1 | 200 | 4.62 | 0.25 |
| 5 | M4 | 450 | 879 | 688 | 50 | 0 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 6 | M5 | 400 | 879 | 688 | 100 | 0 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 7 | M6 | 350 | 879 | 688 | 150 | 0 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 8 | M7 | 300 | 879 | 688 | 200 | 0 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 9 | M8 | 250 | 879 | 688 | 250 | 0 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 10 | M9 | 332.5 | 879 | 688 | 150 | 17.5 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 11 | M10 | 315 | 879 | 688 | 150 | 35 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 12 | M11 | 297.5 | 879 | 688 | 150 | 52.5 | 0 | 0.06 | 200 | 4.62 | 0.25 |
| 13 | M12 | 343 | 879 | 688 | 150 | 0 | 7 | 0.06 | 200 | 4.62 | 0.25 |
| 14 | M13 | 336 | 879 | 688 | 150 | 0 | 14 | 0.06 | 200 | 5.56 | 0.25 |
| 15 | M14 | 329 | 879 | 688 | 150 | 0 | 21 | 0.06 | 200 | 6.94 | 0.25 |

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| |
|---|
| M9 =30% FLY ASH ,5% SILICA FUME ,65% CEMENT , 0.06% glass fibers |
| M10 =30% FLY ASH ,10% SILICA FUME , 60% CEMENT , 0.06% glass fibers |
| M11 =30% FLY ASH ,15% SILICA FUME ,55% CEMENT , 0.06% glass fibers |
| M12 =30% FLY ASH ,2% NANO SILICA , 68% CEMENT , 0.06% glass fibers |
| M13 =30% FLY ASH ,4% NANO SILICA ,66% CEMENT , 0.06% glass fibers |
| M14 =30% FLY ASH ,6% NANO SILICA ,64% CEMENT , 0.06% glass fibers |

Table 8 Mix proportions of GFRSCC

V. RESULTS AND DISCUSSION

A. FRESH PROPERTIES OF GFRSCC

Slump flow , V-Funnel, L-Box were used to test the workability , passing ability of SCC's. Trial batches were made initially , to get the designed slump flow was obtained by adjusting the dosage of the super plasticiser. Flowability of the mixtures was inspected through the V-funnel test. L-box test was carried out as an indication of passing ability. Slump flow, L-box and V-funnels tests were carried out according to the procedure recommended by EFNARC guidelines. The fresh properties for each mix were tabulated in table 9.

Table 9 Fresh Properties of GFRSCC

| S.No | MIX | Slump (mm) | T ₅₀ (sec) | V-Funnel (sec) | T ₅ (sec) | L –box ratio |
|------|-----|------------|-----------------------|----------------|----------------------|--------------|
| 1 | M0 | 650 | 3 | 16 | 18 | 0.85 |
| 2 | M1 | 550 | 5 | 20 | 23 | 0.8 |
| 3 | M2 | 570 | 4 | 16 | 18 | 0.85 |
| 4 | M3 | 540 | 5 | 20 | 22 | 0.9 |
| 5 | M4 | 550 | 5 | 18 | 19 | 0.9 |
| 6 | M5 | 630 | 3 | 12 | 13 | 0.85 |
| 7 | M6 | 700 | 2 | 10 | 12 | 0.81 |
| 8 | M7 | 740 | 1.5 | 8.5 | 10 | 0.8 |
| 9 | M8 | 790 | 1.2 | 7 | 9 | 0.8 |
| 10 | M9 | 690 | 3 | 10.5 | 12 | 0.9 |
| 11 | M10 | 670 | 4 | 11 | 14 | 0.88 |
| 12 | M11 | 650 | 4 | 11 | 13 | 0.89 |
| 13 | M12 | 580 | 3 | 16 | 18 | 0.72 |
| 14 | M13 | 650 | 3 | 12 | 15 | 0.75 |
| 15 | M14 | 630 | 5 | 18.4 | 20 | 0.7 |

