Mechanical Properties of Glass Fiber Reinforced Concrete Using Different Sizes of Glass Fiber

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Abstract - The current study investigates the influence of size of glass fiber on the properties of the concrete. Three different lengths of glass fibers 6 mm, 12mm, 24 mm were selected and the mechanical properties of the concrete were evaluated in terms of compressive strength, tensile strength and flexural strength and compared with the conventional concrete. This follows the cost analysis of 1m^3 of concrete. The results indicates that the addition of glass fibers, particularly the 12mm size, enhances the compressive strength, split tensile strength and flexural strength of the concrete. However, the workability of Glass Fiber Reinforced Concrete (GFRC) is reduced compared to conventional concrete. Further, the cost of GFRC is higher compared with conventional concrete because of inclusion of glass fibers in the concrete.

Key Words: Glass fibers, Size, tensile strength, cost

1.INTRODUCTION *(Size 11, Times New roman)*

Concrete is a composite material that is widely used in the construction of various structures. However, concrete is strong in compression and weak in tension. Due to this brittle behavior, the tensile stresses cause the development of cracks (Hameed et al., 2010). These tensile cracks will extend deeper and deeper, ultimately responsible for the failure of the structure. The introduction of fibers into the concrete helps to minimize the cracks that are formed during the tensile, compressive, and flexural stresses. Further, fibers in the concrete improve the strength and durability. Different researchers studied the properties of concrete using different types of fibers. The fibers include glass fibers, polypropylene fibers, steel fibers, etc. The utilization of fibers in concrete helps to transfer the load across the crack-developing areas (KH et al., 2022; Narwal et al., 2013). Different researchers studied the properties of the fiber-reinforced concrete using different fibers. However, limited studies were exist on the GFRC of varied lengths. So, the present study investigates the influence of the length of the glass fiber on the mechanical properties of the fiber-reinforced concrete. The length of the fibers used was 6mm, 12mm, and 24 mm, respectively. The mechanical properties include the compressive strength, tensile strength, and flexural strength of the concrete. Further, the results were compared with the conventional concrete in terms of cost and mechanical properties.

2. Literature Review

Several studies were conducted on the GFRC in terms of the fresh and hardened concrete properties. The fresh concrete properties include workability and the hardened concrete properties include compressive strength, split tensile strength, and flexural strength etc. Researchers compared the concrete with and without glass fibers at different proportions. From the observations, the increased proportion of glass fibers in the concrete show significant reduction in the workability (Paktiawal and Alam, 2022; Ojhaa et al., 2021). However, there is an improvement in the compressive strength of the GFRC with the addition of glass fibers (Ming-Gin et al., 2022; Hussain et al., 2020; Narayanan et al., 2020). Similar improvements were observed for flexural strength and split tensile strength with the addition of the glass fiber in the concrete (Ming-Gin et al., 2022; Hussain et al., 2020).

Pérez et al. (2024) investigated the mechanical properties of the GFRC with an objective to optimize the glass fiber content in the concrete by varying glass fibers from 0.5% to 2% at an interval of 0.5%, where the length of the glass fiber is 51.3 mm and the diameter is 0.05 mm. The observations revealed that consistent improvements in the mechanical properties of the GFRC with glass fibers up to 1.5%. Further increase in glass fiber reduced the strength of GFRC. The addition of the glass fibers increases the silicate, calcium, and silicon oxide in the mix (Pérez et al., 2024). Kumar et al. (2020) evaluated the properties of the GFRC where the length of the glass fibers used are 12 mm having an aspect ratio of 857.1. The glass fibers were introduced in the concrete at an interval of 0.33% varying from 0 to 1%. The results show an improvement in the compressive strength up to 0.33% of the glass fibers, and further addition of glass fibers reduces the strength of the GFRC. However, there is a continuous improvement in the flexural strength of the GRFC with the addition of glass fibers (Kumar et al., 2020). George et al. (2018) carried out durability studies on GFRC by varying glass fibers from 0 to 1.5% at an interval of 0.5%. It is observed that the optimum strength is observed at 1% of glass fibers in the mix. The durability of GFRC is more than that of conventional concrete (George et al., 2018). Ali et al. (1975) studied the properties of the glass fiber cement composites by changing its proportion which is measured in terms of volume (2-10%) and the glass fibers length. From the results, it is observed that at different percentage of fibers volume for different lengths, the optimum quantity of the fibers varies (Ali et al., 1975). Kasagani and Rao (2018) studied the tensile properties of GFRC with different lengths where the tensile strength is more for short length fibers compared with longer length fibers (Kasagani and Rao, 2018).

