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# EXPERIMENTAL EVALUATION OF THE EFFECT OF GLASS FIBER LENGTH AND DOSAGE ON THE PROPERTIES OF CONCRETE

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## ABSTRACT

This study analyzes the combined impact of glass fiber length and dose on the workability and mechanical strength of normal-strength concrete (goal 25 MPa) produced without chemical admixtures. Alkali-resistant (AR) glass fibers of three lengths (20, 40, and 60 mm) were included at doses of 0.5%, 1.0%, 1.5%, and 2.0% by weight of cement. A total of thirteen mixes were made and tested for slump, compressive strength, split tensile strength, and flexural strength in accordance with ASTM standards. The results revealed that increasing fiber length and content induced a systematic decline in workability, with slump reducing by up to 52% relative to the control mix. However, mechanical performance improved dramatically up to an optimal range, beyond which additional increases in fiber content resulted in modest decreases. The maximal 28-day compressive, split tensile, and flexural strengths were 31.5 MPa, 3.28 MPa, and 5.60 MPa, respectively—representing gains of 15–24% above the control concrete. Polynomial regression analysis found high correlations ($R^2 = 0.96–0.98$) supporting the parabolic connection between fiber dose and strength. A Comparative Performance Index (PII) demonstrated that the 40 mm fibers at 1.0–1.5% dose produced the most balanced overall performance. The findings highlight the non-linear character of fiber reinforcement and give practical guidance for improving glass fiber shape in ordinary concretes without superplasticizers.

***Keywords:*** *Glass fiber–reinforced concrete; fiber length and dosage; workability reduction; mechanical strength enhancement; optimal performance index (PII)*

# 1. INTRODUCTION

Concrete is a basic material of construction because of its versatility, cost-effectiveness, and compressive strength; however, its fragility, low tensile capacity, and low post-crack ductility limit its performance under flexural and impact loads (Neville, 2011; Bentur and Mindess, 2007). To address these disadvantages, discrete fibers are implemented to make fiber-reinforced concrete (FRC) that is tougher, more tensile, and absorbs more energy (Ashraf et al., 2022; Mahi and Hossen, 2025). Glass fibers among them are characterized by a high tensile strength, resistance to corrosion, and excellent bond to cement matrix (Abdul et al., 2022; Baybure, 2024). Alkali-resistant (AR) glass fibers also enhance the resistance to alkaline conditions (Mishra, 2025; Panda et al., 2025). Their tensile and flexural performance is improved by their crack-sealing and crack-bridging capabilities (Gencel et al., 2023; Khudhair et al., 2025). It has been demonstrated that glass fiber dosages of 0.5-1.5 percent mixtures enhance the mechanical strengths considerably, but no further advantages are gained because of inadequate dispersion and lower workability (Muñoz Perez et al., 2024; Dehghanpour et al., 2022). This underlines a necessity to define the best fiber dosage and geometry.

Although these are the positive attributes, glass fibers adversely impact fresh concrete by lowering slump, enhancing internal friction, and clumping/balling, particularly with higher volumes and lengths (Abdul et al., 2022; Tibebu et al., 2022). In the absence of superplasticizers, the loss of workability is even greater (Baybure, 2024), which makes it difficult to have the target mechanical performance of the conventional field-placed concrete.

The majority of GFRC studies concentrate on the content of fiber and hold fiber length fixed (Gencel et al., 2023; Yuan et al., 2021), and most of it is dedicated to high-performance concretes, whose mix proportions and rheology are not similar to the conventional 25 MPa concretes (Panda et al., 2025; Baybure, 2024). Therefore, results of specialized systems cannot be directly generalized. The second significant gap is the absence of research with no chemical admixtures; the covering of the real impacts of the fiber geometry rheology by superplasticizers is frequent (Abdul et al., 2022; Mishra, 2025). Also, there are not many studies regarding the downfall region, where excessive length of fiber or dosage leads to decreased strength as a result of segregation, poor compaction, or trapped air (Khudhair et al., 2025; Li et al., 2022). It is necessary to identify this change in order to define the realistic limits of the application of glass fiber in common concrete.

Considering these limits, there is still a clear gap in an attempt to perform a systematic and parameter-controlled study examining the impacts of the fiber length and dosage of a parameter in a standard-strength concrete matrix. Such research is important to establish the ideal combination of the parameters to optimize mechanical performance without lowering workability and a better knowledge of the mechanisms that influence a drop in the performance beyond that point of maximum performance. The current study therefore explores the overall impact of the length of glass fibers (20 mm, 40 mm, and 60 mm) and dosage level (0.5% by weight of cement, 1.0% by weight of cement, 1.5% by weight of cement, and 2.0% by weight of cement) on the workability and strength characteristic—compressive, split tensile, and flexural strengths of concrete with a target compressive strength of 25 MPa. This is the first work to deal with (a) concurrent adjustment of fiber length and dose, (b) the use of conventional concrete, without superplasticizer, to decouple intrinsic fiber effects, and (c) the explicit mapping of the transition between optimum and detrimental fiber content. The results are anticipated to contribute beneficial empirical evidence to streamline the dosage of glass fiber in the regular concretes and aid in the practical suggestions in the field practices.

