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Experimental Investigation on Fly Ash Based Concrete Mixed with Glass Fiber

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***Abstract:** This study explores the behavior of fly-ash based glass fiber reinforced concrete developed using different combinations of fiber lengths in M30 and M35 grades. In this study, 20% of cement was replaced with Class-F fly ash to improve sustainability and long-term performance, while alkali-resistant (AR) glass fibers were added at a constant dosage of 1% by weight of cementitious material. Three fiber lengths (6 mm, 12 mm, and 24 mm) were used in single-length and graded combinations of two as short graded (6 mm + 12mm length fiber), long graded(12 mm + 24 mm length fiber), and combined graded(Short Graded + Long Graded)to understand how fiber size and distribution influence concrete performance.*

The brittle nature of conventional concrete and its susceptibility to early-age cracking remain major concerns in structural applications, particularly under flexural and tensile loading conditions. This study presents a comprehensive experimental investigation on fly ash-based Graded Glass Fiber Reinforced Concrete (GGFRC) developed for M30 and M35 grades.

Fresh properties were evaluated using slump tests, and hardened properties were assessed through compressive, flexural, and split tensile strength tests at 7 and 28 days. Results indicate that workability decreased by approximately 8–18% with increasing fiber length due to increased internal friction and fiber interlocking. However, graded fiber systems demonstrated improved dispersion efficiency compared to mono 24 mm fiber mixes.

Compressive strength showed marginal improvement at 28 days (3-7%) due to continued pozzolanic reaction of fly ash and enhanced microstructural densification. More significant improvements were observed in flexural strength (12-22%) and split tensile strength (10-18%), confirming enhanced crack-bridging efficiency and stress redistribution mechanisms. Graded fiber systems exhibited superior post-cracking behavior, reduced crack width, and improved ductility compared to mono-fiber systems.A cost analysis revealed that 20% fly ash replacement reduced cement consumption and partially offset fiber cost. While fiber addition increased material cost by approximately 3.5% per cubic meter compared to conventional concrete, the strength enhancement resulted in an improvement of 12% in strength-to-weight efficiency. When normalized against flexural performance, the cost per unit strength decreased, indicating improved structural economy.

The study concludes that optimized fiber grading significantly enhances mechanical performance, structural efficiency, and crack resistance while maintaining acceptable workability. From a sustainability perspective, 20% cement replacement reduces embodied carbon without compromising strength. The results recommend graded fiber reinforcement as a viable approach for structural concrete requiring improved tensile performance and durability

***Keywords:** Fly ash, Alkali-resistant glass fiber, Graded fiber reinforcement, Mechanical properties, Crack resistance.*

I. INTRODUCTION

Concrete is the most widely used construction material worldwide; however, its quasi-brittle behavior and low tensile strength result in microcrack formation even under service-level stresses. These microcracks propagate under sustained or cyclic loading, ultimately compromising durability, serviceability, and structural integrity. Enhancing tensile capacity and post-cracking behavior is therefore essential for high-performance structural applications.

Fiber Reinforced Concrete (FRC) has emerged as a promising solution to mitigate brittle failure through crack-bridging mechanisms and energy absorption enhancement.

Effective blending of short length and long length fibers in concrete is termed as graded fiber reinforced concrete. Earlier research shows that short length fibers primarily control the propagation of micro cracks and improve the ultimate strength whereas long length fibers arrest the macro cracks and improve the post crack deformation of concrete. Thus, different combinations of short and long length fibers would help in arresting the micro and as well as macro cracks to improve both pre and post crack performances of concrete. An attempt has been made to study the effect of addition of Graded Glass Fibers with different fiber length and volume fraction in Glass Fiber Reinforced Concrete.

The experimental work was carried out under uniaxial loading for M30 and M35grades of concrete with the 1%fiber of cementitious material of Mono Glass Fibers (6 mm, 12 mm and 24 mm length fiber). In graded fiber, different fiber combinations of Glass fibers in Short Graded form (6 mm +12mm length fiber), combination of Glass fibers in Long Graded form (12mm+24 mm length fiber) and combination of Short Graded + Long Graded fibers to form Combined Graded fibers (6 mm + 12 mm +24 mm length fiber) were studied. The results shows that the strength, deformation capacity and energy absorption capacity is higher for Graded Glass Fiber Reinforced concrete than Mono Glass Fiber Reinforced Concrete. Graded fibers improved workability.

Previous studies have widely investigated the performance of glass fiber reinforced concrete (GFRC) and the influence of supplementary materials on concrete properties. Kasagani and Rao[6] (2018) reported that the use of graded glass fibers, combining different fiber lengths, improves tensile strength, deformation capacity, and energy absorption due to better crack-bridging efficiency compared with mono-length fibers. Patel et al.[10] (2013) observed that the addition of chopped glass fibers enhances tensile and flexural strength, although workability decreases with increasing fiber content. A review by Blazy, Blazy, and Drobiec[1] (2022) highlighted that GFRC offers improved crack resistance, durability, and reduced structural weight, making it suitable for structural and architectural applications, while emphasizing the need for optimized fiber distribution in mix design. Sumarno, et al.[12] (2022) demonstrated that the incorporation of fly ash improves compressive strength through secondary pozzolanic reactions that produce additional C-S-H gel, enhancing the concrete matrix. Similarly, Chen et al. (2021) reported that glass fiber reinforcement significantly improves crack resistance and tensile strength due to fiber bridging mechanisms. Das and Mishra[4] (2020) found that the combined use of fly ash and glass fibers enhances mechanical properties at optimum fiber content, although excessive fibers reduce workability due to agglomeration. Mermerdaş,et.al[8] (2019) also reported improved compressive and tensile strength in fly ash-based composites reinforced with glass fibers, attributed to matrix densification and reduced pore structure. Studies by Moideen and Benny[9] (2016), Lanjewar and Rayadu[7] (2015), and Qureshi, Ahmed, and Khan[13] (2013) similarly concluded that glass fibers significantly improve tensile and flexural strength, while compressive strength increases moderately and workability decreases with higher fiber dosage. However, most existing studies focus on single-length glass fibers, and limited research has explored graded glass fiber reinforced concrete (GGFRC) combined with fly ash-based concrete systems. Furthermore, the influence of graded fiber combinations on compressive, split tensile, and flexural strength, along with the optimum proportion of fly ash replacement and fiber dosage, has not been clearly established, indicating the need for further investigation.

