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A COMPARATIVE STUDY OF COMPRESSIVE AND TENSILE STRENGTH OF CONCRETE MIXED WITH STEEL AND GLASS FIBERS

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ABSTRACT

The mechanical characteristics of steel and glass fiber reinforced concrete, such as their compressive and tensile strengths, are reviewed in this work. Fibers are used to strengthen concrete and prevent cracking. In order to compare the best options for producing high-strength concrete, steel and glass fiber were used in a laboratory experiment with varying percentages of fiber blended in cube and cylindrical specimens. Glass fiber with a 150 aspect ratio and steel fiber corrugated with a 50 aspect ratio are used as additives at varied proportions of 0%, 0.5%, 1%, and 1.5% by weight of cement. For the M20 grade of concrete, a total of 63 cube specimens for 7, 14, and 28 days, as well as 21 cylinders for 28 days, were casted and tested in accordance with the Indian Standard (IS 516:1959) for compressive strength and (IS 5816:1999) for tensile strength. This study confirmed the beneficial effects of various fibers with a specific limit % increase in specimen compression improvement at 7, 14, and 28 days, as well as specimen splitting improvement at 28 days, by comparing the results of FRC with normal concrete. After 28 days, the maximum compressive strength of 24.39 N/mm^2 and split tensile strength of 2.79 N/mm^2 were achieved with a 0.5% glass fiber addition. After 28 days, the addition of 1% steel fiber resulted in a maximum compressive strength of 25.41 N/mm and a tensile strength of 3.18 N/mm^2.

***Keywords**: Steel fiber, glass fiber, compressive strength, tensile strength, fiber reinforced concrete*

1. Introduction

1.1 Background

Concrete is one of the most adaptable building materials and one that is produced extensively worldwide. Its yearly output exceeds 12 billion metric tons worldwide, meaning that in 2007, more than two metric tons of concrete were produced annually for every person on the planet. The demand for concrete materials and infrastructure development rises as a result of rising living standards, population growth, and economic development (Li Z, 2011).

Concrete of low strength that is utilized for minor compression or temporary loads is known as non-structural concrete. Poor tensile strength, a low strain of fracture, and the need for formwork are some drawbacks of utilizing concrete. The primary drawback is the development of microcracks in concrete while curing. Workability and high strength for the cocnrete is very essesntial. To achieve this, different studies (Wafa, 1990) have suggested the use of fibers in concrete to overcome these disadvantages.

Fiber-reinforced concrete (FRC) is made of hydraulic cement, water, fine and coarse aggregate, and discrete, discontinuous fibers. Generally dispersed at random throughout the concrete matrix, the fibers are discontinuous. In structural applications, fibers are utilized in conjunction with traditional reinforcement. Fiber-reinforced concrete has the potential to be a cost-effective and practical building material due to its flexibility in methods of manufacturing. (ACI 544.IR, 1996)

According to Romualdi and Batson, 1963, The usage of fibers as reinforcement dates back thousands of years. In the past, mudbricks were made with straw and mortar made with horsehair. Asbestos fibers were utilized in concrete in the 1900s. The idea of composite materials emerged in the 1950s, and fiber-reinforced concrete was one of the subjects of discussion. After asbestos's health hazards were identified, a substitute for the material in concrete and other construction materials had to be found.

A study by Biryukovich and Yu, 1965 had stated In the United States, the first significant study to assess the potential of steel fibers as a concrete reinforcement was conducted in the early 1960s. In the late 1950s, an attempt was made in the United States to incorporate glass fibers into concrete.

Himcon Traders have officially started supplying the steel fibers for the use in high strength concrete in Nepal with its detailed specification provided in the website. (source: https://himconnepal.com/product-category/earth-fiber/) . In studies conducted by Shigu et al in 2023 and Gyawali in 2013 are some of the studies that were conducted in the fiber reinforced concrete technology. Also, Fosroc Nepal in its facebook page has started a steel fiber flooring project that spans more than 3000 square meters. Limited studies, high strength concrete possibilities, enhanced tensile strength are some of the proven advantages of FRP concrete which has to be explored through proper study which is the major part of this research.

