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Enhancing Strength And Durability In High-Performance Concrete Through Fiber Reinforcement: An Experimental Study

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Abstract-This study investigates the mechanical properties of concrete reinforced with glass and polypropylene fibers. The goal is to enhance the strength, durability, and crack resistance of concrete for high-performance structural applications. Hybrid fiber-reinforced concrete was prepared using different proportions of glass and polypropylene fibers, with the M50 grade concrete as the base material. Tests were conducted to evaluate the compressive, tensile, and flexural strength of the concrete, with specific emphasis on its behaviour under cyclic loading. Results indicate that the inclusion of glass and polypropylene fibers significantly improves the tensile and flexural strength of the concrete, while also enhancing its crack resistance. The findings suggest that hybrid fiber-reinforced concrete offers superior performance for applications subjected to dynamic loads, such as bridges and high-rise buildings. These results highlight the potential of glass and polypropylene fibers to improve the durability and mechanical behaviour of concrete, making it suitable for modern construction demands.

Keywords: Glass fiber-reinforced concrete**,** Polypropylene fiber**,** Hybrid fiber-reinforced concrete (HFRC)**,** High-performance concrete (HPC)**,** Fiber-reinforced concrete (FRC)

Introduction:

Concrete is one of the most widely used construction materials due to its high compressive strength, durability, and versatility. However, conventional concrete has limitations, particularly in its tensile strength and resistance to dynamic loads. To overcome these challenges, fiber-reinforced concrete (FRC) has emerged as a promising material in civil engineering. The use of fibers, both natural and synthetic, has been shown to improve the mechanical properties of concrete, particularly its tensile and flexural strength, which are critical in resisting cracking and failure under various loading conditions.

In recent years, the incorporation of glass and polypropylene fibers in concrete has garnered attention for their ability to enhance the material's performance under both static and cyclic loading. Glass fibers, known for their high tensile strength and stiffness, improve the overall structural integrity of concrete, while polypropylene fibers contribute to increased toughness and ductility, especially under dynamic loads. The combination of these fibers, referred to as hybrid fiber-reinforced concrete (HFRC), offers a balanced enhancement in mechanical properties, providing better performance compared to concrete reinforced with a single type of fiber.

The primary aim of this research is to investigate the mechanical properties of glass-polypropylene reinforced concrete and its behavior under static and cyclic loading. By evaluating the compressive, tensile, and flexural strength of the concrete, this study seeks to determine the optimal mix proportions of glass and polypropylene fibers for achieving high performance in modern structural applications.

Objective:

The objective of this research is to evaluate the mechanical behavior of concrete reinforced with a combination of glass and polypropylene fibers under both static and cyclic loading conditions. The specific goals are:

1. **To investigate the compressive strength** of glass-polypropylene reinforced concrete at different curing periods (3, 7, 28, 56, and 90 days).
2. **To assess the tensile strength** and flexural behavior of the concrete with varying fiber content.
3. **To evaluate the crack resistance** and durability of the concrete under cyclic loading conditions.
4. **To determine the optimal proportion of glass and polypropylene fibers** for achieving superior mechanical performance in high-performance concrete applications.

Materials and Methods:

1. Materials:

The materials used in this study for the preparation of high-performance fiber-reinforced concrete (HPFRC) include:

- **Cement:** Ordinary Portland Cement (OPC) of 53 grade was used, conforming to IS 8112 standards. The cement was selected to ensure a consistent baseline for evaluating the effects of fiber reinforcement.
- **Fine Aggregate:** River sand (Zone-II) was chosen as the fine aggregate, meeting IS 383-2016 specifications.
- **Coarse Aggregate:** Crushed granite with a nominal size of 20 mm was used as the coarse aggregate.
- **Fibers:**
    - **Glass Fiber:** A synthetic fiber with high tensile strength and resistance to alkalis, commonly used to enhance the tensile properties of concrete.
    - **Polypropylene Fiber (PP):** A synthetic fiber known for its toughness and ability to reduce plastic shrinkage in concrete.
- **Admixtures:**
    - **Fly Ash:** Class-F fly ash was used to enhance the pozzolanic activity, providing long-term strength and durability.
    - **Coir Husk Ash:** This natural admixture was utilized to improve the sustainability and strength of the concrete mixture.
    - **Superplasticizer (Glenium SP430G):** A chloride-free, high-range water-reducing admixture was used to ensure workability at low water-to-cement ratios.