II. MATERIALS AND RESEARCH METHODOLOGY

A. Materials

The materials used in this study included Ordinary Portland Cement (OPC) 43 grade, fine aggregates, and coarse aggregates, whose properties were determined through standard laboratory tests in accordance with relevant Indian Standards.

B. Cement:

Ordinary Portland Cement of 43 grade was used as the primary binding material in the concrete mixes. The physical properties of cement were determined through laboratory testing. The specific gravity of cement was found to be 3.15, with normal consistency observed 31%.

C. Fine Aggregates:

Natural river sand conforming to standard grading requirements was used as fine aggregate in the concrete mixes. The specific gravity of the fine aggregate was 2.62, water absorption was 1.01%, and the bulk density of the sand was found to be approximately 1,594 kg/m³.

D. Coarse Aggregates:

Crushed stone aggregates were used as coarse aggregates in the concrete mixes. The specific gravity of the aggregates was 2.66, water absorption was recorded as 0.58%, aggregate crushing value was 17.34%, the aggregate impact value was 15.72%, and the Los Angeles abrasion value was 24.0%, all within the allowable limit of 30%, indicating that the aggregates are suitable for use in structural concrete.

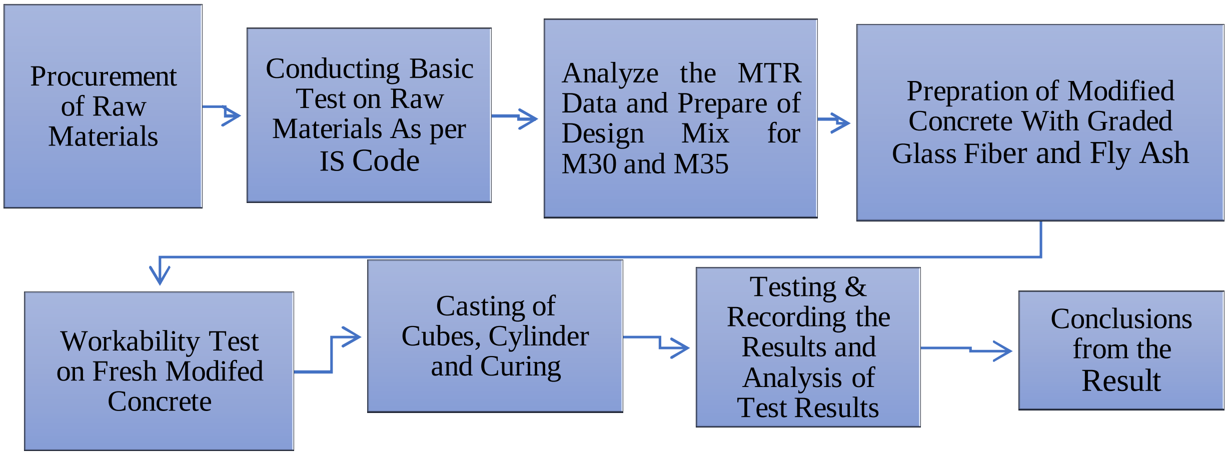

Figure 1:Flow Chart for Research Methodology

III. MIX PROPORTIONS AND CASTING

For the experimental investigation, concrete mixes of M30 and M35 grades were prepared including both reference and modified mixes. The reference mixes (M30-N and M35-N) were designed using conventional ingredients without the addition of glass fiber or fly-ash. In the modified mixes, 20% of cement was replaced with fly ash, and glass fibers were incorporated at a constant dosage of 1% of the total cementitious material. While the fiber content remained constant, the fiber length was varied (6 mm, 12 mm, and 24 mm) to study the influence of fiber size on concrete properties. In addition, combinations of short graded(SG) in which 6 mm+12 mm fiber is used similarlyin long graded (LG), 12 mm+24 mm are usedand in combined graded (CG), 6mm+12mm+24 mm fibers were used to evaluate the performance of graded glass fiber reinforced concrete. The mix proportions for both M30 and M35 grades included cement, fly ash, water, fine aggregate, coarse aggregate, admixture, and glass fibers in specified quantities (kg/m³). Table 1 presents the mix proportions for M30 grade, Table 2 shows the mix proportions for M35 grade, and Table 3 describes the variation in glass fiber lengths and their percentage combinations used in different samples for experimental study.