1.2. Effect of fiber on Compressive and Tensile Strength

Mastan & Rao, 2019 have conducted test on experimental study on compressive strength of concrete by using steel, glass, and polypropylene fiber reinforced concrete at 0%, 0.25%, 0.5%, and 1% replacement of volume of concrete. They observed that the compressive strength of casted concrete using glass fiber reinforced concrete gives 21.8% higher with addition of 1% glass fiber volume of concrete with compared with normal mix and the steel fiber reinforced concrete gives 22.48% higher with addition of 0.5% steel fiber.

Lakshmi & Thaarani, 2015 has conducted study in M20 concrete with the fibrous materials such as steel, coir sugarcane and bagasse where the tensile strength for 7 and 28 days in different volume proportions with 0.5%, 1.0%, 1.5% with different aspect ratios. The added fibers induced reduction in workability however with small increase in compressive and tensile strength, ranging from 8 and 21% in the compressive strength and 23 and 42% in split tensile strength.

Kumar, 2020 has investigated on fiber reinforced concrete with steel fiber which were crimped along with polypropelyne fibres in M40 concrete of pavement quality. The very low water cement ratio of 0.38 and varying fiber dosages (from 0.5% to 2%) for steel and (0.1% to 0.4%) for polypropelyne fibres were used for preparing cubes, cylinders and beams. Finally, it was determined that 1.5% and 0.3%, respectively, are the ideal doses of steel and polypropelyne fibers. When concrete cubes reinforced with steel fibers are given the recommended dosage, their 28-day compressive strength is 54.44 N/mm^2. The concrete's compressive strength is 28.82% higher than that of traditional concrete. When steel fibers are added in the right dose, cylindrical specimens' 28-day split tensile strength is 5.66 N/mm^2. The tensile strength of split concrete is 23.50% more than that of regular concrete.

Patil & Burile, 2016 have conducted research on Comparative Study of Steel and Glass Fiber Reinforced Concrete Composites. Steel, G.I., carbon, glass, aramid, asbestos, polypropylene, jute, and other materials can all be utilized as fibers in FRC, with a volume fraction of hook end ranging from 0% to 0.5%. Without admixture, steel fibers with a 53.85 and 50 aspect ratio and alkali-resistant glass fibers with 0% and 0.25% by weight of cement were utilized. The fibers had a cut length of 12 mm. When comparing the results of FRC with plain M20 grade concrete, they discovered that various fibers had a favorable impact on the specimen's splitting improvement and % rise in compression at 7 and 28 days.

Chandramouli K, 2010 have conducted experimental investigation on strength properties of glass fiber concrete. Glass fibers effect on various properties of M20, M30, M40 and M50 grade concrete was used. Compressive strength, split tensile strength and flexural properties. Bleeding was induced in the mix due to the glass fibers which if reduced improves making them crack resistance by making it consistent through out the mix. The overall gain of the strength in the concrete was observed between 20 and 25% in case of compressive and 15 to 20% for the case of tensile strength.

Kiran & Teja, 2016 have carried out experimental investigation in different proportion of glass fibers by weight of the cement in different ages. They found a maximum compressive strength at 7% of glass fiber whereas at 6% glass fiber content, the maximum split tensile strength. They recommended a 6% of glass fiber content for the concrete.

Tanoli et al, 2014 have done experiment on Effect of Steel Fibers on Compressive and Tensile Strength of Concrete using M20 grade of concrete. Steel fibers of ordinary binding wire cut into small pieces of size 2 inch was used in the preparation of all specimens with 0.1 %, 0.5 % and 1 % along with control samples (0% Fibers). The similar result of increased strength, increase in compressive strength and improved tensile strength (from 2% to 6% and 7% to 49%) respectively were observed due to steel fibers.

Thus, to understand the strength variation with respect to the change in the proportion of fibers in fiber reinforced concrete (using steel and glass fibers), this study is carried out with 0.5%, 1% and 1.5% fiber content and their respective strengths, compressive strengths and tensile strengths along with the workability are compared with the nominal mix concrete of M20 grade.

