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Strength Enhancement of Concrete Tiles Using Short Glass Fibres

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Abstract:- The purpose of this study was to evaluate the strength enhancement of concrete tiles through the incorporation of short glass fibres. Specifically, the research investigated how alkali-resistant glass fibres influence the compressive, split-tensile, and flexural strengths of M-20 grade concrete, designed in accordance with IS 10262. Aggregates with a maximum size of 20 mm were used in casting six cubes, six cylinders, and six prisms, which were then tested to determine their respective strength characteristics. In addition, the study explored a practical application of glass fibre reinforced concrete (GFRC) by developing 20 mm-thick cement concrete tiles without the need for specialised manufacturing methods. For the tile specimens, the maximum aggregate size was reduced to 8 mm. The mix ratio was maintained at 1:1.78:2.66, with a water-cement ratio kept constant and admixture dosages varied from 0.8% to 1.5% to maintain a slump between 50 mm and 100 mm. The study assessed the effect of 30 mm long chopped glass fibres on water absorption, compressive strength, and wet transverse strength. Six full-sized tiles (400 × 400 × 20 mm) were tested, and pulse velocity measurements were conducted to evaluate the internal quality of the concrete. The results demonstrate that the inclusion of short glass fibres significantly enhances the structural integrity and durability of concrete tiles.

Keywords:- GFRC, M-20 Grade Concrete, Flexural Strength, Split Tensile Strength, Compressive Strength, Short Fibers.

1. Introduction

Concrete remains one of the most essential and widely used construction materials across the globe, owing to its cost-effectiveness, abundant raw material availability, and adaptability for various structural applications. Its role is particularly significant in civil infrastructure such as buildings, pavements, bridges, and water-retaining structures. However, despite its widespread use and desirable compressive strength, concrete exhibits certain inherent weaknesses, primarily its brittle nature and low tensile strength. These limitations often lead to crack initiation and propagation under tensile or flexural stress, which can compromise the durability and service life of concrete elements.

To address these challenges, researchers and engineers have incorporated different types of fibres into the concrete matrix. Fibre-reinforced concrete (FRC) has emerged as a practical solution to enhance ductility, improve post-cracking behavior, and increase resistance to impact and fatigue. Over the years, innovations in material technology have allowed the introduction of fibres such as steel, synthetic polymers, carbon, alkali-resistant glass (AR-glass), and polyacrylonitrile (PAN), each offering unique benefits depending on the application.

Among these, alkali-resistant (AR) glass fibres have shown promising results, particularly in architectural and precast applications such as tiles, panels, and façade elements. AR-glass fibres are specifically designed to resist the high alkalinity of the cementitious environment, maintaining their integrity and reinforcing capabilities over time. These fibres, when chopped into short lengths (such as 30 mm), can be uniformly distributed throughout the concrete mix, thereby enhancing tensile strength, reducing crack widths, and contributing to improved structural integrity without the need for conventional steel reinforcement.

In this study, the focus is placed on the strength enhancement of M-20 grade concrete tiles through the incorporation of short AR-glass fibres. The research explores both mechanical performance including compressive, split-tensile, and flexural strengths and practical aspects such as workability and water absorption. The use of admixtures and controlled mix proportions further ensures a workable and durable mix, highlighting the potential of glass fibre reinforced concrete (GFRC) as a viable alternative in the construction of durable, lightweight, and crack-resistant concrete tiles.

1.2 Glass Fibre Reinforced Concrete

Glass Fiber Reinforced Concrete (GFRC) is a cementitious composite material reinforced with discrete glass fibers of varying lengths and sizes. The glass fibers used are alkaline-resistant, as they are otherwise susceptible to alkali, which would reduce the durability of GFRC. Glass strands are primarily used for external cladding, veneer plates, and other elements where their reinforcing properties are needed during construction. In its fresh state, GFRC is stiff with a lower slump, making it less workable, thus necessitating the use of water-reducing admixtures. The properties of GFRC depend on various factors, including the production method, which can include spraying, casting, or extrusion techniques. Additionally, the type of cement, the length of the fibers, the type of sand or filler, the cement ratio, and the methods and duration of curing all significantly affect the properties of GFRC.