Table 1: Mix Proportions for M30 Grade

Mix ID	Cement (kg/m³)	Fly Ash (kg/m³)	Water (kg/m³)	FA (SSD) (kg/m³)	CA(SSD) (kg/m³)	Admixture (kg/m³)	Glass Fiber (kg/m³)
M30-N	408.29	0	167.4	618.79	1205.17	4.08	0
M30-6	326.63	81.66	167.4	606.35	1184.39	4.08	4.08
M30-12	326.63	81.66	167.4	606.35	1184.39	4.08	4.08
M30-24	326.63	81.66	167.4	606.35	1184.39	4.08	4.08
M30-SG	326.63	81.66	167.4	606.35	1184.39	4.08	4.08
M30-LG	326.63	81.66	167.4	606.35	1184.39	4.08	4.08
M30-CG	326.63	81.66	167.4	606.35	1184.39	4.08	4.08

Table 2: Mix Proportions for M35 Grade

Mix ID	Cement (kg/m³)	Fly Ash (kg/m³)	Water (kg/m³)	FA (SSD) (kg/m³)	CA(SSD) (kg/m³)	Admixture (kg/m³)	Glass Fiber (kg/m³)
M35-N	440	0	167	597.8	1199.37	4.40	0
M35-6	352	88	167	585.73	1175.16	4.40	4.40
M35-12	352	88	167	585.73	1175.16	4.40	4.40
M35-24	352	88	167	585.73	1175.16	4.40	4.40
M35-SG	352	88	167	585.73	11337	4.40	4.40
M35-LG	352	88	167	585.73	1175.16	4.40	4.40
M35-CG	352	88	167	585.73	1175.16	4.40	4.40

Table 3: Glass fiber Variation

ID	Length of glass fiber	% (sample I)	% (sample II)	% (sample III)
6	6 mm	100%		
12	12 mm	100%		
24	24 mm	100%		
SG	6 mm + 12 mm	30%+70%	50%+50%	70%+30%
LG	12 mm+24 mm	30%+70%	50%+50%	70%+30%
CG	6 mm+12 mm+24 mm	20%+30%+50%	30%+50%+20%	50%+30%+20%

IV. RESULT AND DISCUSSION

Introduction

This section presents the experimental results obtained from the fresh and hardened concrete tests conducted on M30 and M35 grade concrete containing graded glass fibers and fly ash. The performance of modified concrete mixes is evaluated in comparison with the reference mixes without fibers. The study primarily focuses on the influence of fiber length and fiber grading (mono-length and hybrid combinations) on the workability, compressive strength, flexural strength, and split tensile strength of concrete. In addition, a cost analysis is carried out to assess the economic feasibility of the modified mixes. The results are interpreted to understand the role of fiber-matrix interaction, crack-bridging mechanisms, and graded fiber distribution in improving the mechanical performance of concrete.

A. Slump Value Test Results

The workability of both M30 and M35 concrete mixes was evaluated using the slump value test. The results indicate that fiber length and fiber distribution significantly influence the workability of fresh concrete. In M30 concrete, mixes containing shorter fibers exhibited higher slump values due to better dispersion and reduced fiber interlocking within the matrix. On the other hand, mixes containing longer fibers showed noticeable reduction in workability, as longer fibers tend to create higher internal resistance and entanglement. The SG mixes demonstrated relatively improved slump values because of the higher proportion of short fibers, whereas LGmixes exhibited lower slump values due to the greater presence of longer fibers. The CG mixes maintained moderate and stable slump values, indicating balanced rheological behaviour resulting from the combination of different fiber lengths.

A similar trend was observed in M35 concrete, although the slump values were generally higher than those of M30 mixes. The higher workability in M35 mixes can be due to the richer paste content and improved lubrication effect within the matrix, which allows better accommodation of fibers. SG mixes again showed improved slump with increasing shortfiber proportion, whereas LG mixes showed reduced workability due to the dominance of longer fibers. CG mixes showed stable slump behaviour, confirming that balanced fiber grading improves compatibility within the fresh concrete matrix. The slump test results are illustrated in Fig.2 for M30 and for M35 concrete.

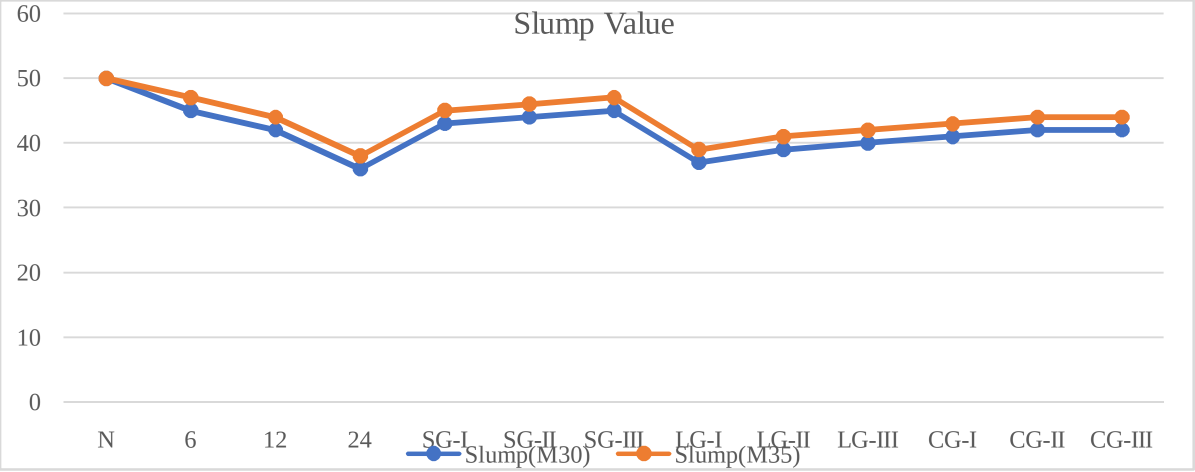

Figure 2: Slump Value for M30and M35

B. Compressive Strength Results

The compressive strength results for M30 and M35 grade concrete indicate that glass fiber inclusion has limited influence on early-age strength but contributes to improved strength at later ages. In M30 concrete, early-age compressive strength showed minimal variation compared with the reference mix, whereas 28-day strength increased gradually with effective fiber length. Hybrid mixes such as SG-III, LG-III, and CG-III demonstrated better compressive strength performance compared with other combinations due to improved crack control and fiber–matrix interaction.The compressive strength results are presented in Fig. 3 for M30 concrete.