2. Materials and methods

2.1 Fibers:

Fiber is a small piece of reinforcing material possessing certain characteristic properties. The fiber is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fiber is the ratio of its length to its diameter (l/d). Generally, fibers with aspect ratio varying from 30 to 150 are used in concrete (Kumar, 2020). The selected fibers for the test along with the physical properties have been discussed in the underlying sections.

2.1.1 Glass Fibers:

The melting point of many minerals, such as dolomite, kaolin clay, limestone, silica sand, etc., is reached in a furnace. Tiny brushings are then used to extrude the melted glass. Usually little larger than 25 micrometers in diameter, these are extremely tiny orifices. Filaments are what these extrusions are known as. Glass fibers with alkali resistance are specifically made for concrete building. They contain silicates of alkaline zirconium. Concrete cracking can be effectively avoided with their help. This gives concrete more strength and flexibilities (Kiron, 2012).

According to certificate provided by company, the properties of glass fiber used were as tabulated in the Table 1.

Table 1 Properties of glass fibers as per the supplier [Source : Kapilvastu glass fiber]

Properties	Details
Type	E-Glass
Cross -section	circular
Length, l mm	50
Diameter, d mm	0.3
Aspect Ratio, l/d	150
Specific gravity	2.56
Tensile strength, (Mpa)	363.912

Figure 1 E- Glass fibers and corrugated steel fiber

[Source : Indianmart Sun Shine]

2.1.2 Steel Fibers:

Steel fibers are discrete, short lengths of steel with an aspect ratio (length to diameter) between 20 and 100 with any number of cross-sections. They are small enough to be readily and randomly distributed in a fresh concrete mix using a standard mixing technique (ACI 544.IR, 1996). The properties of the steel fibers collected from the providers has been included in the Table 2. Figure 1 shows the image of glass fibers and corrugated steel fiber being used in the study.

Table 2 Properties of steel fibers as per supplier

Properties	Details
Type	Crimped/Corrugated
Cross -section	Circular
Length (L)	50 mm
Diameter (d)	1.0 mm
Aspect Ratio, L/d	50
Tensile strength, (Mpa)	1100N /mm^2
Specific gravity	7.85

[Source : Indianmart Sun Shine]

2.2 Aggregate

The crushed coarse aggregate and fine aggregate used for test were collected from Rashu suppliers Bharatpur-11, of Manahari river. The coarse aggregate having maximum size of 20 mm were used in study. Test results are shown in Table 3.

Table 3 Test result of crushed coarse aggregate and fine aggregate

Tests	Crushed coarse aggregate	Fine aggregate	Standard limit	Reference standards
Specific gravity	2.7	2.54	2.5-3.0	As per IS: 2386-part 3- 1963
Water absorption	0.37%	0.5%	0.1-2%	As per IS: 2386-part 3- 1963
Impact value	7.7%		<45 %	As per IS 2386.
Los Angeles Abrasion	15.67%		<30 %	IS 2386.
Silt content		2.66 %	< 8%.	IS 2386-part 2