2. Mix Design:

The M50 grade of concrete was chosen as the base mix for this study. The mix design was computed based on IS 10262:2019 standards. The water-binder ratio was kept at 0.30, ensuring high strength and durability. The mix proportions of glass and polypropylene fibers were varied to determine the optimal performance.

The following fiber proportions were used:

- Coir fiber: 0.5%, 1%, 1.5%, and 2% by weight of cement.
- Polypropylene fiber: 0.5%, 1%, 1.5%, and 2% by weight of cement.
- Hybrid fiber combinations: Various ratios of glass and polypropylene fibers were used to explore the benefits of hybridization.

3. Experimental Methods:

The concrete was subjected to a series of tests to evaluate its mechanical properties under different loading conditions.

- **Slump Test:** The workability of the fresh concrete was measured using the slump cone test, conforming to IS: 1199 standards.
- **Compaction Factor Test:** This test was used to assess the workability of concrete with different fiber proportions, especially for mixes with low workability.
- **Compressive Strength Test:** Concrete cubes (150mm x 150mm x 150mm) were tested for compressive strength at 3, 7, 28, 56, and 90 days as per IS: 516-1959.
- **Split Tensile Strength Test:** Cylindrical specimens (150mm diameter x 300mm height) were used to evaluate the tensile strength of the concrete. The test was conducted according to IS 5816-1999 standards.
- **Flexural Strength Test:** Beam specimens (150mm x 150mm x 700mm) were tested for flexural strength to evaluate their behavior under bending loads. The tests were carried out using a loading frame to simulate static and cyclic loading conditions.
- **Cyclic Loading Test:** The beam specimens were subjected to cyclic loading to assess their crack resistance and durability under repeated load conditions. Parameters such as modulus of elasticity, stiffness, and flexibility were recorded.

4. Data Analysis:

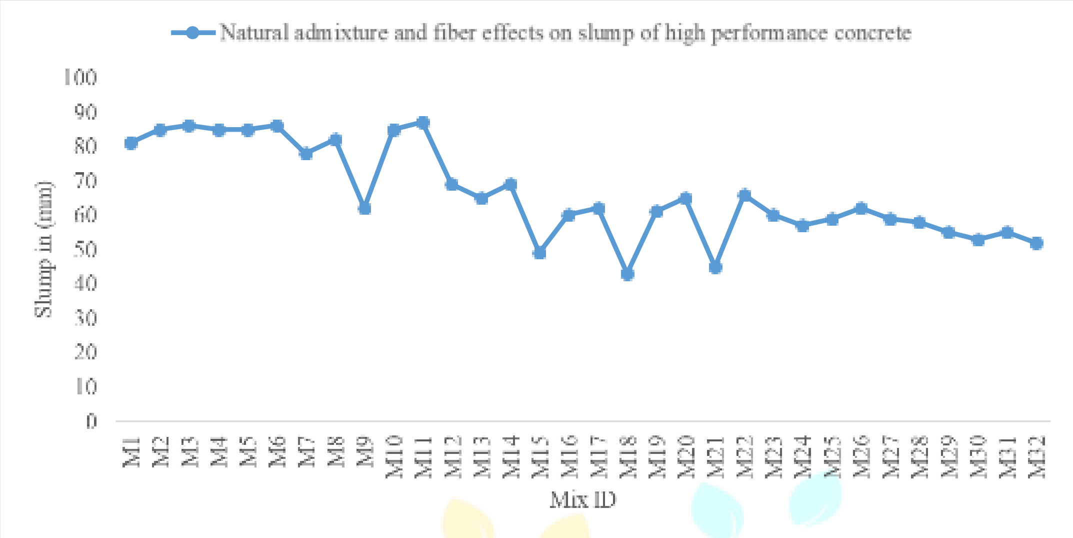
The experimental results were analyzed to compare the mechanical performance of glass-polypropylene reinforced concrete against standard concrete. Statistical methods were used to evaluate the significance of the fiber content on compressive, tensile, and flexural strength. The crack resistance and durability were also examined to assess the behavior of the hybrid fiber-reinforced concrete under cyclic loading.