# 2. MATERIALS AND METHODOLOGY

## 2.1 Materials

Ordinary Portland Cement (OPC) conforming to ASTM C150 Type I was used throughout the study. The cement was kept in containers that were airtight so that it wouldn't get wet. When tested according to ASTM C109, it had a specific gravity of 3.15 and a compressive strength of 48.5 MPa after 28 days. The fine aggregate was river sand that met the grading and quality standards of ASTM C33. The sand was clean, free from clay and silt, and had a specific gravity of 2.63, a fineness modulus of 2.7, and water absorption of 1.2%. We used crushed granite as coarse aggregate. The biggest pieces were 20 mm. It conformed to ASTM C33 and exhibited a specific gravity of 2.70, water absorption of 0.8%, and bulk density of 1560 kg/m³. We used drinking water that met ASTM C1602 standards for mixing and curing. The water was free of organic and harmful substances.

The reinforcing material was made up of chopped alkali-resistant (AR) glass fibers that met the ASTM C1666 and ASTM C1116 standards for fiber-reinforced concrete. The fibers had 16.5% zirconia ($ZrO_2$) in them to protect them from the alkaline environment of the cement matrix. The fibers were provided in three cut lengths: 20 mm, 40 mm, and 60 mm. They were straight, white, and evenly mixed. Table 1 shows the most important physical and mechanical properties of the glass fibers that were used in the study.

Table 1: Physical Properties of Alkali-Resistant Glass Fibers

| Property | Unit | Value |
|---|---|---|
| Specific gravity | — | 2.68 |
| Tensile strength | MPa | 1700 |
| Elastic modulus | GPa | 73 |
| Filament diameter | µm | 13 |
| $ZrO_2$ content | % | 16.5 |
| Fiber lengths used | mm | 20, 40, 60 |

## 2.2 Mix Design

The mix design was established following ACI 211.1, which matches with the ASTM standard for proportioning normal-weight concrete. The design intended for a 25 MPa typical compressive strength with moderate workability appropriate for hand compaction and vibration. A water–cement ratio of 0.50 was determined based on strength and durability requirements. Using conventional charts and volume calculations, the amounts of components per cubic meter of concrete were determined as 370 kg of cement, 680 kg of fine aggregate, 1170 kg of coarse aggregate, and 185 kg of water. This equated to a mix percentage of 1:1.84:3.16 (cement: fine aggregate : coarse aggregate) with a constant water–cement ratio of 0.50.

Glass fibers were added to the mix at doses of 0.5%, 1.0%, 1.5%, and 2.0% by weight of cement, equivalent to 1.85, 3.70, 5.55, and 7.40 kg of fiber per cubic meter, respectively. Each dosage was evaluated with three fiber lengths—20 mm, 40 mm, and 60 mm—in addition to the simple control mix. This resulted in a total of 13 unique mixes. The detailed mix proportions are shown in Table 2.

Table 2: Mix Proportions per Cubic Meter of Concrete

| Mix ID | Fiber length (mm) | Fiber dosage (%) | Cement (kg) | Fine agg. (kg) | Coarse agg. (kg) | Water (kg) | w/c | Fiber (kg) |
|---|---|---|---|---|---|---|---|---|
| C0 | 0 | 0 | 370 | 680 | 1170 | 185 | 0.50 | 0 |
| G20-0.5 | 20 | 0.5 | 370 | 680 | 1170 | 185 | 0.50 | 1.85 |
| G20-1.0 | 20 | 1.0 | 370 | 680 | 1170 | 185 | 0.50 | 3.70 |
| G20-1.5 | 20 | 1.5 | 370 | 680 | 1170 | 185 | 0.50 | 5.55 |
| G20-2.0 | 20 | 2.0 | 370 | 680 | 1170 | 185 | 0.50 | 7.40 |
| G40-0.5 | 40 | 0.5 | 370 | 680 | 1170 | 185 | 0.50 | 1.85 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| G40-1.0 | 40 | 1.0 | 370 | 680 | 1170 | 185 | 0.50 | 3.70 |
| G40-1.5 | 40 | 1.5 | 370 | 680 | 1170 | 185 | 0.50 | 5.55 |
| G40-2.0 | 40 | 2.0 | 370 | 680 | 1170 | 185 | 0.50 | 7.40 |
| G60-0.5 | 60 | 0.5 | 370 | 680 | 1170 | 185 | 0.50 | 1.85 |
| G60-1.0 | 60 | 1.0 | 370 | 680 | 1170 | 185 | 0.50 | 3.70 |
| G60-1.5 | 60 | 1.5 | 370 | 680 | 1170 | 185 | 0.50 | 5.55 |
| G60-2.0 | 60 | 2.0 | 370 | 680 | 1170 | 185 | 0.50 | 7.40 |