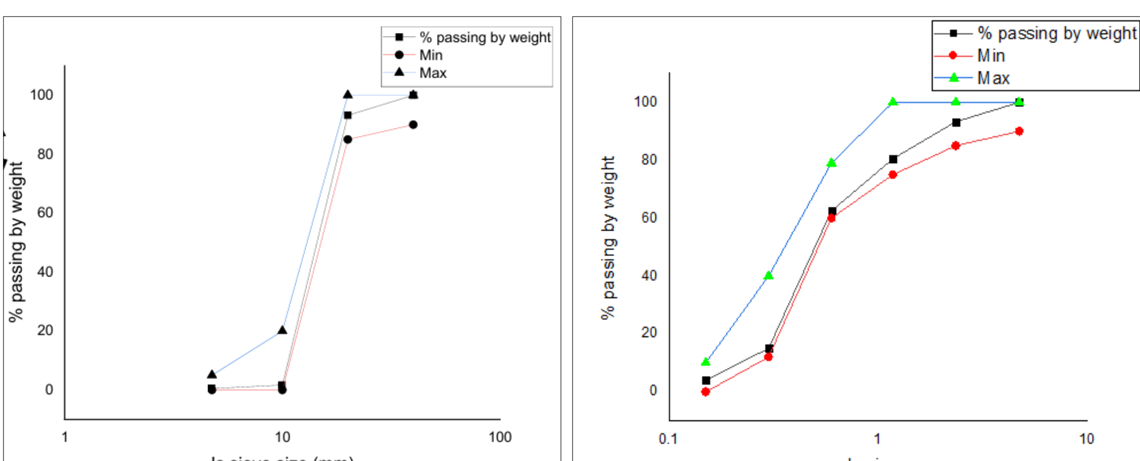

Figure 2 Gradation result of fine aggregate and coarse aggregates used in concrete

The fine aggregate selected lies in the gradation zone III as per IS 383, 1970 whereas the coarse aggregate satisfies the gradation provided by the same standard for 20 mm nominal size which can be seen in figure 2.

2.3 Cement

Cement used for the tests were 43 grade OPC cement. The various test on cement were carried out based on IS: 4031-1998 and the test results obtained and their comparison with the standard is shown in the Table 4.

Table 4 Results of test on cement

SN	Tests	Result	Standard of Tests as per IS 4031-V-1988
1	Specific Gravity	3.11	2.9-3.15
2	Initial Setting	40 minutes	Shall not be less than 30min
3	Final Setting	380 minutes	Shall not be more than 10hrs
4	Fineness of cement	3%	Less than 10%

2.4 Experimental design

In the present study, different fiber glass and steel, were used with varying percentage by weight of cement as an admixture for M20 grade concrete and the flow of the experimental design can be seen in Figure 3. Thus, all the concrete of M20 grade with varying proportion are the population. For each for varying percentage of fiber, 63 cubes specimen of size 150 mm x 150 mm x 150 mm were made for compressive strength test and tested for 7, 14, and 28 days . 21 cylindrical specimen of size 150 mm x 300 mm were be made for tensile strength test and tested for 28 days.

Figure 3 shows the flow chart of tests on concrete. Workability tests (slump test), compressive strength tests, and tensile strength tests were performed for the study in different fiber contents by weight of cement. The test specimens required for the tests are calculated and shown in Table 5 and Table 6 respectively.

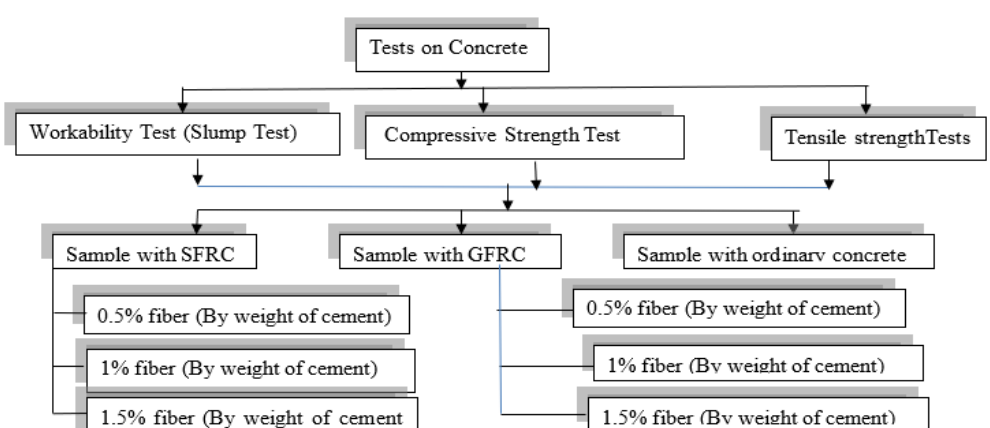

Figure 3 Flowchart for test on concrete

Table 5 Calculation for total number cube specimen for compressive strength test

Description		Number of Test Specimen			
		7 Days	14 Days	28 Days	Total
Sample of plain M20 grade of concrete		3	3	3	9
Sample with SFRC	0.5% fiber (By weight of cement)	3	3	3	9
	1% of fiber (By weight of cement)	3	3	3	9
	1.5% of fiber (By weight of cement)	3	3	3	9
Sample with GFRC	0.5% of fiber (By weight of cement)	3	3	3	9
	1% of fiber (By weight of cement)	3	3	3	9
	1.5% of fiber (By weight of cement)	3	3	3	9
Total		21	21	21	63