1.5 Present Investigation

The present study focuses on experimentally investigating the mechanical behavior of M-20 grade concrete reinforced with short, discrete alkali-resistant glass fibres. The primary objective is to evaluate how the inclusion of these fibres influences the compressive strength, split-tensile strength, and flexural strength of concrete. Glass fibres used in the study were 30 mm in length, and their dosage was maintained at 0.30% of the total weight of concrete for strength tests conducted on standard specimens. Notably, no chemical admixtures were employed during these tests, to isolate and clearly observe the effect of fibre addition alone on the mechanical properties of the concrete matrix.

2. Literature Review

An extensive study of literature suggests that glass fibres may enhance the toughness, flexuralstrength, tensile strength, impact strength, fatigue performance as well as the failure mode of the concrete when compared to plain concrete. The fire resistance of glass fibre reinforced concrete is also good.

Recent studies have demonstrated that incorporating chopped glass fibres into M-20 grade concrete enhances its mechanical properties. For instance, research by Jha (2022) revealed that adding glass fibres to self-compacting bacterial concrete increased the flexural strength by approximately 9%, from 7.944 N/mm² to 8.666 N/mm². This improvement was attributed to the fibres' ability to bridge microcracks, thereby enhancing the concrete's tensile capacity.

Similarly, Manojkumar et al. (2022) investigated the compressive strength of glass fibre reinforced self-healing concrete. Their findings indicated that the inclusion of glass fibres, combined with microbial-induced calcite precipitation, resulted in a significant increase in compressive strength, highlighting the synergistic effect of fibres and microbial activity in enhancing concrete performance.

Determining the optimal percentage of glass fibre addition is crucial for maximizing strength gains without compromising workability. A study by Tahir et al. (2023) explored various fibre dosages and concluded that incorporating 1.25% glass fibres by weight yielded the best results, with improvements of 11.76% in compressive strength, 17.63% in split-tensile strength, and 17.73% in flexural strength. This optimal dosage also enhanced the concrete's durability and reduced its carbon footprint.

In contrast, another investigation reported that a 1% glass fibre addition led to the highest compressive strength of 28.46 N/mm² after 28 days, suggesting that the optimal fibre content may vary based on specific mix designs and desired properties.

The application of glass fibre reinforced concrete (GFRC) in tile production has garnered attention due to the material's enhanced durability and mechanical properties. Bhoi et al. (2022) studied the effects of incorporating 30 mm long glass fibres into M-20 grade concrete tiles. Their research demonstrated improvements in compressive, split-tensile, and flexural strengths, with fibre contents ranging from 0.3% to 0.7% by weight. The study emphasized that GFRC tiles exhibited better resistance to cracking and improved load-bearing capacity compared to conventional concrete tiles.

Similarly, **Darbar and Golkhade (2022)** conducted experiments on GFRC tiles and observed that the inclusion of short glass fibres enhanced the tiles' mechanical properties without necessitating specialized casting techniques. Their findings support the feasibility of producing high-strength concrete tiles using standard manufacturing processes.

Beyond immediate strength enhancements, the long-term durability of GFRC is a critical consideration. A comprehensive review by Chen et al. (2021) highlighted that GFRC exhibits superior resistance to drying shrinkage and cracking compared to traditional concrete. The study noted that increasing glass fibre content improved flexural strength and reduced the propensity for crack formation, thereby extending the service life of concrete elements.

3. Materials and Methods

3.1 Materials

3.1.1 Concrete

Concrete, composed of Portland cement, water, fine aggregates (sand), and coarse aggregates, is the most widely used construction material. It is initially malleable and hardens over time due to chemical reactions between water and cement compounds (C_2S and C_3S). In this study, Portland Slag Cement (PSC, 43 grade - Konark) was used. Tests for 28-day compressive strength, setting times, and consistency were performed per IS standards. Clean river sand (Zone III, specific gravity 2.68) served as fine aggregate, while angular coarse aggregates (20 mm max size, specific gravity 2.72) were used. Tap water was used for mixing and curing. For tiles, 8 mm maximum aggregate size and a 0.45 water-cement ratio were maintained, with admixtures added to ensure proper workability.

3.1.2 Cement

Cement is a finely ground substance with cohesive and adhesive qualities that acts as a binding medium for the individual elements. There are two types of cement manufacturing processes: wet and dry. Portland cement, also known as hydraulic cement, is the type of cement that is frequently used. It is characterized by a chemical reaction that hardens the cement when it comes into contact with water, creating a product that is resistant to water. When calcareous and argillaceous elements are combined in a specific ratio, ground to a fine powder, and heated to a high temperature, Portland cement is created. Portland Slag Cement (PSC) is the name given to the cement that is produced when blast furnace slag is also utilized as an ingredient. For the experimental programme, Portland Slag Cement (PSC) of grade 43 (Konark Cement) was utilized.