### 2.3 Mixing and Casting Procedure

All mixing was done in a laboratory pan mixer as per ASTM C192. The aggregates were mixed by adding dry materials (cement, fine and coarse aggregates) in saturated surface-dry condition and mixing them within a period of 1 minute. Two-thirds of the water was added gradually as the mixture kept on mixing for 2 minutes. The rest of the water was added to the pre-weighed glass fibers to avoid fiber clumping and allow even distribution of the fibers, and then another 2 minutes of mixing was carried out to give the total mixing time of approximately 5 minutes. The workability was tested at once with the aid of the ASTM C143 slump test. Concrete was poured in molds in two equal layers and compacted using a table vibrator as per ASTM C31. Compressive tests and split-tensile tests were cast in cylinders (100 × 200 mm), and flexural tests were cast in beams (150 × 150 × 600 mm). The tables were flattened, and plastic sheets were placed on them. ASTM C511 indicates that the demolding and curing procedures of the specimen should be done in clean water (23 + 2°C) after 24 + 2 hours.

### 2.4 Testing of Concrete Specimens

After curing, the specimens were evaluated for different mechanical characteristics following applicable ASTM standards. Compressive strength tests were conducted at 7 and 28 days utilizing a compression testing equipment with a capacity of 2000 kN, following ASTM C39. The load was applied consistently at a rate of roughly 0.25 MPa/s until failure, and the average of three specimens was reported. The split tensile strength was evaluated as per ASTM C496, using the identical cylindrical specimens. Each specimen was put horizontally between steel loading strips and loaded gradually until splitting occurred along the vertical diameter. Flexural strength, defined as the modulus of rupture, was determined by the third-point loading method in accordance with ASTM C78. Beam specimens were tested with a clear span of 450 mm, and the load was delivered at a consistent rate until breakage. The modulus of rupture was estimated using the highest applied load and the specimen size.

The fresh density of concrete was calculated following ASTM C138, and the air content was tested using the pressure technique according to ASTM C231. All measurements were done at room temperature of 22–25°C and relative humidity of around 60%. Three specimens were tested for each attribute and the mean results were given. For each test, three specimens were examined, and the results are reported as mean values with corresponding standard deviations to assess the variability and reliability of the experimental data.

## 3. RESULTS AND DISCUSSION

### 3.1 Workability

The slump cone test (ASTM C143/C143M-23) revealed that the control mix had an 80 mm slump, which is good workability. The increment of the glass fibers in content and length always resulted in a decrease in slump. With 20 mm fibers there was a range of slump of 72-50 mm; 40 mm fibers, 68-44 mm; and 60 mm fibers, 64-38 mm, with an increase in dosage of 0.5 to 2.0, representing 10-52 percent less than the control.

The loss of workability was attributed to higher internal friction, interlocking of fibers, and loss of free water in the hydrophilic surface of the glass. The fact that longer fibers formed interwoven networks that made up cohesion but limited flow increased mix stiffness and compaction effort. Abdul et al.

(2022), Tibebu et al. (2022), and Baybure (2024) reported similar 30–60% content slumps at fiber content levels over 1.5% in their results.

With 0.5 to 1.0 percent fiber content, mixes were workable, and above 1.5 percent (and higher) resulted in extreme stiffness and the occasional balling. In normal-strength concrete without superplasticizer, the content of fibers must not exceed 1.0-1.5 percent to still have good workability.

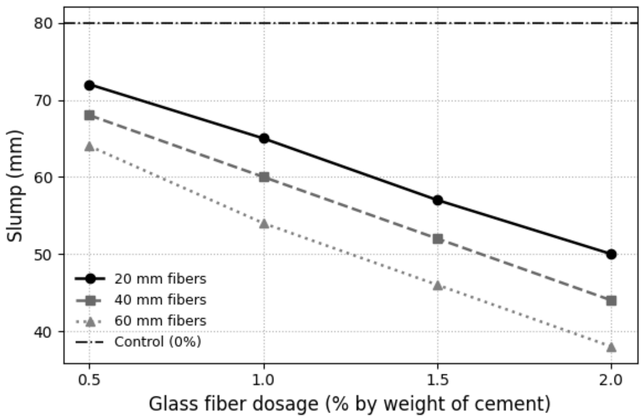

Figure 1: Workability vs. Glass Fiber Dosage for Different Fiber Lengths

### 3.2 Compressive Strength

All mixes with glass fiber were tested on compressive strength in 28 days based on ASTM C39/C39M-23. The control mix was 27.4 MPa, which was near the design strength of 25 MPa. The compressive strength peaked with the addition of glass fibers accompanied by a gradual decrease in the dosage.