Figure 4 Samples with steel fibers (concrete cubes and cylindrical samples)

2.5 Test on Concrete

Three tests namely, slump tests, compressive strength and the split tensile strength were conducted in hardened concrete to determine the workability, compressive strength and tensile strength.

Table 6 Calculation for total number of cylinder specimen for tensile strength test

Description		28 days	Total
Sample of plain M20 grade of concrete		3	3
Sample with SFRC	0.5% fiber (By weight of cement) md	3	3
	1% of fiber (By weight of cement)	3	3
	1.5% of fiber (By weight of cement)	3	3
Sample with GFRC	0.5% of fiber (By weight of cement)	3	3
	1% of fiber (By weight of cement)	3	3
	1.5% of fiber (By weight of cement)	3	3
Total		21	21

The test procedure were as follows:

2.5.1 Slump Test for Workability of Concrete

Slump test is one of the widely used tools to measure the workability that can be employed at the site or the laboratory.

Figure 5 Slump test

The slump test were carried out by following the procedure provided in (IS: 7320-1974) and (IS:1199-1959).

2.5.2 Test on hardened concrete

Compressive Strength of Concrete

The Indian Standard (IS 516:1915) which details the methods of compressive strength test were followed during the testing of compressive strength of concrete. In this standard, the compressive strength of concrete is given in terms of the characteristic compressive strength of 150 mm size cubes tested at 28 days (fck).

Split Tensile strength Test (IS 5816:1999)

Cylindrical specimens of diameter 150 mm and the height of 300 mm were used to test against split tensile strength. The test was carried in 28 days cured samples tested in digital compression machine of 200 tons capacity. Each category, 3 specimen were prepared to produce the average tensile strength in that group using the formula:

$$\text{Tensile strength } (MPa) = \frac{2P}{\pi DL}$$

3. Results and discussions

3.1 Comparative Study of Compressive Strength of GFRC, SFRC and Normal concrete

Table 7: Compressive Strength of Fibre Reinforced Concrete

Sample	Average Compressive Strength (N/mm^2)		
Glass Fibre	**7 days**	**14 days**	**28 days**
0.5%	20.68	22.12	24.39
1%	19.53	21.49	23.45
1.5%	17.23	19.23	20.95
Steel Fibre			
0.5%	21.51	23.36	24.49
1%	22.61	24.34	25.41
1.5%	20.01	22.04	23.64
Normal	17.36	21.11	22.24

Figure 6 represents comparison of compressive strength between M20 grade of concrete and glass fiber , steel fiber with varying percentage (0.5%, 1% and 1.5%) by weight of cement after 7, 14 and 28 days of curing. It is observed that compressive strength is in increasing order from 7 to 28 days. It is seen that maximum strength is obtained by steel fiber concrete at 1% (25.41N/mm2) at 28 days. Among GFRC, maximum strength is observed at 28 days of 0.5% fiber contents whereas at 1% for steel fiber contents, maximum compressive strength is observed.