3.1.3 Fine Aggregates

Aggregates are typically sourced from natural deposits or quarried rocks. Among these, riverbed sand and naturally weathered rock are the most economical. Stream deposits, such as those from the Koel River, provide high-quality aggregates. Crushed quarried rock is also commonly used. Fine aggregates are defined as materials passing through a 4.75 mm IS sieve, with coarse particles limited by IS standards. In this study, Zone III sand with a specific gravity of 2.68 from the Koel River was used.

3.1.4 Coarse Aggregates

The aggregates the vast majority of which are held on 4.75mm IS sieve and contains just that a lot of fine material as is allowed by the code specifications are termed as coarse aggregates. The coarse aggregates may be crushed gravel or stone obtained by the crushing of gravel or hard stone; uncrushed gravel or stone resulting from natural disintegration of rock and partiallycrushed gravel or stone obtained as a product of the blending of the naturally disintegrated and crushed aggregates. In our case crushed stone was used with a nominal maximum size of 20 mm and specific gravity of 2.78.

3.1.5 Water

Water is the one most essential element of cement. Water assumes the vital part of hydration of concrete which frames the coupling lattice in which the dormant totals are held in suspension medium until the grid has solidified, furthermore it serves as the lubricant between the fine and coarse aggregates and makes concrete workable.

3.1.6 Fiber

Fibers, whether natural or synthetic, are used in concrete to enhance its tensile and flexural properties, addressing its inherent brittleness. These fibers can be short and discrete, rods, textiles, or woven meshes. In this study, short alkali-resistant glass fibers were used due to their strength and durability. Glass fibers, made primarily from silica (SiO_2), may include additives like alumina to modify their properties. They are produced by melting raw materials (sand, alumina, limestone) at around 1260°C, forming filaments of about 10 μm in diameter. These filaments are bundled into strands or mats, either long or short, and held together by chemical bonding. While glass fibers have lower abrasion resistance and fatigue strength than carbon fibers, surface treatments (sizing) enhance their durability and bond with the concrete matrix. Fiberglass-reinforced composites are commonly referred to as GFRP.

3.1.7 Admixture

Admixtures are chemical compounds added to concrete—excluding water, cement, and aggregates—to modify its properties in fresh or hardened states. They help achieve desired characteristics that can't be economically attained by adjusting mix proportions alone. Common types include accelerators, retarders, air-entrainers, and water reducers. In this study, a water-reducing admixture was used only for casting concrete tiles to improve workability as fiber content increased.

The experimental program included casting cubes, cylinders, and prisms to assess the impact of varying glass fiber content (0% to 0.3%) on compressive, flexural, and split tensile strength. No admixture was used for these tests. Specimens were tested at 7 and 28 days. Additionally, concrete tiles (400×400×20 mm) with fiber contents ranging from 0% to 0.7% were tested for compressive strength, wet transverse strength, and water absorption as per IS 1237:2012, using 8 mm maximum aggregate size.

3.2 Casting of Tiles

The tiles were made in accordance with IS 1237:2012 requirements. The selected size was 400 mm × 400 mm × 20 mm, one of the standard measurements listed in the code. Natural aggregates and Portland slag cement were combined to create the tiles, which were vibrated once they were cast. Since these were single-layer tiles, great care was taken to make sure that the thickness variation between the thickest and thinnest tiles didn't go above 10% of the required minimum thickness. A machine was used to make the mixture, which was then manually compressed and vibrated on a vibrator table after being placed into each mould one at a time.

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A finishing trowel was used to achieve the surface finishing. The material was poured into the moulds, crushed on the vibrator table, and then the moulds were laid aside for a full day to set. The moulds used to cast the tiles

are shown in Figure 3.1.

Figure 3.1:- Mold for Casting of Tiles

3.3 Materials for Casting

3.3.1 Cement: Portland Slag Cement (PSC) of 43 grade was used, tested as per IS standards.

3.3.2 Fine Aggregates: Sourced from the Koel riverbed, Zone III sand with 2.68 specific gravity and passing through 4.75 mm sieve.