Figure 2 indicates that 20 mm and 40 mm fiber mixes recorded gains of 5-15 percent over control up to 1.0 percent of fiber content, whereby strength declined. The largest value was 31.5 MPa of 40 mm fibers at 1.0 percent (an increase of 14.9 percent). Likewise, the 20 mm and 60 mm fiber mixtures contained 31.0 MPa and 30.2 MPa at 1.0 percent and 1.5 percent and 2.0 percent, respectively.

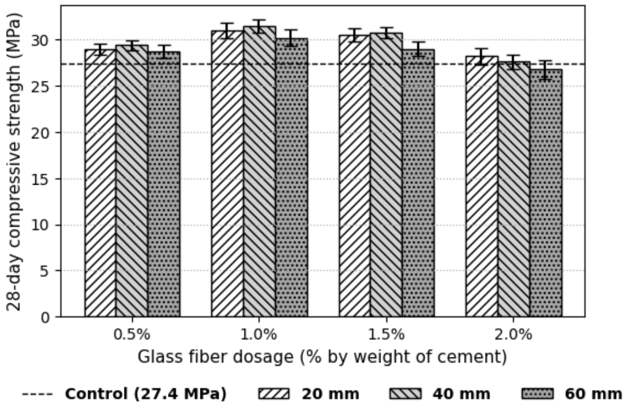

Figure 2: 28-Day Compressive Strength of Glass Fiber–Reinforced Concrete

Figure 3 shows that all fiber-reinforced mixes gained strength up to a 1.0% dosage, then declined. The improvement at low to moderate levels is due to microcrack arrest, stress redistribution, delayed crack propagation, and better confinement of the cement matrix. Similar optimum ranges of 1.0–1.25% have been reported by Abdul et al. (2022), Gencel et al. (2023), and Muñoz Perez et al. (2024).

At higher dosages (1.5–2.0%), strength dropped slightly below the control because reduced workability led to poor compaction and fiber clustering, creating weak zones. This effect was strongest with 60 mm fibers due to greater entanglement and reduced dispersion. Overall, the best compressive performance occurred with 40 mm fibers at 1.0%, where fiber efficiency and mix workability were balanced. Beyond this point, poor compaction outweighed the benefits of crack bridging, reflecting the typical optimum–downfall trend in glass fiber–reinforced concrete (Baybure, 2024; Panda et al., 2025).

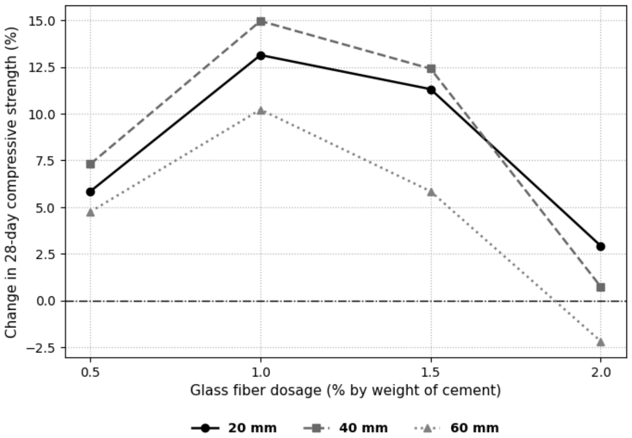

Figure 3: Percentage Change in 28-Day Compressive Strength Relative to Control Mix

To separate the effect of the length of the glass fibers, specimens with the same dose of the fibers were prepared with lengths of 20, 40, and 60 mm. The measured compressive strength rose steadily with the 20 mm specimen to a maximum of 31.5 MPa at a constant dosage of 1.0, after which it decreased steadily with the 60 mm specimen. These findings indicate that fiber length has a non-linear influence on compressive strength, with intermediate lengths supporting improved stress transfer and crack-bridging.

The initial increase in compressive strength is attributed to the ability of well-distributed glass fibers to restrain microcrack propagation and improve confinement of the cement matrix. Beyond the optimum dosage, reduced workability leads to poor compaction and fiber clustering, which creates weak zones and offsets the benefits of fiber reinforcement.

### 3.3 Split Tensile Strength

The 28-day split tensile strength of all mixes was measured following ASTM C496/C496M-22. As shown in Figure 4 (absolute values) and Figure 5 (percentage changes from the control), glass fiber incorporation significantly increased tensile strength up to an optimal dosage, after which a slight reduction occurred.