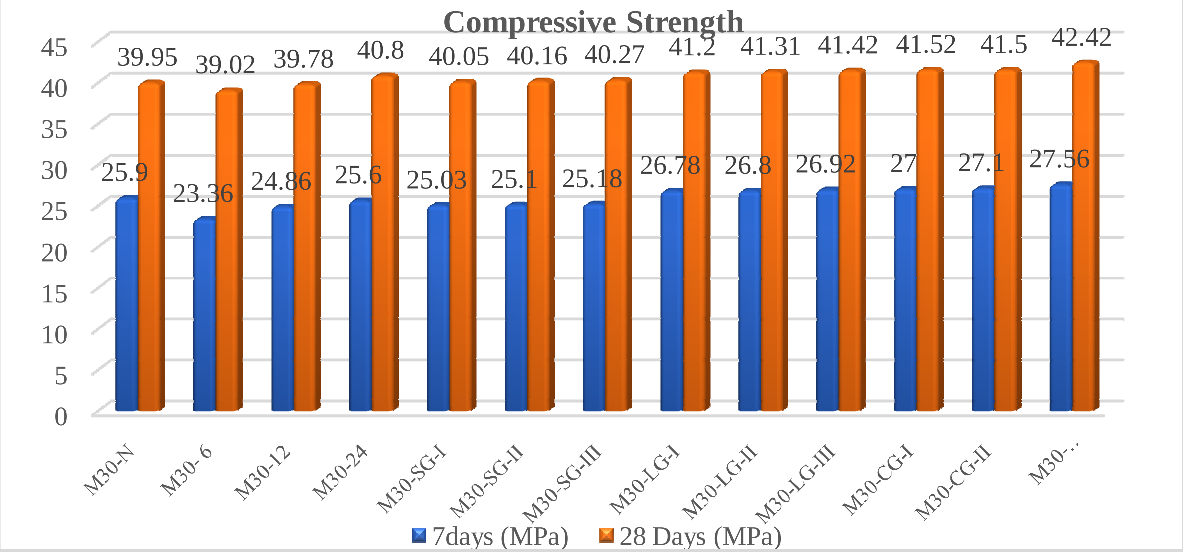

Figure 3: Compressive Strength for M30

A similar pattern was observed in M35 concrete, although the overall compressive strength values were higher due to the denser matrix and higher cementitious content. Hybrid mixes again showed improved performance compared with mono-length fiber mixes, confirming that graded fiber systems improve crack resistance and internal load distribution. The compressive strength results are presented in Fig. 3 for M35 concrete.

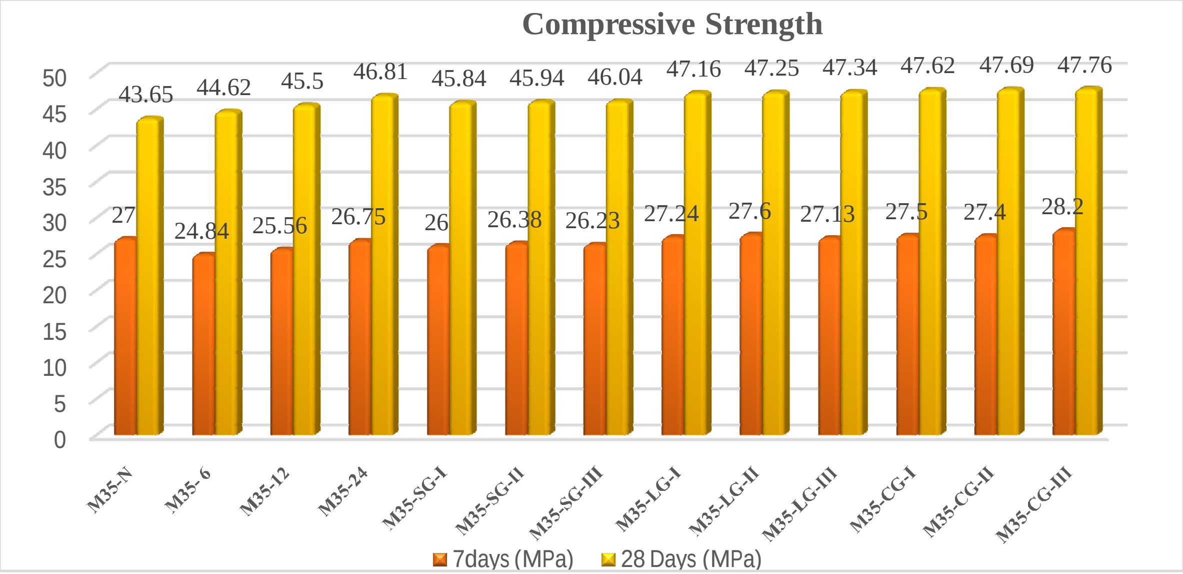

Figure 4:Compressive Strength for M35

C. Flexural Strength Results

The addition of glass fibers significantly influenced the flexural strength of concrete, as fibers improve crack bridging and resistance under bending loads. In M30 concrete, flexural strength increased from the control mix to mono-length fiber mixes, with strength improving as fiber length increased.

In the SG series, the SG-I mix showed higher flexural strength compared with SG-II, indicating the beneficial role of medium-length fibers in resisting bending stresses. In the LG series, LG-I demonstrated better performance, confirming that longer fibers are more effective in controlling flexural cracks. In the CG series, the CG-II mix exhibited the highest flexural strength, suggesting that balanced fiber proportions provide effective stress redistribution.The flexural strength results are illustrated in Fig. 5 for M30concrete.