3.3.3 Coarse Aggregates: Non-reactive aggregates in two gradings: 4.75–10 mm and 10–20 mm for cubes, prisms, and cylinders; 4.75–8 mm for tiles.

3.3.4 Water: Tap water fit for drinking and mixing was used.

3.3.5 Glass Fibres: AR-glass fibres were used for their alkali resistance. They had 72 GPa Young's modulus, 1700 MPa tensile strength, and 2.7 gm/cm³ density.

3.3.6 Formwork: Standard moulds were used for specimens; custom steel moulds from local fabricators were used for tiles. Formwork provided shape and support until concrete set, resisting dead and live loads such as fresh concrete, equipment, and workers.

4. Experimental Study

This section presents and explains the results of various tests conducted on the specimens, emphasizing their significance. The experiment was carried out in two phases. In the first phase, M20-grade concrete was used to cast cubes, cylinders, and prisms. The concrete mix had no admixtures, and the maximum nominal aggregate size used was 20 mm.

4.1 Compressive Strength

Compressive strength is the most vital property of concrete, especially since it is primarily used in compression-based applications in construction. Standard 150 mm concrete cubes were cast and tested to assess the influence of fibres on compressive strength. The compressive strength was recorded at 7 and 28 days.

- The concrete mix had a water–cement ratio of 0.5.
- Fibre content ranged from 0% to 0.30%.
- Though there was a noticeable reduction in workability, no extra water or admixtures were used.

4.2 Split Tensile Strength

Concrete is inherently weak in tension and is rarely designed to resist direct tensile stresses. However, understanding its tensile capacity is essential, as cracking under tensile load often governs failure.

- The split tensile strength test was conducted on cylindrical specimens.
- A compressive load applied along the specimen's length generates tensile stress along the diameter.
- The specimen splits once the ultimate tensile stress is reached.

Note: A diagram illustrating this setup may be included for clarity.

4.3 Flexural Strength

Flexural strength, or the modulus of rupture, is another indirect measure of concrete's tensile strength. It is crucial for members subjected to bending, such as beams.

- Tests were performed to assess how well the concrete could resist bending under load.
- The standard procedure was followed as per IS recommendations.

4.4 Tests on Cement and Concrete Tiles

Cement and concrete flooring tiles were tested according to **IS 1237:2012**. While several tests are prescribed in the code, the following were conducted:

- Wet Transverse Strength Test
- Water Absorption Test
- Pulse Velocity Test **(Non-destructive)**
- Compressive Strength Test **(Though not listed in IS 1237, conducted additionally**

4.5 Water Absorption Test

This test measures the porosity and water-absorbing capacity of tiles.

$$\frac{M1 - M2}{M2} X100$$

Where

M1= mass of the saturated specimen;

M2= mass of the oven-dried specimen.

4.9 Testing Procedure Summary

All materials were tested as per relevant Indian Standards (IS codes) before use. Cement, sand, and fibres were characterized to ensure standardization. Regular tap water from the municipal supply was used, and no water quality tests were performed.

Tests Conducted:

- **Specific Gravity Test:** As per IS 2720 (Part III) – Specific gravity of cement = **3.11**
- **Consistency Test:** As per IS 4031 (Part IV), using Vicat's apparatus (IS 5513) – Standard consistency = **29.98%**
- **Fineness Test:** As per IS 4031 (Part I), using 90-micron sieve – Negligible residue retained

5. Results

5.4 Tests Carried Out on Cement and Concrete Tiles

In accordance with IS 1237:2012, cement and concrete tiles were tested. Wet transverse strength and water absorption tests were conducted. Although the code does not specify it, the compressive strength test was carried out because fibres can weaken concrete. Tests for natural frequency and pulse velocity were also carried out. The outcomes are displayed in tabular form below:

5.4.1 Compressive Strength Test

The compressive strength over a period of seven days was examined, and the average results of the three samples are displayed in tabular form. The statistics for the 28-day compressive strength achieved are displayed in Table 5.7. Table 5.7 lists the concrete's compressive strength after seven days when the maximum nominal aggregate size is 8 mm. Additionally, the compressive strength after a period of seven days was plotted, as seen in Fig. 5.7. Overall, the addition of fibres was found to reduce the compressive strength.