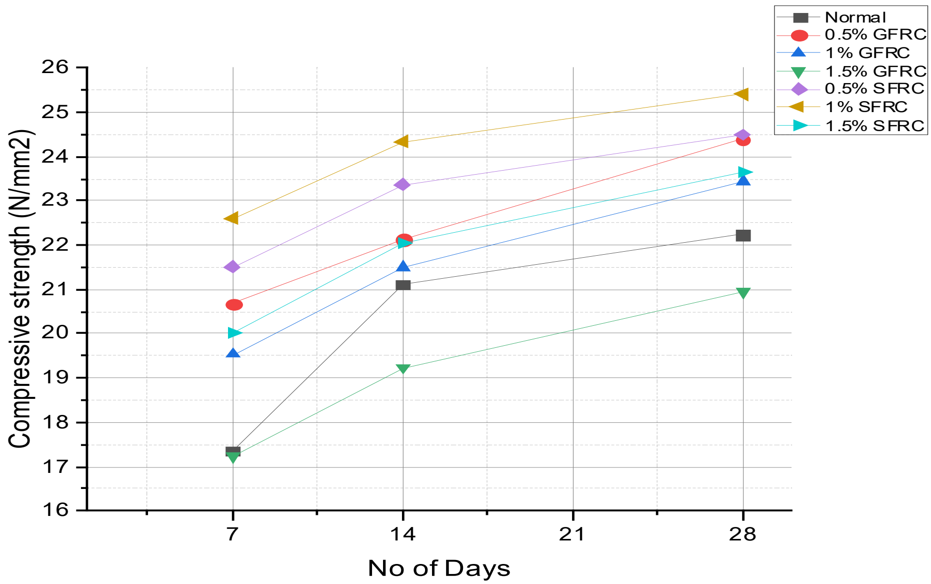

Figure 6 Compressive strength of GFRC, SFRC and Normal

An optimum fiber content is observed for both the cases of Glass Fiber Concrete and Steel Fiber Reinforced Concrete respectively at 0.5% and 1% of the fiber content. While, the lowest strength is observed at 1.5% GFRC which comes out to be lower than the control mix, a virgin mix without any fiber content in it standing at 21 MPa. The strength of GFRC keeps reducing with the increase of the fiber content. Thus, it is not advisable to have fiber content greater than 1%.

Similarly, in the case of Steel Fiber Reinforced Concrete, the peak strength is observed at 1% SFRC and the strength reduces with the increase or the decrease in the fiber content. The highest reduction is observed when there is high amount of the steel fibers i.e., of 1.5%. However, at every steel fiber contents in fiber reinforced concrete strengths are greater than the control mix.

It is noticed that the percentage increment of steel fiber (1%) increases the strength of the concrete by 4.18% more than highest strength of GFRC at glass fiber content, 0.5%. The interesting portion is seen that the more addition of glass fiber (1.5%) decreases strength less than normal concrete by 5.8%.

In the study conducted by (Raza et al., 2021) where the comparison between the Fiber reinforced concrete with 2% fiber content of steel fibers and 2% fiber content of glass fibers by volume of concrete observed the similar result where higher compressive strength was observed with the concrete 1% steel fibers and 0.5% glass fiber content by weight of cement. In the investigation of Lakshmi & Thaarani, 2015 addition of steel, coir and sugarcane bagasse fiber by volume of concrete was observed maximum strength obtained by steel fiber, in this study also achieved similar result among SFRC, GFRC and normal concrete. In the study conducted by Patel & Buriel 2016, comparison between steel fiber of 0% and 0.5% by volume of concrete and glass fiber of 0% and 0.25% by weight of cement was found higher compressive strength by addition of steel fiber, similar positive result also found in this study.

3.2 Comparison of Tensile Strength of the Fiber Reinforced Concrete

Table 8 : Tensile Strength of Fibre Reinforced Concrete

Fibre %	28 days average Tensile strength N/mm^2 Normal	28 days average Tensile strength N/mm^2 SFRC	28 days average Tensile strength N/mm^2 GFRC
0.5		3.02	2.79
1	2.18	3.18	2.31
1.5		2.39	2.11