The majority of the studies are concentrated on the optimization of glass fibers in the concrete based on the compressive strength, tensile strength, and flexural strength. Further, compared with the nominal concrete in terms of strength enhancement and durability. And there are certainly limited studies that are concentrated on the length of the glass fiber that influences the fresh and hardened concrete properties. Even those studies are limited to certain properties only. The present study aimed to evaluate the properties of the concrete by varying the different types of glass fibers based on the length and aspect ratio. The fresh concrete properties include workability, and the hardened concrete properties include compressive strength, tensile strength, and flexural strength of the concrete. Based on the literature, the glass fiber content is fixed at 0.5%, and the length of the glass fibers varies from 6 mm, 12 mm, and 24 mm, respectively. Further, the cost analysis is carried based on the standard schedule of rates.

3. Materials and Methods

Materials used

In the current study, the M30 concrete is prepared with glass fibers and without glass fibers. The glass fibers of length 6mm, 12mm, and 24 mm were used and its properties were presented in Table 1. The Ordinary Portland Cement of 53 grade is used and tested its properties according to IS 4031: 1988 and shown in the Table 2. River sand is used as fine aggregate and crushed stone aggregate of 20 mm nominal maximum size is used as coarse aggregate and tested their properties according to the IS 383: 1970 and IS 2386: 1963 as shown in the Table 3 and Table 4. It is observed that all the properties of the fine aggregate and coarse aggregate fall within the specification limitations.

Table -1: Characteristics of Glass fibers

Specific gravity	2.68
Tensile strength (MPa)	1700
Elastic modulus (MPa)	72
Diameter (microns)	14
Length (mm)	6, 12, 24

Table-2: Properties of Cement

Test	Result	Specification limitation	Test Code
Fineness of Cement (%)	2	10	IS 4031: 1988 (Bureau of Indian Standards, 1988)
Specific gravity	3.10	3.10-3.15	IS 4031: 1988 (Bureau of Indian Standards, 1988)
Normal Consistency (%)	32	26-33%	IS 4031: 1988 (Bureau of Indian Standards, 1988)
Initial Setting time (min)	28	>30	IS 4031: 1988 (Bureau of Indian Standards, 1988)
Final Setting time (min)	590	<600	IS 4031: 1988 (Bureau of Indian Standards, 1988)

Table-3: Physical Properties of fine aggregates

Test	Result	Specification limitation	Test Code
Specific gravity	2.67	2.4-2.9	IS: 2386-1963 (Bureau of Indian Standards, 1963)
Fineness modulus	2.47	Zone-II	IS 383-2016 (Bureau of Indian Standards, 2016)
Water absorption (%)	0.8	<2	

Table-4: Physical Properties of Coarse aggregates

Test	Result	Specification limitation	Test Code
Specific gravity	2.78	2.5-3.0	IS: 2386-1963 (Bureau of Indian Standards, 1963)
Water Absorption	0.2%	1-2%	IS:2386 -1963 Part-III (Bureau of Indian Standards, 1963)
Flakiness Index	11.8%	25%	IS: 2386-1963 (Bureau of Indian Standards, 1963)
Elongation Index	5.4%	45%	IS: 2386-1963 (Bureau of Indian Standards, 1963)

Experimental Methodology

The mix design comprises of selecting the water to cement ratio, and calculating the quantities of cement, fine aggregate and coarse aggregate. In this study, M30 grade of concrete is prepared by taking water to cement ratio of 0.45. Two types of mixes were considered one is with glass fibers of different lengths and the other is a nominal concrete mix. The control or nominal mix does not consist of glass fibers. Further, the glass fibers were considered is 0.5% of the total weight. After curing the samples for 7 days and 28 days, the compressive strength, split tensile strength and flexural strength is measured. To avoid discrepancies in the results, 3 identical specimens were considered for each combination at each curing period. To determine the workability of concrete, slump cone test is used immediately after mixing the concrete. Fig. 1 shows the steps involved in the preparation of the concrete samples.

Immediately after the preparation of fresh concrete mix, the workability of the concrete is measured using the slump cone test, which is very simple one having a slump cone whose height is 30 cm and the diameter of the lower end of the cone is 20 cm and the top end of the cone is 10 cm. The test is conducted according to the IS 7320: 1974.

The compressive strength is the primary property used to measure the strength of hardened concrete after a sufficient curing period. Standard cubes of dimensions 150 mm × 150 mm × 150 mm are casted and cured for 7 days and 28 days. After, the specimens are subjected to compression at a rate of 140 kg/cm² per minute until failure. The maximum load at which the specimen breaks and the needle descends back is recorded. Three specimens were considered for each type of mix to avoid discrepancies in the results. The compressive strength is calculated using the equation (1).

$$\sigma = \frac{P}{A} \qquad \ldots. (1)$$

Here, σ is the compressive strength, P is the maximum or peak load, and A is the surface area of the specimen.