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Table 5.7:- 7 Days Compressive Strength of Concrete

Fibre Content (% of the Total Weight of Concrete)	Weight (KG)	Average 7 Days Compressive Strength (N/mm^2)
0	2.494	32
0.1	2.477	28
0.2	2.477	30
0.3	2.499	31
0.4	2.485	28
0.5	2.499	27
0.6	2.401	26
0.7	2.391	25

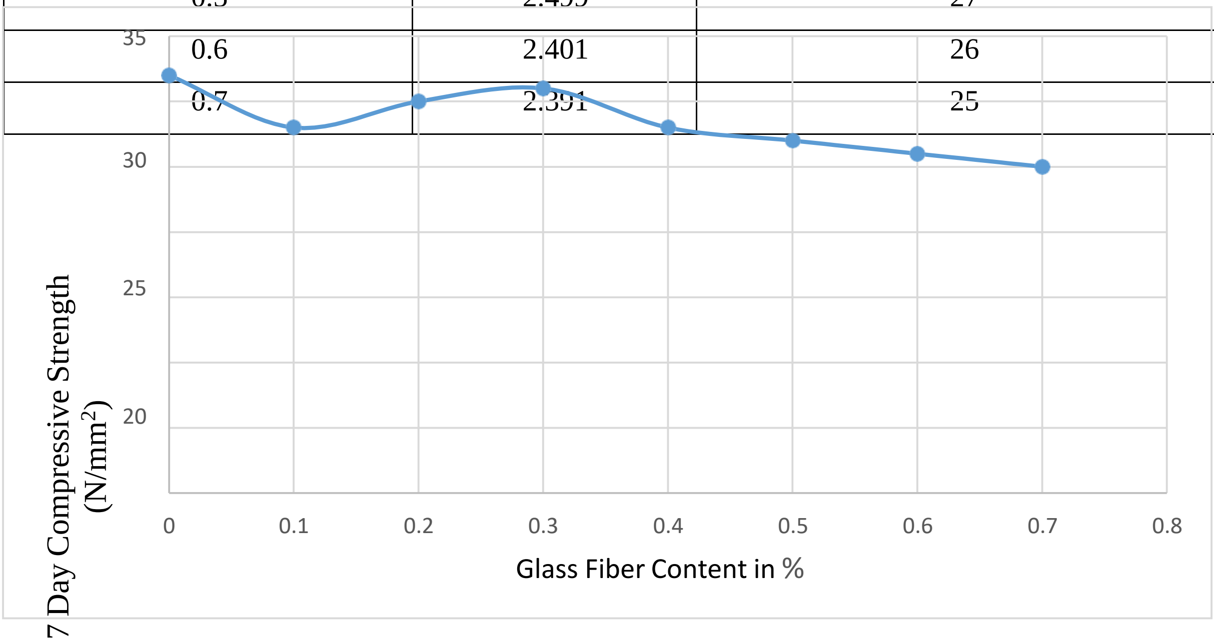

Figure 5.7:- Effect of Glass Fibers on 7 Days Compressive Strength

The average values of the three samples examined during the 28-day compressive strength study are displayed in tabular form. The data for the 28-day compressive strength achieved are displayed in Table 5.8. The 28-day compressive strength of concrete with aggregates no larger than 8 mm is provided in Table 5.8. Additionally, the 28-day compressive strength was plotted, as seen in Fig. 5.8. Overall, the addition of fibres was found to lower the compressive strength.

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Table 5.8 28 Days Compressive Strength of Concrete

Fibre Content (% of the Total Weight of Concrete)	**Weight (KG)**	**Average 28 Days Compressive Strength (N/mm^2)**
0	2.494	45
0.1	2.476	37
0.2	2.476	37
0.3	2.501	36
0.4	2.485	38
0.5	2.503	33
0.6	2.404	32
0.7	2.392	31