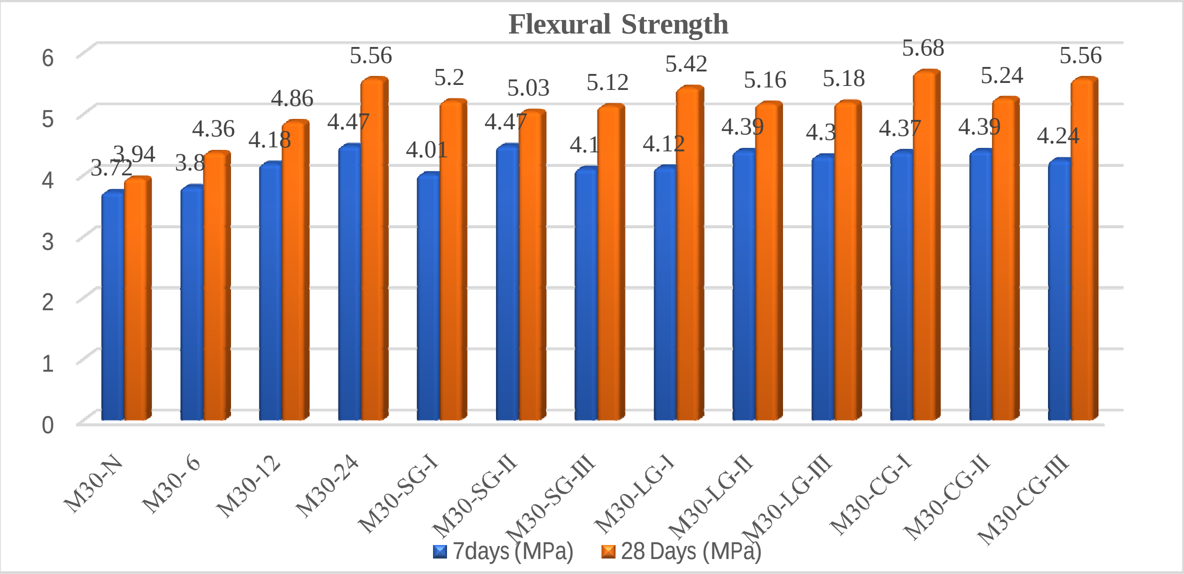

Figure 5: Flexural Strength for M30

In M35 concrete, the flexural strength followed a similar trend but showed higher overall values compared with M30 mixes. Mono-length fiber mixes showed steady improvement with increasing fiber length. In SG mixes, performance improved with increased proportion of 12 mm fibers, while in LG mixes, balanced combinations provided more uniform behaviour. In CG mixes, combinations dominated by 12 mm and 24 mm fibers demonstrated improved flexural strength, indicating efficient stress transfer and crack control.

These results confirm that graded fiber combinations enhance flexural performance through collaborative crack bridging mechanisms. The flexural strength results are illustrated in Fig. 6 for M35 concrete.

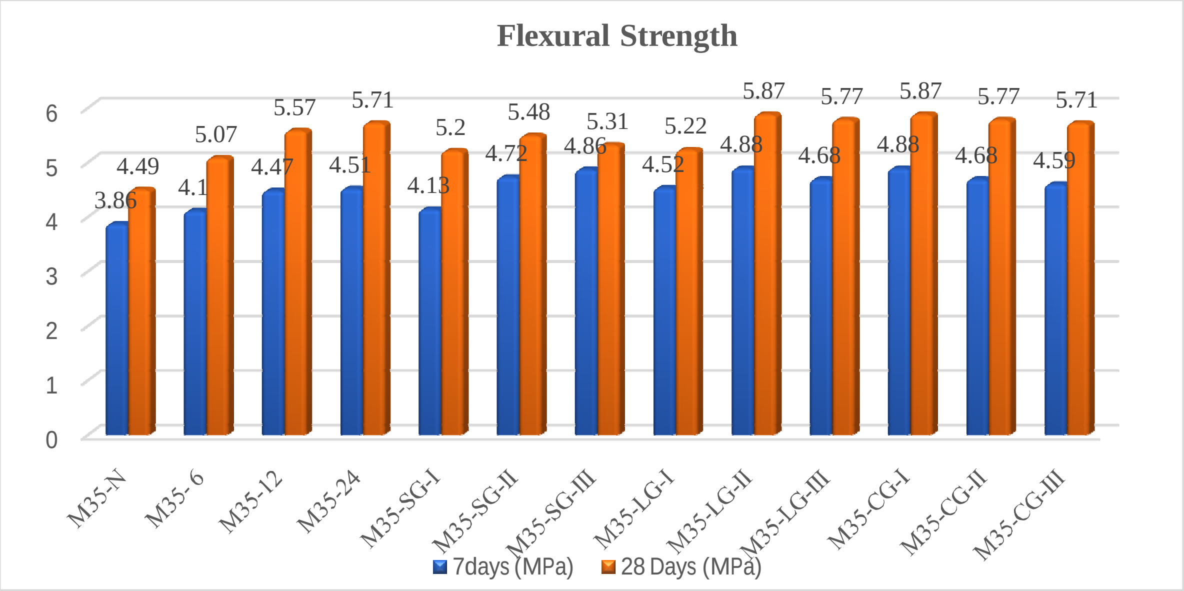

Figure 6: Flexural Strength for M35

D. Split Tensile Strength Results

The split tensile strength results show significant improvement with the inclusion of glass fibers in both grades of concrete. In M30 concrete, tensile strength increased progressively from the reference mix to mono-length fiber mixes, with improvement observed as fiber length increased. In the SG mixes, SG-I showed higher tensile strength compared with SG-II, while SG-III showed slight reduction due to excessive short fibers reducing crack-bridging efficiency. In the LG mixes, LG-II produced the highest tensile strength, while further increase in longer fiber proportion resulted in marginal reduction due to fiber interaction effects. In the CG mixes, CG-I exhibited better tensile strength, demonstrating that balanced multi-length fiber distribution improves crack control and tensile stress redistribution.