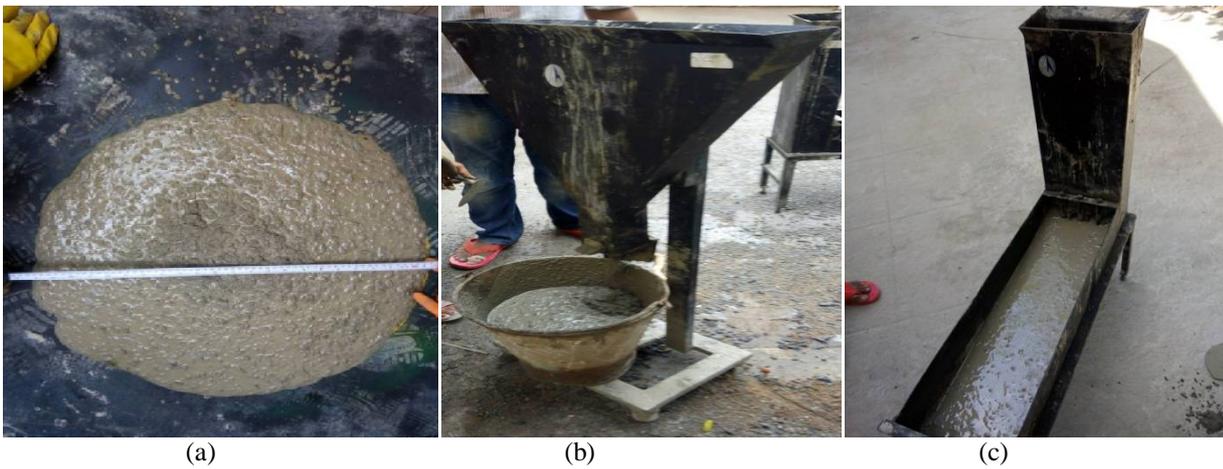


Fig 1 Workability tests (a) Slump flow test (b) V-Funnel test (c) L-Box test

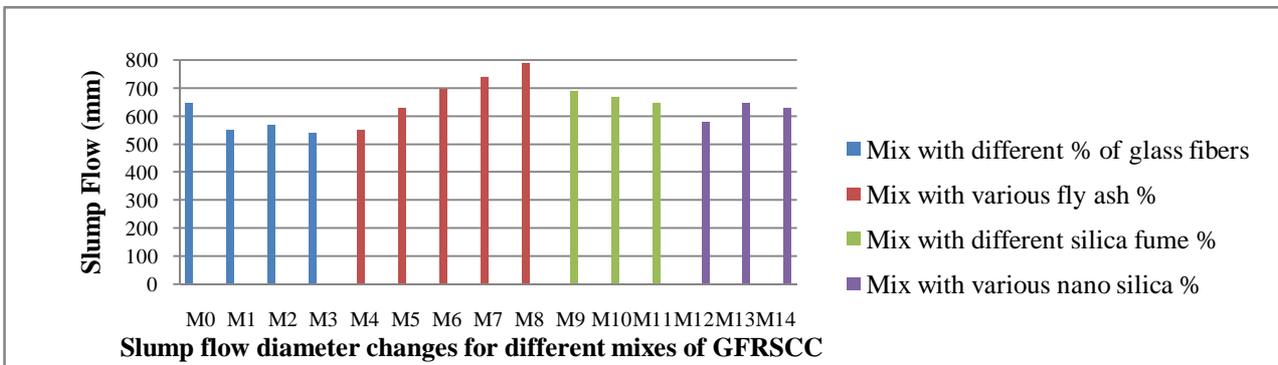


Fig 2 Variation of Slump Flow

It was observed that by the increase of percentage of fibers slump flow decreased compared to the mix with 0% fibers, but again increased at 0.06%. With the increase of fly ash slump flow diameter also increased gradually. Silimilarly by the increase of silica fume % the slump flow diameter decreased. For the mixes with nano silica , the percentage of super plasticiser was also increased in order to satisfy the EFNARC guidelines.