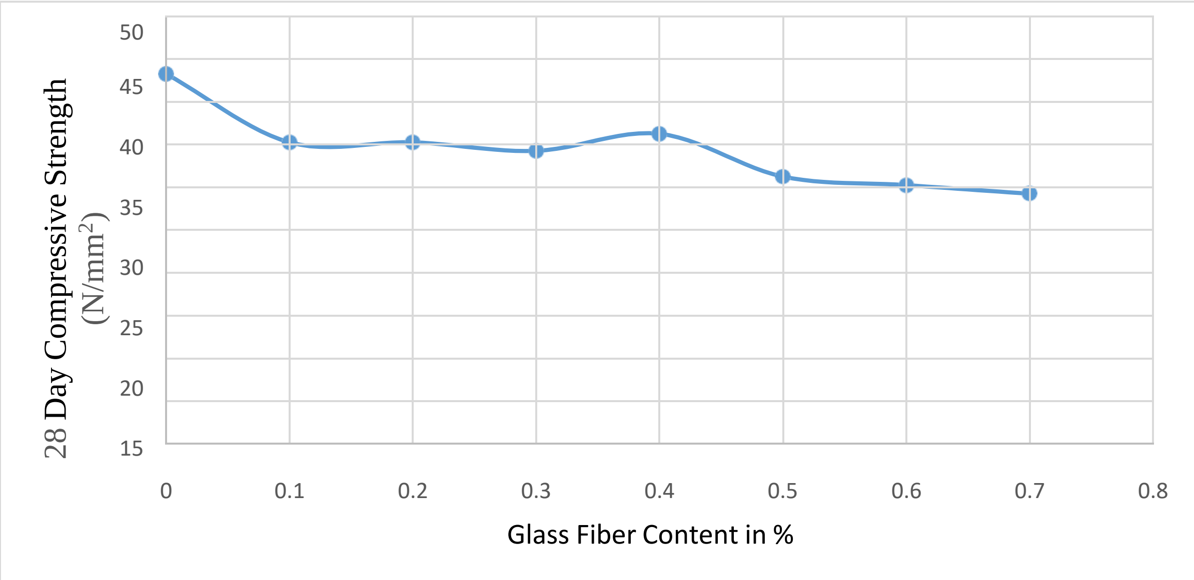

Figure 5.8:- Effect of Glass Fibers on 28 Days Compressive Strength

5.4.2 Wet Transverse Strength

The average values of the three samples that were examined for the 28-day flexural tensile strength are displayed in tabular form. The data of the 28-day wet transverse strength achieved are displayed in Table 5.9. The 28-day wet transverse strength of concrete with aggregates up to a maximum nominal size of 8 mm is provided in Table 5.9. Additionally, the 28-day wet transverse strength was plotted, as seen in Fig. 5.9; overall, the addition of fibres was found to improve the wet transverse strength.

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Table 5.9:- 28 days Wet Transverse Strength of Concrete

Fibre Content (% of the Total Weight of Concrete)	Average 28 Day Transverse Strength (N/mm^2)
0	1.40
0.1	1.62
0.2	1.70
0.3	1.85
0.4	1.942
0.5	2.22
0.6	2.34
0.7	2.540