Fig -1: Preparation of concrete specimens

Concrete is strong is compression and weak in tensile. In order to determine the tensile strength of the concrete, a split tensile strength test is used where the tensile strength is determined by applying the stress on the diametric plane of the cylindrical concrete specimen. This will induce the tensile stress in the concrete and the maximum load that is taken by the specimen is noted and the split tensile strength is calculated using equation (2). This test is used to measure the probability of tensile cracks formation ultimately the tensile strength of the concrete. The cylindrical specimens of length 300 mm and diameter of 150 mm were casted and cured for 7 days and 28 days before testing. The cured specimens were tested in a compression testing machine until it splits, and the failure load is recorded.

$$ITS = \frac{2P}{\pi DL} \qquad \ldots (2)$$

Here, ITS is Indirect Tensile Strength, P is the peak load, D is the diameter of the specimen and L is the length of the specimen.

Flexural strength is one of the important properties of concrete where most of the concrete structures experience both tension and compression especially beams where the top fibers undergo compression and the bottom fibers undergo tension and similarly for columns. So, it is important to calculate the resistance towards bending which is measured in terms of flexural strength. For this purpose, a beam of size 100mm× 100mm× 500mm is prepared. Total 6 specimens were prepared for each mix combination and 3 are tested after 7 days of curing period and remaining are tested after 28 days of curing period. The beam is tested on a flexural strength testing machine and loaded at two points until failure. The flexural strength is calculated by using the equation (3).

$$f_{cr} = \frac{Pl}{bd^2} \qquad \ldots. (3)$$

Here, f_{cr} is the Tensile Strength, P is peak load, l is Length of the specimen, b is the width of the specimen, d is the depth of the specimen.

4. Experimental results and analysis

The obtained results from the investigation are explained throughout the undermentioned paragraphs. The exposition is subdivided into two parts. The first part is entirely related to the mechanical characterization of GRFC with different lengths of glass fibers. The secondary part deals with the cost analysis and comparison with the conventional concrete.

Mechanical Characteristics of GFRC

The slump cone test which is performed on the fresh concrete to measure the workability is presented in the Fig-2. The slump value is comparatively lower than that of the conventional concrete. However, the introduction of glass fibers of length 12 mm fiber in the concrete has a good workability compared to that of the other lengths. It is well known that there is a decline in the workability of concrete with the addition of the glass fibers (Paktiawal and Alam, 2022; Ojhaa et al., 2021).

The compressive strength results of GRFC are compared with the conventional concrete as shown in the Fig-3. It is observed that there is a significant improvement in the compressive strength of the concrete with glass fiber. This improvement continues up to 12 mm length of the glass fiber. Further increase in the length of glass fiber to 24 mm reduces the compressive strength. However, the strength is above that of the conventional concrete. The increase in strength is more than 25% that of compressive strength of conventional concrete. So, the optimum length of fibers to be used in the GFRC is around 12 mm.

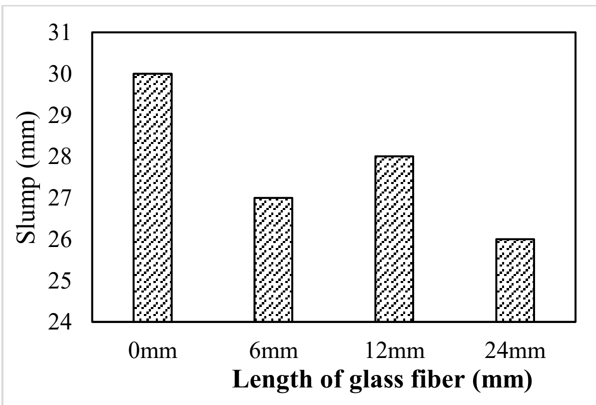

Fig- 2: Comparison of Slump value of GFRC

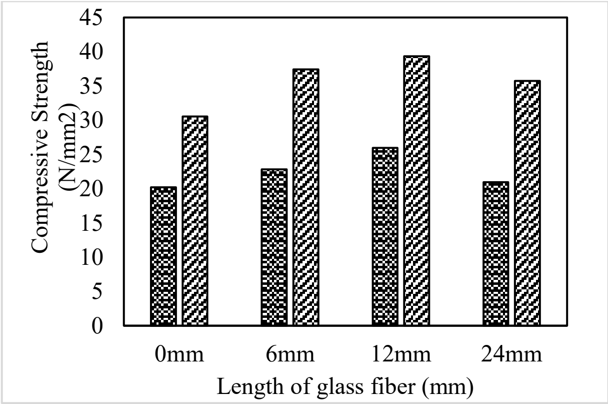

Fig- 3: Comparison of Compressive strength of GFRC

The tensile strength results of GRFC are compared with the conventional concrete as shown in the Fig-4. It is observed that the tensile strength is maximum at the 12 mm size fiber content in the mix. Further increase in the length reduces the tensile strength of the concrete. Previous studies shows that there is an improvement in the tensile strength when the glass fibers length is shorter that is 3 mm and 6 mm than that of the long length fibers like 12 mm and 20 mm. (Kasagani and Rao, 2018). However, there is a significant improvement in the tensile strength of the concrete independent of the length of the fibers compared with conventional concrete as observed in the Figure 5. The maximum increase in the tensile strength is around 25% that of the conventional concrete at 12 mm length of the glass fibers.