B. STRENGTH PROPERTIES OF HARDENED CONCRETE

The compressive strength and split tensile strength are obtained by testing the cube specimens and cylinder specimens in Compression Testing Machine (CTM). The flexural strengths are obtained by testing beam specimens in Universal Testing Machine (UTM). The results are tabulated in table 10.

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Table 10 Strength Properties of GFRSCC

| S . No | MIX | Compressive strength (MPa) | Split tensile strength (MPa) | Flexural strength (MPa) |
|--------|-----|----------------------------|------------------------------|-------------------------|
| 1 | M0 | 38.45 | 2.95 | 4.1 |
| 2 | M1 | 39.11 | 3.20 | 4.15 |
| 3 | M2 | 44.44 | 3.15 | 4.29 |
| 4 | M3 | 27.3 | 2.8 | 4.2 |
| 5 | M4 | 25.55 | 3.39 | 3.14 |
| 6 | M5 | 27.5 | 2.33 | 3.49 |
| 7 | M6 | 35.11 | 2.44 | 2.9 |
| 8 | M7 | 22.44 | 2.26 | 1.98 |
| 9 | M8 | 18.2 | 2.48 | 1.85 |
| 10 | M9 | 37.2 | 3.1 | 3.09 |
| 11 | M10 | 50.22 | 3.7 | 3.09 |
| 12 | M11 | 39.21 | 2.97 | 2.78 |
| 13 | M12 | 49.78 | 3.64 | 3.98 |
| 14 | M13 | 58.7 | 3.93 | 4.3 |
| 15 | M14 | 48.1 | 3.11 | 3.69 |

From the experimental results it is observed that mix M2 with 0.06% fiber content has higher compressive strength compared to other mixes . With the replacement of fly ash for cement, strength increases upto 30% of replacement of fly ash and then decreases. So with 30 % of fly ash and 0.06% of fibers as constant ,compressive strength increases upto replacement level of 10% silica fume, similarly the compressive strength increases upto replacement of 4% nano silica and then decreases.

It is observed that by the increase in the fiber content, there is an increase in the flexural strength of GFRSCC. For mix with fly ash content flexural strength increased upto 20% replacement of fly ash and then decreases. Comparatively the value of flexural strength is high for the mix M3 and M13.