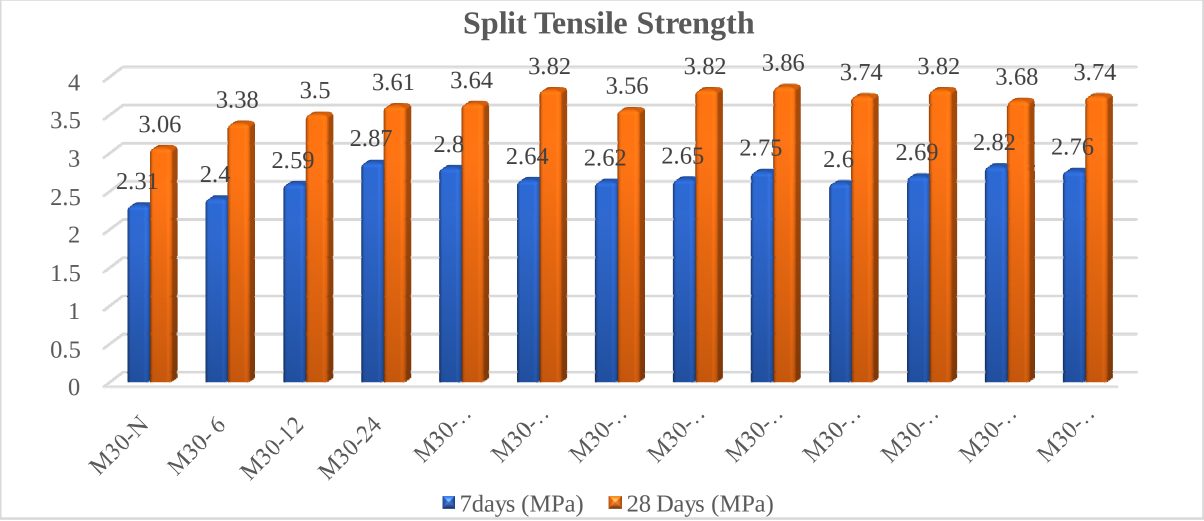

Figure 7:Split Tensile Strength for M30

In M35 concrete, the split tensile strength values were generally higher than those of M30 mixes due to the denser cementitious matrix and stronger fiber–paste bonding. Mono-length fiber mixes showed gradual improvement with increasing fiber length. SG mixes achieved maximum strength at SG-I, while LG-II showed the best tensile performance among LG mixes. CG-I again demonstrated superior performance, indicating that optimized graded fiber distribution improves tensile resistance in higher-grade concrete. The split tensile strength results are presented in Fig. 7 and Fig. 8.

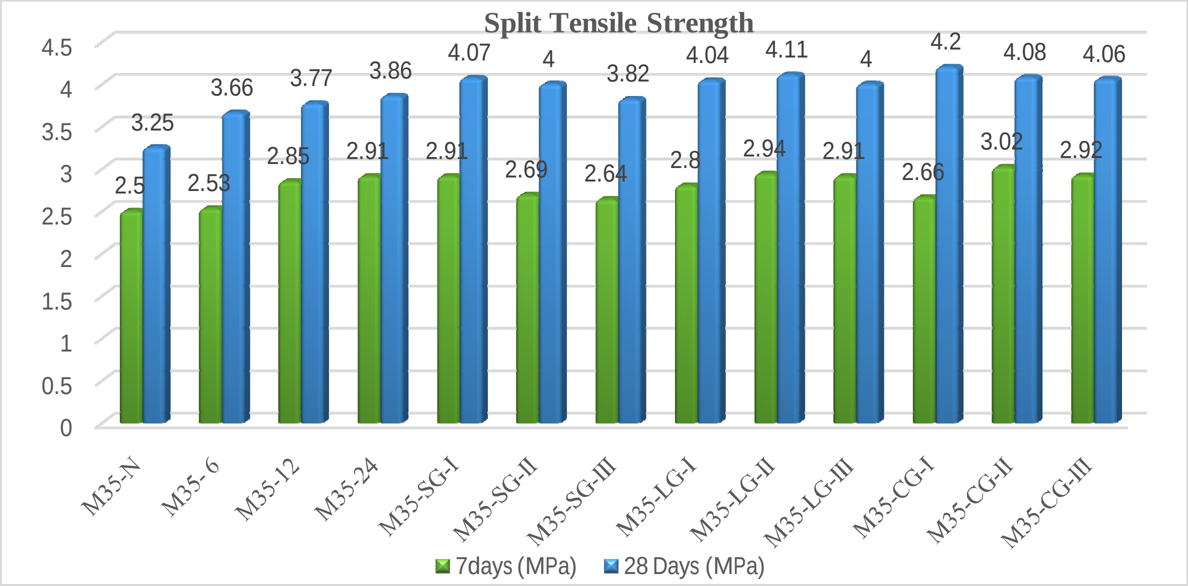

Figure 8:Split Tensile Strength for M35

E. Cost Analysis

A cost comparison was carried out between the reference concrete mixes and the modified mixes containing fly ash and glass fibers using rate analysis per cubic meter. The adopted material rates were based on market surveys and supplier listings. The results show that the cost of M30 concrete increased from ₹7052/m³ to ₹7278/m³, representing a 3.21% increase, while M35 concrete increased from ₹7312/m³ to ₹7560/m³, corresponding to a 3.4% increase. Although the 20% replacement of cement with fly ash reduces cement consumption, the inclusion of AR glass fibers at 1% of cementitious material increases the overall material cost due to the higher unit price of fibers. However, the overall increase in cost remains less than 4%, which is relatively small considering the improvements observed in tensile strength, flexural strength, crack resistance, and durability performance. The cost comparison results are illustrated in Fig. 9.