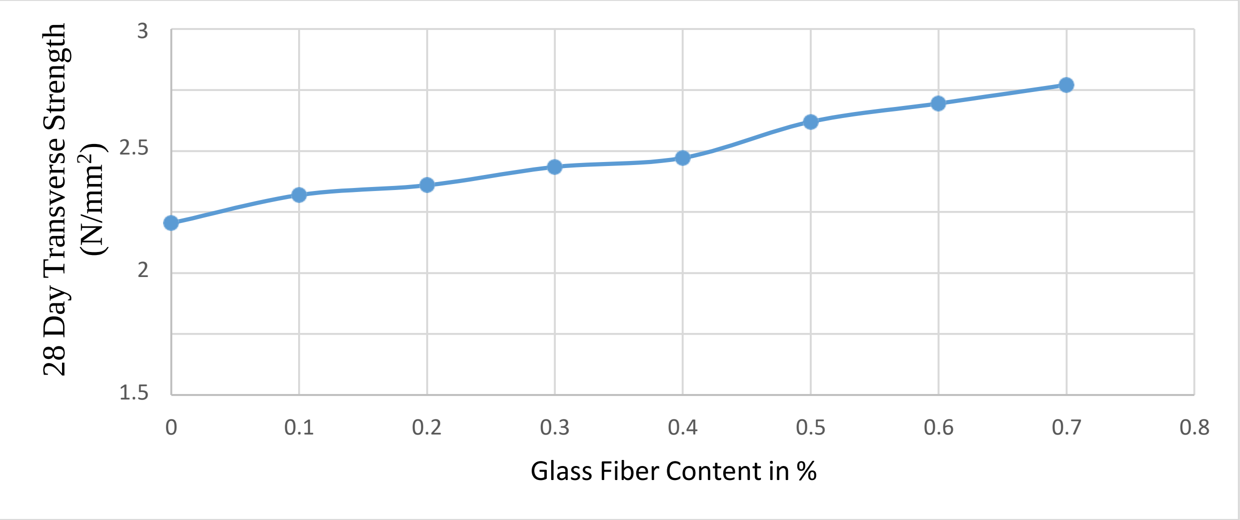

Figure 5.9:-Effect of Glass Fibers on 28 Days Wet Transverse Strength

5.4.3 Water Absorption

After 28 days, the water absorption of the concrete was examined, and the average water absorption values of the six samples that were collected are displayed in a tabular format. The data of the 28-day water absorption collected is displayed in Table 5.10. The 28-day water absorption of concrete with particles no larger than 8 mm is shown in Table 5.10.An overall decrease in water absorption was found with the addition of fibres, as demonstrated in Fig. 5.10, which also plotted the water absorption over a 28-day period.

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Table 5.10 28 Days Water Absorption of Concrete

Fibre Content (% of The Total Weight of Concrete)	Average Water Absorption After 28 Days (%)
0	2.68
0.1	2.31
0.2	1.94
0.3	1.56
0.4	1.21
0.5	1.18
0.6	1.16
0.7	1.01

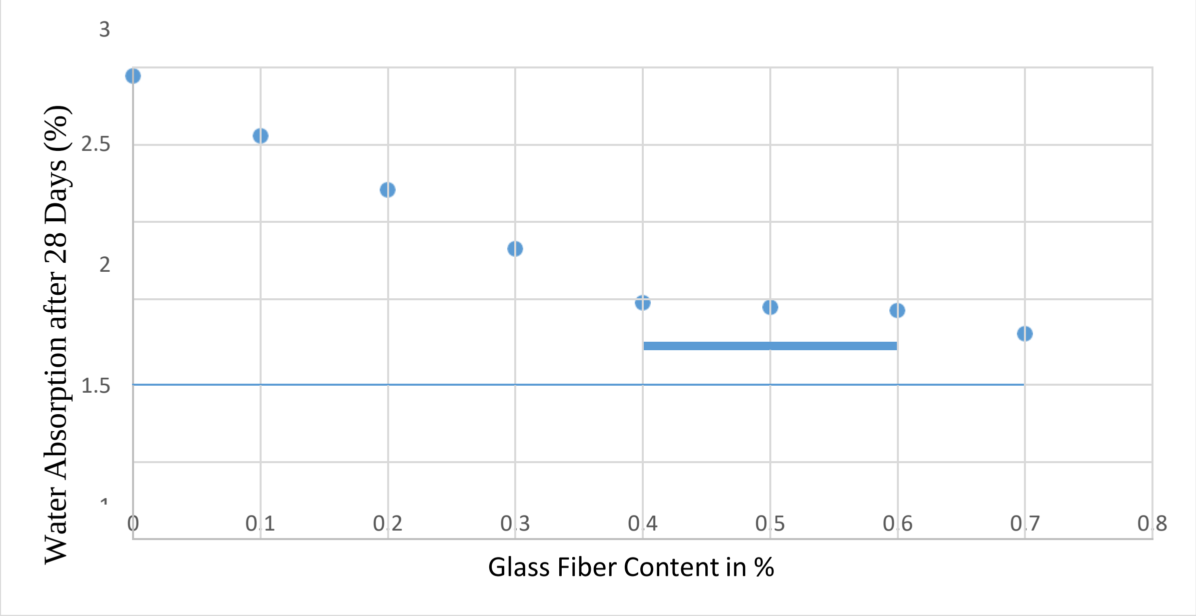

Figure 5.10:- Effect of Glass Fibers on 28 Days Water Absorption of Concrete

5.4.4 Pulse Velocity Test

The tiles were subjected to a pulse velocity test; the average values of the velocities, which varied by no more than 15%, are recorded, and Table 5.11 illustrates the consequences.

Table 5.11 Obtained Pulse Velocity

Fibre Content (% of the Total Weight of Concrete)	Average Velocity (m/s)	Grade of Concrete
0	4496	Good
0.1	4801	Excellent
0.2	4364	Good
0.3	4611	Excellent
0.4	4394	Good
0.5	4456	Good
0.6	4385	Good
0.7	4435	Good

6. Conclusion

The effect of short discrete glass fibres on concrete's flexural, split tensile and compressive strengths was examined in this experimental programme. Furthermore, the impact of glass fibres on cement and vibration-produced concrete tiles was investigated. Wet transverse strength, compressive strength, and water absorption were among the characteristics evaluated.