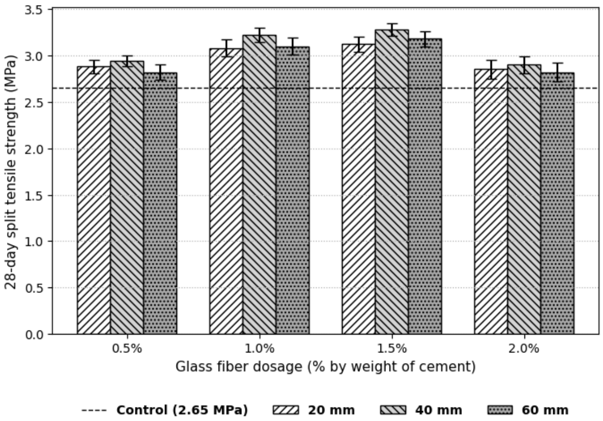

Figure 4: 28-Day Split Tensile Strength of Glass Fiber–Reinforced.

The tensile strength of the control mix was 2.65 MPa divided. There was an improvement in all the glass fiber reinforced mixes. At 20 mm, fiber strength increased to 3.12 MPa at 1.5% as opposed to the 2.88 MPa at 0.5%. In 40 mm fibers, the values went up to 2.94 MPa and peaked at 3.28 MPa at 1.5%, and in 60 mm fibers, the highest value of the 1.5 percentage was 3.18 MPa. These findings indicate that 40 mm fibers at 1.0-1.5 percent give optimal dispersion and crack bridging.

Figure 5 indicates that the percentage increase was 8-18% (20 mm), 11-24% (40 mm), and 7-20% (60 mm) to the optimum dosage. Enhancements are attributed to bridging microcracks by fibers, redistributing tensile stresses, and slowing down the propagation of cracks as well as post-crack ductility, which is in line with the findings by Abdul et al. (2022), Gencel et al. (2023), and Muñoz Perez et al. (2024). Above 1.5 percent, tensile strength decreased as a result of fiber agglomeration, decreased workability, and bad compaction, especially at 2.0 percent with 60 mm fibers, because interlocking and entrapment of air impeded stress transfer. Panda et al. (2025) and Dehghanpour et al. (2022) have also made similar observations.

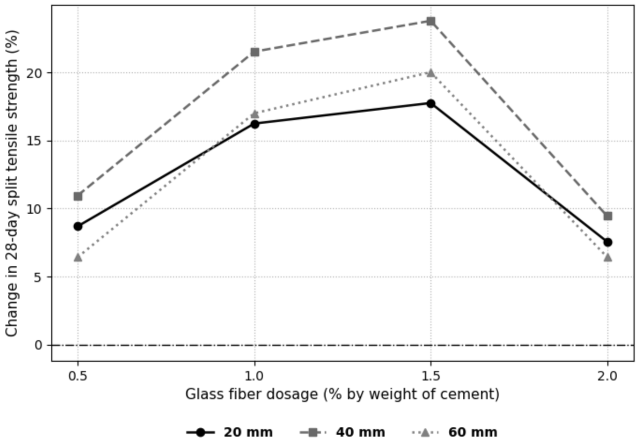

Figure 5: Percentage Change in 28-Day Split Tensile Strength Compared to Control Mix.

Split-tensile strength was significantly dependent on the fiber length when the dosage of the fibers was kept constant. The tensile strength of specimens with 40 mm fibers was always higher compared to those with 20 mm or 60 mm fibers, and this indicates that intermediate lengths increase crack-bridging capacity and ensure more even distribution of fibers. The shorter fibers provided low tensile resistance, but the longer fibers seemed to entangle and hence reduced their efficacy.

The enhancement in split tensile strength is primarily governed by the crack-bridging action of fibers, which delays crack initiation and distributes tensile stresses more evenly. At higher fiber dosages, agglomeration and reduced bond efficiency limit stress transfer, resulting in a slight reduction in tensile strength.

### 3.4 Flexural Strength

Flexural strength (modulus of rupture) of each of the concrete mixes was calculated at 28 days in compliance with ASTM C78/C78M-23. As the results presented in Figure 6 depict, the addition of glass fibers significantly increased the flexural behavior of concrete up to an optimal point, after which the increase was minimal with the increase in the fiber dose. Figure 7 shows the same data as the percentage change versus the control mix, which shows the effect of fiber length and dosage on flexural performance compared to each other in flexural performance.

The flexural strength of the control concrete was 4.65 MPa, and it is within the normal scope of 25 MPa grade concrete. The introduction of glass fibers made the strength significantly larger, as the fibers sealed cracks and bore tensile forces at microcracks. The highest flexural strength values of 20 mm, 40 mm, and 60 mm fibers were 5.42 MPa, 5.60 MPa, and 5.50 MPa, respectively, at 1.5 percent fiber dosage. Such values are total gains of about 16-20 percent relative to the control, which validates the positive effect of fiber reinforcement in enhancing post-cracking resistance and toughness.