Results and Discussion:

1. Slump and Workability

The workability of the concrete was measured using the slump test for various fiber-reinforced mixes. The results indicated that the addition of fibers, particularly natural fibers like coir and kenaf, led to a reduction in workability. This is primarily due to the high water absorption capacity of the natural fibers. The highest slump value of 87 mm was observed for the control mix (M1), whereas the lowest slump value of 49 mm was recorded for Mix M15, which contained 1.5% polypropylene fiber.

The inclusion of glass and polypropylene fibers significantly affected the workability. As the fiber content increased, the slump value decreased, indicating reduced fluidity and more difficulty in handling the concrete. However, the use of a superplasticizer helped maintain adequate workability across most fiber-reinforced mixes. Overall, hybrid fiber mixes demonstrated slightly better workability than mixes with a single type of fiber.

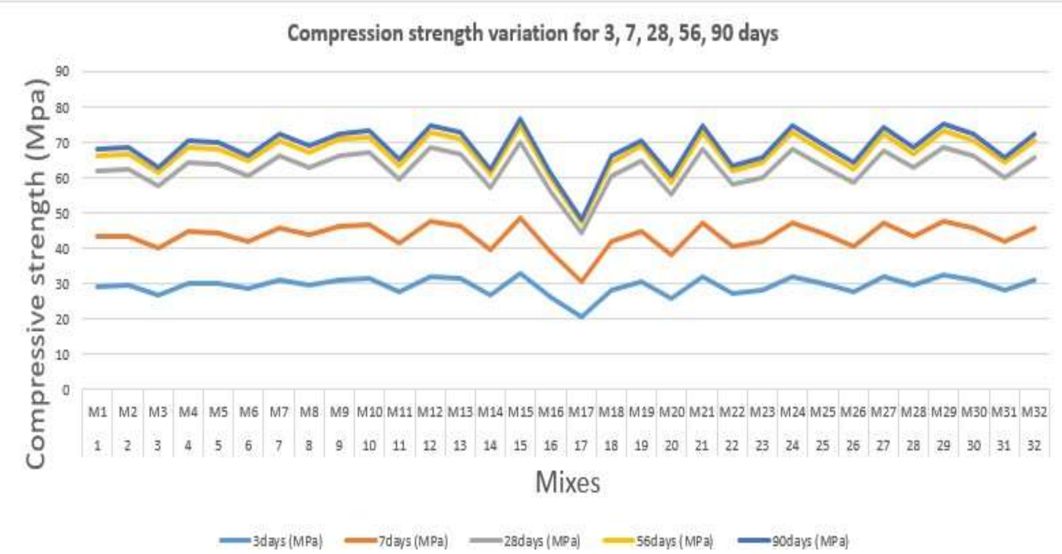


2. Compressive Strength

The compressive strength of the glass-polypropylene reinforced concrete was measured at different curing periods: 3, 7, 28, 56, and 90 days. The results showed a clear increase in compressive strength as the curing time progressed, with the highest compressive strength recorded at 90 days.

Mix M15 (containing 1.5% polypropylene fiber) achieved the highest compressive strength of 70 MPa at 28 days, which was 13% higher than the control mix (M1). Other mixes, such as M12, M21, and M29, also showed significant improvement in compressive strength, with increases of approximately 10% compared to the control. The enhancement in compressive strength is attributed to the hybrid effect of glass and polypropylene fibers, which contributed to better load distribution and crack resistance.