Admixtures were required because the concrete mix got harder and less workable as the fibre level rose. However, obtaining enough workability proved difficult, and considerable segregation was noted, even with admixture concentrations as high as 1.51%. As a result, adding additional fibre to the mixture than 0.71 % was not practical.

The study found that while the addition of glass fibres improved the concrete's tensile and compressive strengths, it had a negative impact on the mix's workability and homogeneity. This restriction highlights the significance of maximizing admixture doses and maybe looking at different approaches or materials to enhance workability while preserving the advantageous properties of the fibres. The results also showed that, after certain fibre content, the detrimental effects on workability outnumbered the positive ones, emphasizing the need for the mix design to strike a crucial balance.

The various observations based on the experimental result are as follows:

1. When the amount of short, discrete glass fibres in the concrete weighs between 0.1% and 0.3%, the fibre content has no effect on the concrete's compressive strength without admixtures. This suggests that the concrete's capacity to tolerate compressive loads is unaffected by the fibres' addition in this amount.
2. The insertion of glass fibres to concrete improves its split tensile strength. This increase in tensile strength implies that glass fibres help the concrete withstand tensile stresses and lessen the chance of cracking under tension.
3. A larger fibre content in concrete results in an increase in its flexural strength, which suggests that it

can carry more tension in flexural applications. Because of this enhancement, glass fiber-reinforced concrete is less prone to fail under flexural stress and can withstand bending better.

4. Adding fibres to concrete tiles also increases their wet transverse strength. This increase in transverse strength shows how the tiles get stronger and more resilient to stresses that could otherwise bend or shatter when wet.
5. As the amount of fibre in concrete grows its absorption of water decreases. The concrete's resilience to weathering and other environmental conditions can be enhanced by the addition of glass fibres, as seen by the reduction in water absorption.
6. The addition of admixtures has no effect on concrete's compressive strength up to 0.4% fibre content. Nevertheless, compressive strength decreases as the amount of fibres increases beyond this point. This suggests that while moderate fibre additions from admixtures can help preserve compressive strength, excessive fibre concentration can have a detrimental effect on the structural integrity of the concrete.

6.2 Scope for Future Work

While the present investigation successfully highlights the enhancement of mechanical properties such as compressive strength, split-tensile strength, and flexural strength in M-20 grade concrete and concrete tiles using short glass fibres, several avenues remain open for future research:

1. **Use of Hybrid Fibres:-** Future work can explore the combined use of glass fibres with other types of fibres such as polypropylene, steel, basalt, or carbon to evaluate synergistic effects on mechanical and durability properties.
2. **Incorporation of Admixtures and Supplementary Cementitious Materials:-** The current study excluded chemical admixtures; future investigations could include the use of superplasticizers, fly ash, silica fume, GGBS, or metakaolin to further enhance workability, durability, and strength development.
3. **Long-Term Durability Studies:-** Long-term performance characteristics such as shrinkage, creep, freeze-thaw resistance, chloride penetration, and sulphate resistance of fibre-reinforced concrete and tiles can be investigated under various environmental exposures.
4. **Micro structural Analysis:-** Advanced characterization techniques like Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), or Fourier Transform Infrared Spectroscopy (FTIR) can be employed to understand the fibre–matrix interaction and crack-bridging mechanisms.
5. **Optimization Using Statistical or Machine Learning Tools:-** Future studies can use statistical methods (e.g., Response Surface Methodology) or AI-based models (e.g., ANN, regression models) to optimize fibre content, mix proportions, and predict performance outcomes.
6. **Scale-Up and Practical Applications:-** Investigating the performance of GFRC tiles under real-life loading conditions, including dynamic or impact loads, can provide more confidence for large-scale industrial or infrastructural applications.
7. **Life Cycle Assessment (LCA) and Sustainability Analysis:-** Environmental impact and sustainability assessment through life cycle analysis can provide insights into the eco-friendliness of GFRC tiles

compared to conventional alternatives.

8. **Fire Resistance and Thermal Properties:-** Future work may include evaluating the fire performance and thermal conductivity of fibre-reinforced concrete to assess its suitability in fire-sensitive environments.
9. **Design Guidelines and Code-Based Validation:-** Based on accumulated data, empirical models and design recommendations can be developed for incorporating chopped glass fibres in standard building codes for structural and non-structural applications.

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