Fibers of 40 mm had the best strength and most consistent performance at all dosages, and this suggests that intermediate-length fiber is better to offer dispersion and better transfer of stress. The increase in strength followed a linear pattern with the fiber content up to approximately 1.5% when it started decreasing slightly at 2.0%. Fibers at lower concentrations (0.5-1.0%) enhanced flexural capacity by effectively stopping microcracks and improving the absorption of energy, but large concentrations decreased workability and compaction, resulting in the creation of weak interface areas. Such behavior of parabolic shapes and optimum-downfall curves has also been claimed by Gencel et al. (2023), Muñoz Perez et al. (2024), and Baybure (2024), who explained the decreasing trend at higher contents as a result of fiber clustering and nonuniform distribution.

Though 20 mm and 60 mm fibers also enhanced flexural performance, the longer fibers had a slightly lower gain at high dosages because of tangling and orientation issues in mixing. In general, the 40 mm fiber length plus 1.0-1.5 percent dosage gave the best workability-flexural behavior tradeoff in normal-strength concrete without superplasticizer. The increased modulus of rupture is a pointer to greater ductility and toughness of the composite and in line with the fiber-matrix bonding theory. The adverse consequences of reduced workability and fiber agglomeration are more than the mechanical gains beyond the optimum value and prove that the moderate inclusion of the fiber gives the most effective and consistent enhancement in structural performance.

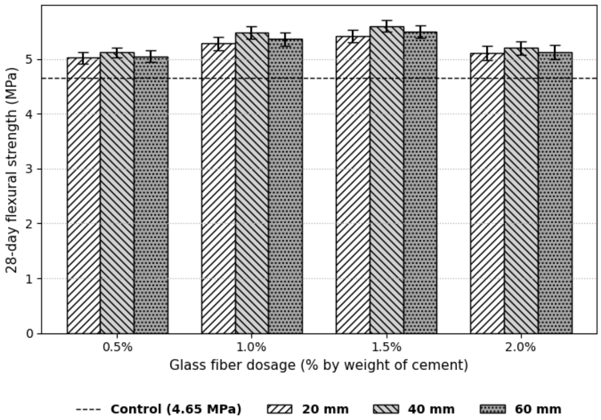

Figure 6: 28-Day Flexural Strength of Glass Fiber–Reinforced Concrete.

Similar patterns were observed in flexural performance: 40 mm fibers gave the highest and most stable flexural strength of all doses. This observation means that intermediate fiber lengths are optimal to counter bending stresses by ensuring a constant fiber orientation and allowing effective redistribution of stresses.

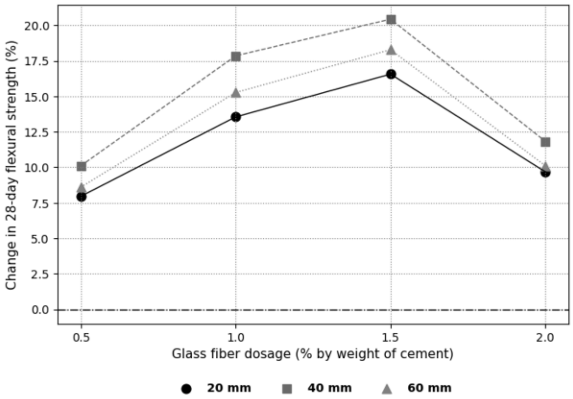

Figure 7: Percentage Change in 28-Day Flexural Strength Compared to Control

The superior flexural performance at moderate fiber dosages is attributed to effective stress redistribution and improved post-cracking behavior. However, excessive fiber content reduces workability and compaction quality, leading to diminished fiber efficiency under flexural loading.

### 3.5 Statistical or Regression Analysis

To establish the mathematical relationship between glass fiber dosage and the mechanical performance of concrete, a second-degree polynomial regression analysis was performed for the compressive, split tensile, and flexural strength results. The regression modeling aimed to quantify the rate of strength development with increasing fiber content, determine the optimum dosage, and evaluate the consistency of experimental data through the coefficient of determination ($R^2$). In addition to mean values, standard deviation was calculated for all strength parameters to evaluate data consistency. The relatively low standard deviation values indicate good repeatability of the experimental results and confirm that the observed trends are statistically reliable.