The flexural strength of different concrete mixes is calculated and shown in the Fig-5. Similar results as that of the compressive strength and tensile strength are observed in the flexural strength results. Maximum flexural strength is obtained at 12 mm length of the fiber and around 14% more than that of the conventional concrete. The same trend is observed for 7 days and 28 days of curing period for flexural strength.

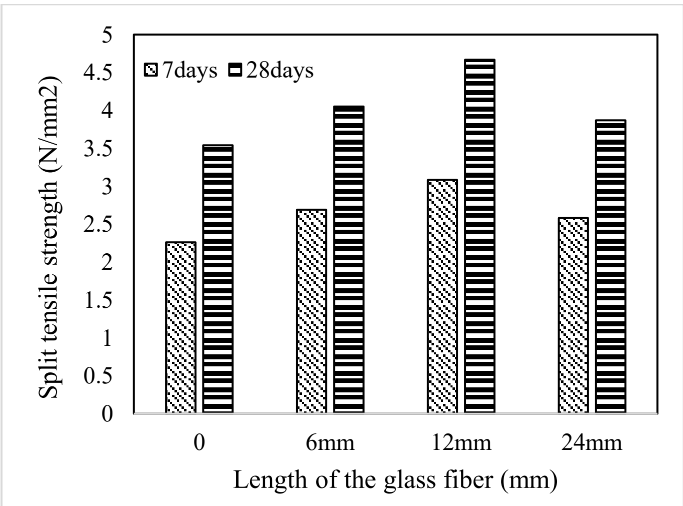

Fig- 4: Comparison of Split Tensile Strength of GFRC

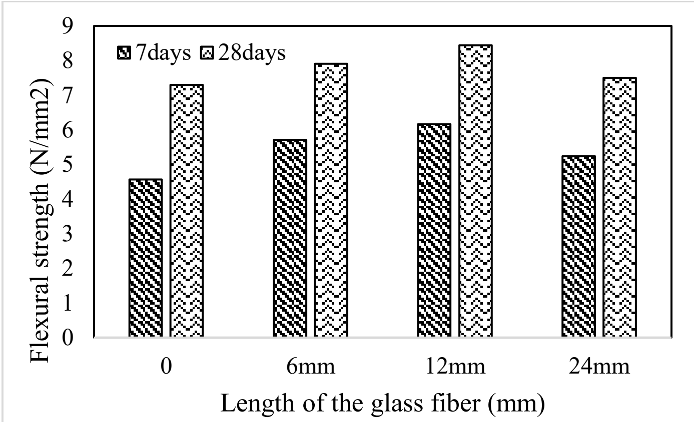

Fig- 5: Comparison of Flexural Strength of GFRC

5. CONCLUSIONS

A detailed cost analysis is carried based on the standard schedule rates according to Andhra Pradesh government (https://apaeeawg.in/). From the Table 5, the cost of the nominal concrete is significantly lower than that of the GFRC. The increase in the cost of the GFRC is due to the presence of glass fibers. However, there is a 25% improvement in the compressive strength and tensile strength, 14% improvement in the flexural strength with the addition of GFRC when compared with 37% increase in the cost of the construction. The addition of GRFC in turn helps in reducing the amount of cement required for the similar strength with the addition of GFRC in turn reduces the global warming that is produced from the manufacturing of cement.

Table-5: Cost estimate for 1 m^3 of material

Material	Unit Price per tonne	Total Cost (INR)	
		Nominal Concrete	GFRC (0.5%)
Fine Aggregate	2500	1732.5	1732.5
Aggregate	1676	1973	1973
Glass Fibers	1,85,000		3809
OPC	7000	2893.31	2893.31
Total cost (INR)		6598.81	10407.81

3. CONCLUSIONS

Based on the evaluation of GFRC, the following conclusions can be drawn:

1. The addition of glass fibers into the concrete significantly reduced the workability of concrete irrespective of the length of the glass fibers.
2. Based on the compressive strength, split tensile strength and flexural strength results, the obtained length of the glass fiber is 12 mm.
3. The compressive strength and tensile strength is significantly improved by 25% when 0.5% of the 12mm size glass fibers were added in the mix.

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BIOGRAPHIES (Optional not mandatory)

1'st Author Photo

Description about the author1
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