Figure 7 illustrates the tensile strength of M20 grade of concrete and addition of glass and steel fiber in varying proportion (0.5%, 1%and 1.5%) after 28 days of curing. It is observed that addition of steel fiber from 0.5% show tensile strength is in increasing order and maximum at 1% (3.18N/mm2). Further addition of steel fiber (1.5%) lead to fall in strength by 37.66%. It is noticed that addition of steel and glass fiber upto certain limit increases split tensile strength than normal concrete. Tensile strength of normal is 2.18 N/mm2 which is 27.98% less than 0.5% GFRC and 38.53% than 0.5% SFRC. This result can also be observed in the work of (Raza et al., 2021) where the split tensile strength for the steel fiber concrete for 2% fiber content yielded higher strength compared to that of glass fiber concrete of the same proportions. At 1% of the steel fiber content for the steel fibers the split tensile strength to the compressive strength ratio is 12.5% and for that of 0.5% of glass fiber content the ratio is found to be 9.5 % which is also aligned with the result of Raza which produced a 10.1% and 8.71% respective results for steel and glass fiber concrete.

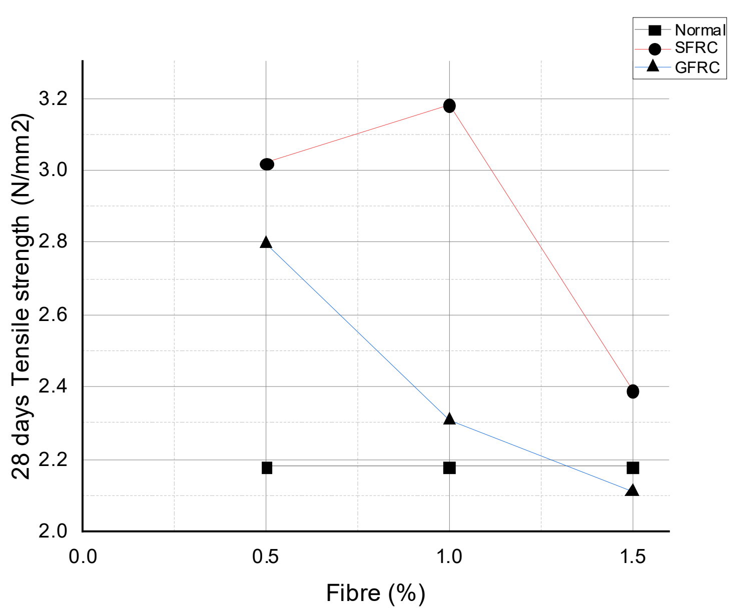

Figure 7 Tensile strength of SFRC, GFRC and Normal

In the study conducted by Patel & Buriel 2016, comparison between steel fiber of 0% and 0.5% by volume of concrete and glass fiber of 0% and 0.25% by weight of cement was found higher tensile strength by addition of steel fiber, similar positive result also found in this study. According to Tanoli et al, 2014, the study on Effect of Steel Fibers on Compressive strength of Concrete using M20 grade of concrete. Steel fibers of 0.1 %, 0.5 % and 1 % along with control samples (0% Fibers) found that addition of Steel Fibers tensile strength of concrete beams increase from 7% to 49%.

In the investigation of Lakshmi & Thaarani, 2015 the possibility of reusing the locally available waste fibrous materials (steel, coir and sugarcane bagasse fiber) as concrete composites was observed the marginal improvements found in the split tensile strength of concrete increases which ranges from 23% to 42% with fibers content volume fractions 0.5%, 1.0%, 1.5% and aspect ratios 80. Also in this study split tensile strength of fiber increases from 38.53% to 74.31%.

In the study of (Jahami et al, 2022) the production of low-cost, high-strength concrete by partially replacing fine aggregates (FA) with waste glass sand of (0%, 25%, 50%, and 75%) compressive strength, split tensile strength increased by 27% and 9% respectively

On performing ANOVA analysis on 7, 14 and 28 days compressive strength of concrete separately, the alternative hypothesis is accepted which indicated that the concrete's overall compressive strength at different curing days differed significantly depending on the presence of steel and glass fiber and the similar result were observed in the case of the tensile strength with the different proportions of fibers.

3.3 Workability of Fresh concrete

The slump value is a measure indicating the workability of cement concrete. Higher the slump value greater is workability. The figure shows the obtained results for various concrete produced by addition of glass and steel fiber in varying percentage (0.5%, 1% and 1.5%) by weight of cement.