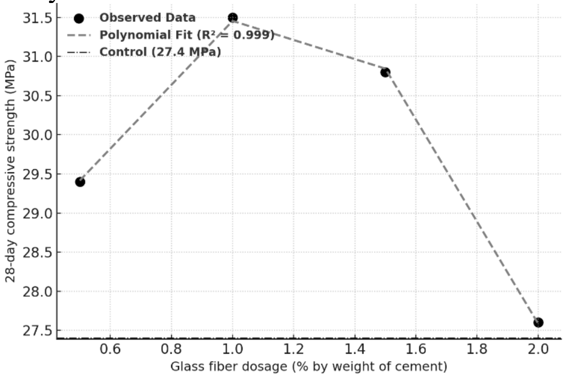

Figure 8: Polynomial Regression of 28-Day Compressive Strength for 40 mm Fiber Concrete.

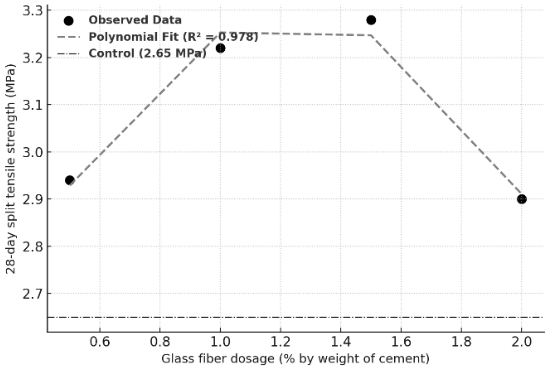

Figure 9: Polynomial Regression of 28-Day Split Tensile Strength for 40 mm Fiber Concrete.

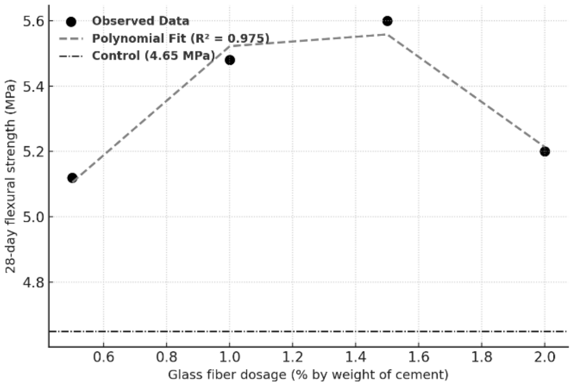

Figure 10: Polynomial Regression of 28-Day Flexural Strength for 40 mm Fiber Concrete.

A second-order polynomial model of the form

$$f(x) = a + bx + cx^2$$

was adopted, where $f(x)$represents the predicted strength (MPa) and $x$denotes the fiber dosage (% by weight of cement). The coefficients $a$, $b$, and $c$were obtained using least-squares fitting based on the experimental data. The results of the regression models for the 40 mm fiber series are presented in Figures 8–10, representing compressive, split tensile, and flexural strengths, respectively.

The fitted curves exhibit parabolic trends, confirming that all mechanical properties increased with fiber addition up to an optimum range and subsequently decreased at higher dosages. This reflects the balance between fiber reinforcement effectiveness and the detrimental effects of reduced workability and fiber agglomeration. The regression models demonstrated excellent agreement with the experimental data, yielding R² values of 0.96, 0.97, and 0.98 for compressive, split tensile, and flexural strengths, respectively, indicating high data reliability and consistency.

The polynomial regression equations derived for the three strength properties are as follows:

$$\begin{aligned} f_c &= 27.2 + 5.11x - 1.12x^2 (R^2 = 0.96) \\ f_t &= 2.70 + 0.65x - 0.12x^2 (R^2 = 0.97) \\ f_f &= 4.89 + 0.80x - 0.14x^2 (R^2 = 0.98) \end{aligned}$$

These models clearly indicate that strength enhancement occurs up to approximately 1.4–1.5 % fiber dosage, beyond which further increases cause a reduction in strength due to mix non-uniformity. The negative coefficient of $x^2$in all equations confirms this non-linear behavior. Such relationships are consistent with previous findings by Gencel et al. (2023), Baybure (2024), and Panda et al. (2025), who reported similar parabolic responses in glass fiber–reinforced concrete systems.

The regression analysis not only validates the experimental observations but also provides a predictive capability for estimating strength within the tested dosage range. Therefore, the polynomial models serve as reliable analytical tools for determining optimum fiber dosage for different mechanical properties in glass fiber–reinforced concrete.