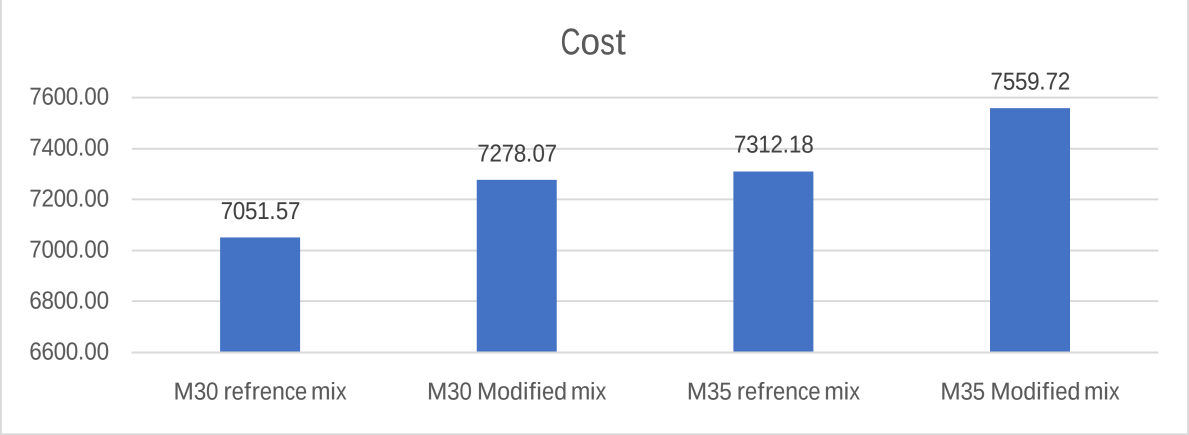

Figure 9: Cost Analysis for M30 and M35

V. CONCLUSION

Based on the experimental investigation on graded glass fiber reinforced concrete (GGFRC) with fly ash in M30 and M35 grades, the following conclusions are drawn:

A. Fresh Properties

1) In both M30 and M35 concrete, workability decreases progressively with increase in effective fiber length due to higher interlocking and resistance to flow caused by longer fibers.
2) Mixes containing shorter fibers exhibit better slump values because of improved dispersion and reduced fiber entanglement, whereas mixes dominated by longer fibers show significant loss of workability.
3) In SG hybrid mixes, higher proportion of shorter fibers improves slump performance; conversely, LG mixes demonstrate reduced workability due to greater presence of longer fibers affecting rheological behaviour.
4) CG mixes maintain moderate and comparatively stable slump values in both grades, indicating balanced fiber distribution and controlled flow characteristics.
5) M35 concrete consistently shows higher slump than M30 for similar fiber combinations, attributed to its richer paste content, improved lubrication effect, and better tolerance to fiber incorporation.
6) Overall, workability in both grades is primarily governed by effective fiber length and its percentage distribution, along with matrix richness and paste quality.

B. Compressive Strength Behaviour

1) In both M30 and M35 concrete, early-age compressive strength shows only small changes after adding glass fibers. This indicates that fibers mainly influence later-age performance rather than initial strength development.
2) At 28 days, compressive strength increases gradually with increase in effective fiber length. Longer fibers help in controlling cracks and improving load transfer inside the concrete.
3) Mono-length fiber mixes show steady improvement in strength as fiber length increases, due to better crack-bridging action.
4) In SG mixes, SG-III shows better compressive strength. Short fibers help in controlling micro-cracks and improve bonding at the paste–aggregate interface.

5) In LG mixes, LG-III gives higher compressive strength because longer fibers are more effective in restricting crack growth and improving internal resistance under load.
6) In CG mixes, CG-III shows the best and most consistent strength development. The combination of different fiber lengths controls both micro and macro cracks, which improves overall load-carrying capacity.
7) M35 concrete shows overall higher compressive strength than M30 due to its denser matrix, higher cement content, reduced porosity, and better fiber–paste bonding, which also leads to improved stress distribution and stronger fiber anchorage.
8) Hybrid fiber mixes perform better than mono-length mixes, especially in M35 concrete, because the richer paste content improves fiber–matrix interaction, provides better tolerance to fiber inclusion, and results in more uniform and consistent strength gain compared to M30.

C. Flexural Strength Performance

1) Flexural strength increases with fiber length in both grades, with M35 consistently showing higher values due to its denser and stronger matrix.
2) Mono-length mixes show steady improvement, while graded combinations enhance stress transfer and crack control efficiency.
3) In SG mixes, higher proportion of 12 mm fibers improves performance (SG-I most effective); in LG mixes, balanced proportion (LG-I) provides more uniform behaviour than dominance of longer fibers alone.
4) CG-I exhibits superior flexural strength in both grades, confirming effective tensile stress redistribution and crack-bridging ability.
5) M35 utilizes graded fiber proportions more efficiently under bending due to improved fiber–paste interaction.

D. Split Tensile Strength Performance

1) Split tensile strength increases from reference to mono-length fiber mixes in both grades, with progressive improvement as fiber length increases due to enhanced crack-bridging action.
2) In SG mixes, moderate proportion of longer fibers (SG-I) yields better tensile strength, while excessive short fibers reduce effectiveness.
3) In LG mixes, LG-II provides optimum tensile performance; dominance of a single longer fiber length leads to marginal reduction because of fiber interaction effects.
4) CG-I achieves superior tensile strength in both grades, confirming that balanced multi-length fiber distribution improves crack control and tensile stress redistribution.
5) M35 consistently exhibits higher split tensile strength than M30 due to denser matrix structure and stronger fiber–paste bonding, demonstrating better utilization of graded fiber synergy.