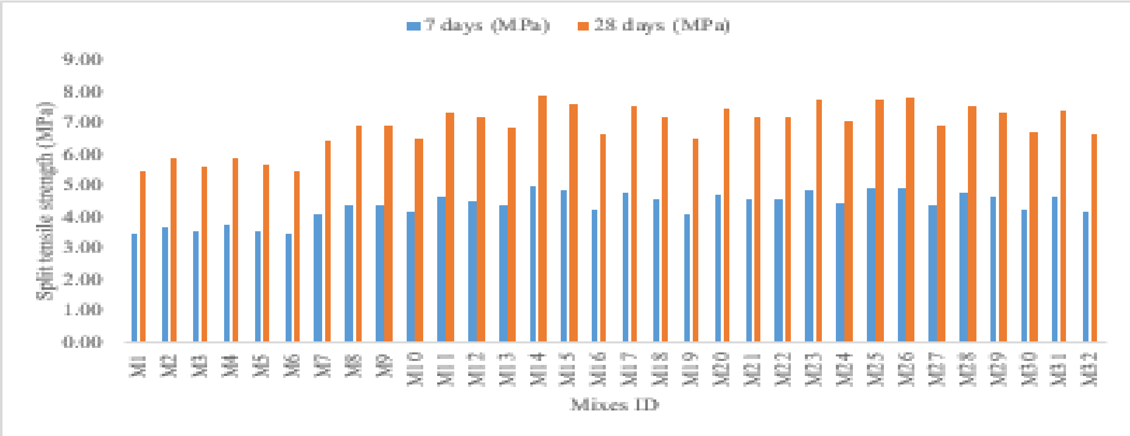
However, mixes with higher proportions of natural fibers, particularly kenaf, showed a slight reduction in compressive strength compared to the synthetic fiber mixes. This can be attributed to the higher water absorption and lower stiffness of natural fibers, which resulted in a less compact concrete matrix.



3. Tensile Strength

The split tensile strength test was conducted to assess the concrete's resistance to tensile forces. The results indicated a marked improvement in tensile strength with the addition of fibers. Mix M12, containing 1% polypropylene fiber, exhibited the highest tensile strength, which was 15% higher than the control mix. The hybrid fiber mixes (M22, M23, and M25) also demonstrated significant increases in tensile strength, owing to the complementary effects of glass and polypropylene fibers.

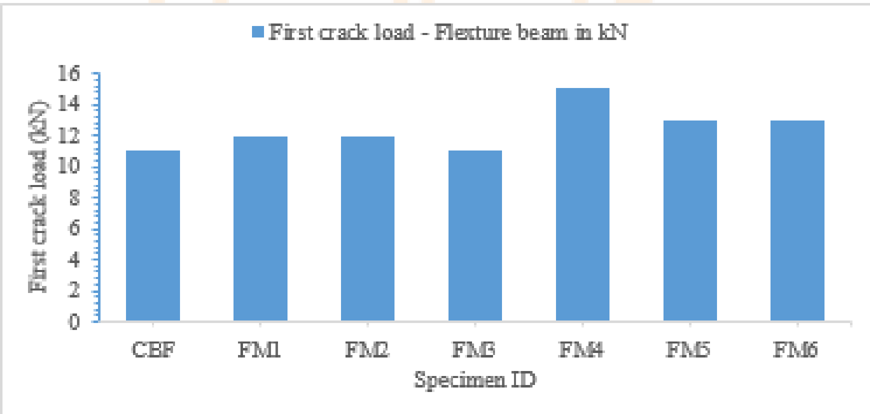
Polypropylene fibers contributed to better bridging of cracks, thus enhancing the tensile strength. The natural fibers (coir and kenaf) also helped improve tensile properties, though to a lesser extent than polypropylene. Overall, hybrid fiber-reinforced concrete showed superior tensile strength compared to concrete reinforced with a single type of fiber.