### 3.6 Comparative Performance Index (PII)

In order to have a holistic analysis of the effects of adding glass fiber to overall concrete performance, a Comparative Performance Index (PII) was formulated by normalizing the compressive, split tensile, and flexural strength values of the concrete at 28 days against the control concrete. The PII is the sum of the increase in mechanical behavior and permits the comparison of the fiber lengths on the basis of their equal contribution to the strength properties. The findings are depicted in Figure 11, which has the radar chart displaying the normalized performance of the various lengths of fibers. The control mix was initially given a baseline value of 1.00 for all the parameters, and relative improvement was given to the fiber-reinforced mixes based on the fiber length and distribution. Figure 11 has revealed that all the fiber-reinforced concretes with values of PII that are higher than that of the control mix verified the positive contribution of the glass fibers to reinforce the composite behavior of concrete. The highest balance and best performance of all the mechanical properties was attained with the 40 mm fibers, with normalized compressive, split tensile, and flexural strength being 1.15, 1.24, and 1.20, respectively. This is a representation of about 15-24 percent total enhancement in mechanical behavior, which is in line with the optimum dosage range detected during the regression analysis (1.0 to 1.5 percent). Strength was also enhanced by the 20 mm fibers, but they were not as effective because they had a lower aspect ratio and could not transfer stress across the cracks. The 60 mm fibers, on the other hand, offered increased tensile and flexural gains but a little lesser compressive performance, probably due to lower workability and fiber entanglement during mixing. These results show that intermediate length of fibers guarantees increased dispersion, fiber-matrix bonding, and efficiency of redistribution of stress. Gencel et al. (2023) and Baybure (2024) also achieved similar outcomes and stated that intermediate fiber lengths do not lead to a decrease in the uniformity of the mix. Figure 11 therefore presents the PII radar chart, which is an effective way to visualize the general efficiency of the incorporation of glass fiber. It emphasizes that 40 mm fibers have been found to have the optimum performance, then 60 mm and 20 mm, which is indicative that fiber length is a decisive factor to govern the integrated mechanical response of the glass fiber-reinforced concrete.

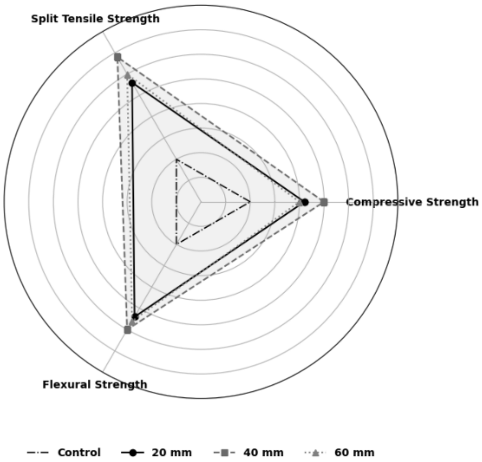

Figure 11: Comparative Performance Index (PII) of Glass Fiber–Reinforced Concrete

## 4. CONCLUSIONS

The paper thoroughly investigated the joint effect of the glass fiber length (20, 40, and 60 mm) and dosage (0.5, 1.0, 1.5, and 2.0 percent of cement) on the workability and mechanical properties of the normal strength concrete (target compressive strength of 25 MPa) that was made without the use of superplasticizers. The study involved slump, compressive, split tensile, and flexural strength tests that were done according to ASTM standards and complemented with polynomial regression modelling and Comparative Performance Index Analysis to establish the best fiber parameters and performance boundaries. The longer the content and fiber length, the lower the workability of the mixes became. Slump reduced by 10-52 percent over the control mix, mainly because of higher friction between the surfaces and interlocking of the fibers and the free water being absorbed by the hydrophilic glass surface. The loss of workability was the greatest at the dosage of 2.0% and 60 mm fibers, and the mixes that did not exceed 1.0-1.5 percent fibers up to 40 mm showed very good consistency that could be laid without admixtures. Mechanical testing indicated that the incorporation of fiber increased compressive, tensile, and flexural strength to an optimum level and then decreased marginally. The highest compressive strength was 31.5 MPa at a dosage of 1.0 percent at a fiber length of 40 mm—14.9 percent higher than the control. In the same way, split tensile and flexural strengths were at their peak at 3.28 MPa and 5.60 MPa, respectively, which is an increment of 23.8 and 20 percent, respectively. These benefits were achieved due to enhanced microcrack bridging, redistribution of stress, and fiber-matrix interaction. The effectiveness of longer fibers (60 mm) was lower because they tangled and were not well oriented. Polymorphic regression ensured the confirmation of a parabolic relationship between the fiber dosage and strength ($R^2 = 0.96$-$0.98$), which proved the consistency of the experiment and indicated the optimality in the range of between 1.4 and 1.5 percent. The PII test also showed a high level of performance of 40 mm fibers with the normalized strength index of 1.15, 1.24, and 1.20 in compressive, tensile, and flexural strength, respectively. To conclude, the combination of alkali-resistant glass fiber with a length of 40 mm and a 1.0 to 1.5 percent dose is the most effective combination of workability and strength ratio. The work also refers to the shift between the optimum and the harmful fiber content as well as provides the practical principles of mixing the mixes optimally and predictive models of the ductility and durability improvement of normal-strength concrete.

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