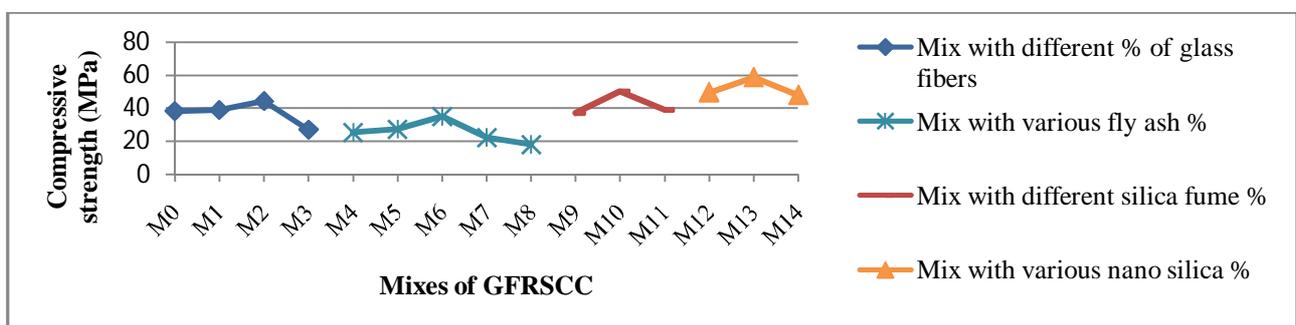


Fig 3 Variation of compressive strength

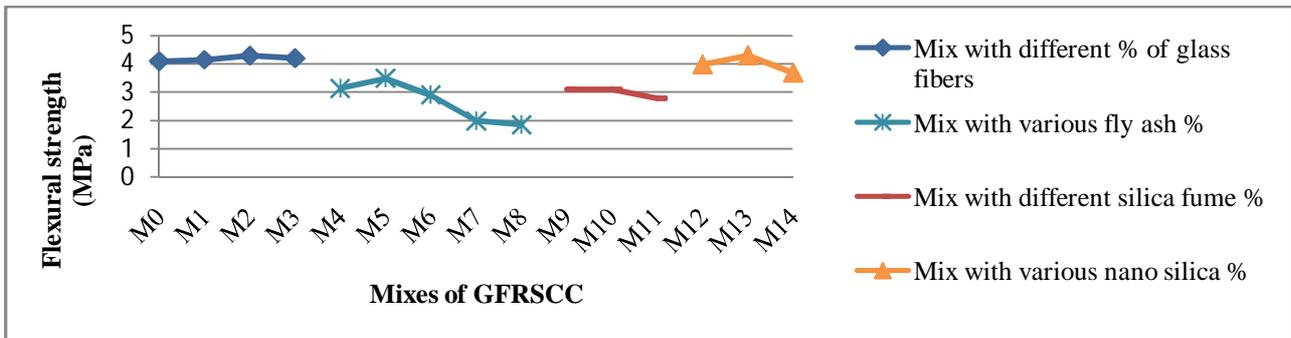


Fig 4 Variation of Flexural Strength

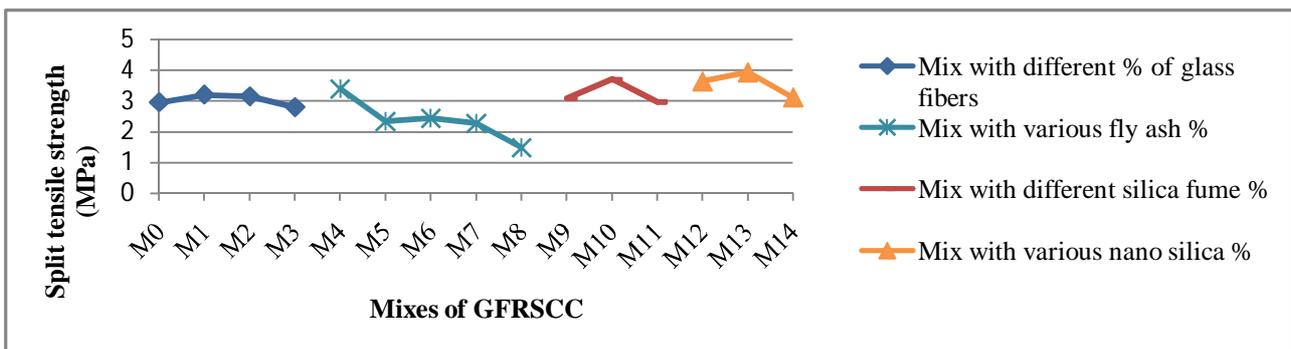


Fig 5 Variation of Split Tensile Strength

Split tensile strength increases with the addition of glass fiber content of 0.06% and then decreases. For the set of mixes with fly ash the split tensile strength was decreasing, also split tensile strength was higher than control mix for the mixes with silica fume and nano silica.

VI. CONCLUSIONS

The following conclusions are drawn from the experimental investigations:

- Slump flow in GFRSCC increases with the addition of glass fibers upto fiber content of 0.06% and then it decreases for the fiber content above 0.06%.
- The percent increase in compressive strength and the strength in split tension and flexure are observed to be 15.5, 6.8 and 4.6 percent respectively for the fiber content of 0.06 percent.
- Slump flow increases as the fly ash content in the mix has been increased. Similarly it decreases by the addition of silica fume and nano silica instead of fly ash. These slump values are observed to be comparatively higher than those observed for control mix.
- Mix M13 (FA-30%, NS-4%, 0.06% glass fibers) has attained high compressive strength of 58.7 MPa among all comparable mixes. The percent increase in the compressive strength, split tensile strength and modulus of rupture are observed to be 52.6, 33.2, 4.9 percent respectively when compared to those values of control mix.
- Compressive strength of GFRSCC is observed to be high at replacement levels of 30% ,10% ,4% of cement for mixes with FA , SF and NS respectively.
- Bleeding and segregation for all the mixes decreases with the addition of glass fibers.

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