E. Cost Analysis

1) For M30 grade concrete, the total cost increased from ₹7052/m³ (Reference Mix) to ₹7278/m³ (Modified Mix), resulting in an increment of ₹226.5/m³, which corresponds to a 3.21% increase.
2) For M35 grade concrete, the cost increased from ₹7312/m³ (Reference Mix) to ₹7560/m³ (Modified Mix), giving an increment of ₹247.5/m³, equivalent to approximately 3.4% increase.
3) Although 20% cement replacement with Class-F fly ash reduces cement consumption from 408.29 kg for M30 to 326.29 kg for M30 and 440 kg to 352 kg for M35, the inclusion of 1% AR glass fiber (by weight of cementitious powder) increases the overall binder cost due to its high unit rate (₹180/kg).
4) The marginal cost increase ₹226 per m³ for M30 and ₹248 per m³for M35 is technically justified considering the enhanced tensile strength, flexural strength, crack resistance, and durability performance achieved in fiber-reinforced concrete.

VI. FUTURE SCOPE

The following scope for future research is identified based on the results of the present study:

1) Long-term durability performance such as resistance to chloride penetration, sulphate attack, carbonation, water absorption, and freeze–thaw cycles should be evaluated.
2) Microstructural studies using techniques such as SEM and XRD may be carried out to understand fiber–matrix interaction, crack bridging mechanisms, and the role of fly ash in pore refinement.

3) The behavior of graded glass fiber reinforced concrete under cyclic loading, fatigue loading, and impact loading may be studied for applications in seismic and dynamic conditions.
4) Hybrid fiber systems combining glass fibers with steel, polypropylene, or basalt fibers may be explored to further enhance ductility and toughness.

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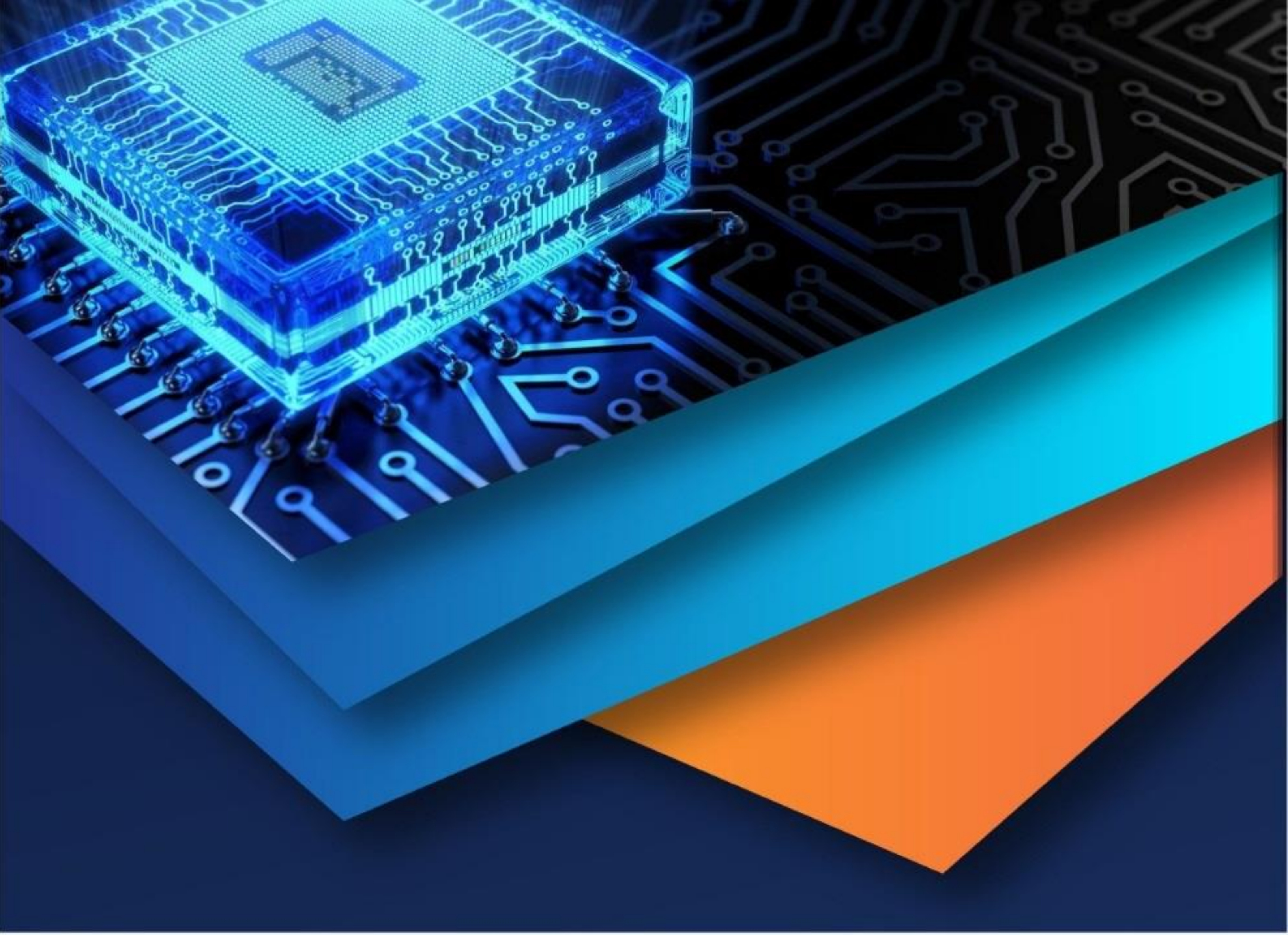

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