4. Flexural Strength and Crack Resistance

The flexural strength tests revealed that the addition of fibers significantly improved the bending resistance of the concrete. Beam specimens reinforced with 1.5% polypropylene fiber (M15) and hybrid fiber combinations (M27 and M29) showed the highest flexural strengths. The hybrid mixes exhibited an increase in flexural strength of up to 20% compared to the control.

Under cyclic loading conditions, the fiber-reinforced concrete demonstrated enhanced crack resistance. Beams reinforced with hybrid fibers were able to resist crack propagation more effectively, with smaller crack widths and reduced crack growth under repeated loading. The inclusion of both glass and polypropylene fibers contributed to higher energy absorption and toughness, which are critical for structures subjected to dynamic loads.



5. Effect of Fiber Content on Mechanical Properties

The study revealed that the proportion of fibers plays a critical role in determining the mechanical performance of the concrete. While low fiber content (0.5% to 1%) provided modest improvements in strength, higher fiber content (1.5% to 2%) yielded the most significant enhancements in both compressive and tensile strength.

Polypropylene fibers, in particular, proved effective in improving the mechanical properties of the concrete. However, the hybridization of fibers (combining glass and polypropylene) resulted in the best overall performance, particularly in terms of tensile strength, flexural behavior, and crack resistance under cyclic loads.

6. Comparison with Previous Studies

The findings of this study are consistent with previous research on fiber-reinforced concrete, where the use of synthetic fibers such as polypropylene has been shown to enhance tensile and flexural properties. However, this study provides additional insights into the benefits of hybrid fiber reinforcement, where the combination of glass and polypropylene fibers offers a balanced improvement in both static and dynamic performance. The reduction in crack growth and improved toughness under cyclic loading conditions further validates the use of hybrid fibers for high-performance concrete applications.

Conclusion

This research focused on enhancing the mechanical properties of concrete by incorporating glass and polypropylene fibers under both static and cyclic loading conditions. The key findings from this study are as follows:

1. **Improved Compressive Strength:** The addition of glass and polypropylene fibers resulted in a significant improvement in the compressive strength of concrete, with the highest strength recorded for the mix containing 1.5% polypropylene fiber. The hybrid fiber mixes also demonstrated a notable increase in compressive strength compared to the control mix, with the best results obtained by combining glass and polypropylene fibers.
2. **Enhanced Tensile and Flexural Strength:** The inclusion of fibers, especially polypropylene, greatly improved the tensile and flexural strengths of the concrete. The hybrid mixes outperformed the single-fiber mixes, offering better resistance to cracking and higher load-bearing capacity. This makes hybrid fiber-reinforced concrete a suitable candidate for structures where tensile and flexural strength are critical.
3. **Superior Crack Resistance under Cyclic Loading:** The crack resistance of the concrete under cyclic loading conditions was significantly enhanced by the use of hybrid fibers. The combination of glass and polypropylene fibers reduced crack propagation, increased energy absorption, and improved the overall toughness of the concrete. These properties are particularly beneficial for structures exposed to dynamic loads, such as bridges and high-rise buildings.
4. **Optimized Fiber Proportions:** The study showed that the optimal proportion of fibers for achieving the best mechanical performance was around 1.5% polypropylene and 1% glass fiber. This combination provided the best balance of compressive strength, tensile strength, and flexural performance.
5. **Practical Implications:** The findings suggest that hybrid fiber-reinforced concrete can be effectively used in modern construction projects where high strength and durability are required, particularly for structures subject to dynamic loading conditions. The improved crack resistance and durability also make it an excellent choice for coastal structures, pavements, and infrastructure exposed to harsh environmental conditions.

Future Work:

Further research is recommended to:

- Investigate the long-term durability of glass-polypropylene reinforced concrete in extreme environmental conditions, such as high temperatures and chemical exposure.
- Explore the economic viability of using hybrid fiber-reinforced concrete in large-scale infrastructure projects.
- Study the behavior of hybrid fiber-reinforced concrete under different dynamic loading conditions, including seismic and wind loads, to assess its full potential for structural applications.

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