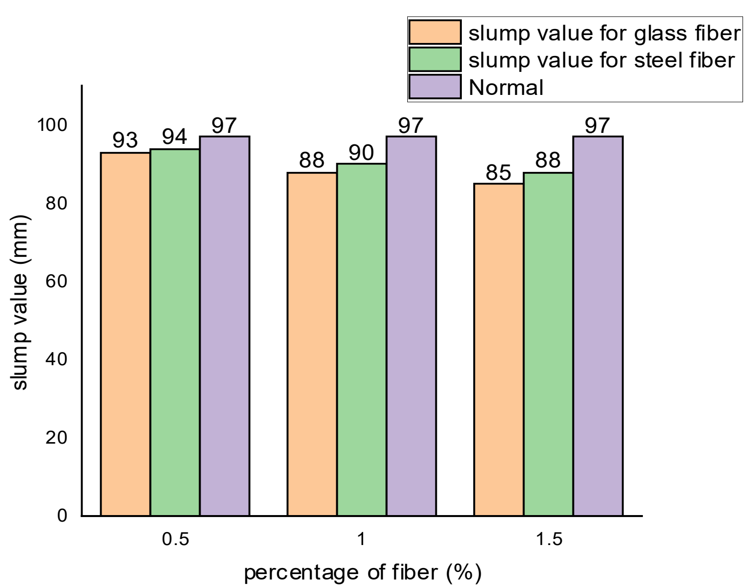

Figure 8 Slump Test for different composition of fiber in fiber reinforced concrete

Figure 8 represents that slump value gets reduced with increase in fiber content in concrete. The workability of GFRC degrades by 9.41% from 0.5% to 1.5% addition of glass fiber by weight of cement where the GFRC gains maximum compressive strength at 0.5%. Similarly the workability of SFRC degrades by 6.81 % from 0.5% to 1.5% addition of glass fiber by weight of cement where the SFRC gains maximum compressive strength at 1%. (Biswas et al., 2021) incorporated the effects of the fibers in the concrete and concluded that the incorporation of the steel fibers reduces the flowability of the concrete in a linear ratio. The similar result in workability, the slump value was also observed in the work of (Lv et al., 2024) in the case of Glass fiber concrete where slump value reduced with the increased fiber content in the concrete.

4. Conclusions

The purpose of this study was to compare the compressive and tensile strengths of M20 grade of concrete with addition of glass and steel fiber in 0.5%, 1% and 1.5% by weight of cement. Concrete was prepared using nominal mix. For the investigation, 63 cubes of size 150 mm x 150 mm x 150 mm was prepared and tested at 7, 14, and 28 days, their average compressive strength was evaluated. Also split tensile tests were carried out on 21 numbers of cylinders of dimension 300 mm x 150 mm and tested after 28 days. In addition to that economic analysis was also undertaken.

The workability of the fiber mixed reinforced decreased with the additional inclusion of the fibers which would require additives for maintaining required level of workability in the fresh concrete. Regarding the compressive strength, compressive strength is enhanced with the optimum fiber contents inclusion in the concrete. A 14.25% increase of the strength is observed with 1% steel fiber inclusion in comparison with 10.11% increase with the 0.5% glass fibers. The mix design should incorporate the optimum amount of fibers for the optimum result in compressive strength. Including higher or lower amount of the fibers in the concrete results in lower strength and in some condition lower than the virgin concrete mix. The similar results were obtained in split tensile strength test as well where at 1% steel fiber content and 0.5% glass fiber content concrete an increase of 45.87% and 27.98% tensile strength were observed when compared to concrete without addition of fibers. Similarly, at 0.5% and 1.5% steel fiber content, increase of 38.53% and 9.63% were obtained while that for glass fibers 1% and 1.5%, increase of 5.96% and 3.21% was observed after 28 days of curing.

The fiber reinforced concrete with the curing age, strength gain is observed. So, curing has to be recommended for fiber reinforced concrete for full 28 days to observed high strength.

5. Conflict of interest

There are no any conflict of interest while doing this study.

6. Acknowledgements

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