The Performance Enhancement of Concrete Using Hybrid Fibers and Optimized Curing

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Abstract : *This study undertakes a comprehensive comparative investigation into the synergistic influence of hybrid fiber reinforcement on the flexural component of concrete, alongside an evaluative inquiry into the repercussions of diverse curing regimens on its compressive strength. By integrating heterogeneous fiber typologies—such as steel, polypropylene, and coir—within a singular cementitious matrix, the research delineates how hybridization helps crack-bridging capacity, enhances post-cracking ductility, and mitigates brittleness typically inherent in conventional concrete. Experimental results reveal that the strategic orchestration of fiber combinations engenders a pronounced elevation in flexural rigidity and energy absorption characteristics. Concurrently, the study scrutinizes the mechanistic interplay between curing methodologies, moisture availability, and microstructural densification, elucidating their cumulative effect on compressive strength development. The findings substantiate that optimized curing protocols significantly potentiate hydration kinetics and matrix consolidation, thereby yielding superior strength profiles. Collectively, the analysis underscores the pivotal role of hybrid fiber systems and curing environments in engineering high-performance concretes with improved structural reliability and long-term durability*

***Key Words*:** **(Hybrid Fibres, Flexural strength, curing, compressive strength)**

INTRODUCTION

Concrete remains the backbone of modern infrastructure due to its multifaceted and high compressive strength. However, its inability to resist tensile stresses makes it vulnerable to cracking, which influences long-tern durability and structural performance to improve its tensile and flexural behaviour, the addition of fibres has become a widely research remodelled to conventional concrete. Fibres act as bridging element across cracks, distributing stress preventing sudden failure.

Hybrid fibre-reinforced concrete (HFRC) incorporates two or more different fibre types in the same mix to achieve balanced advancement in strength, toughness, ductility, shrinkage control, and crack resistance. Each fibre types.

contributes uniquely: steel fibres enhance toughness and flexural capacity, polypropylene and microfibres control early-age cracking, while natural fibres such as coir and bamboo bark add sustainability benefits. Combining these fibres helps address weaknesses that a single fibre type cannot overcome.

In addition to fiber reinforcement, curing is a critical factor influencing the strength development of concrete. Proper curing supports hydration, reduces porosity, and enhances compressive strength. Comparing different curing techniques such as water curing, air curing, sprinkling, wet gunny bags, and membrane curing provides insight into optimal field practices.

This review focuses on the influence of hybrid fiber combinations and varied curing conditions on the mechanical performance of concrete, with emphasis on flexural strength and compressive strength.

IMPORTANCE

The use of fibres in concrete has gained importance as an alternative or supplement to steel reinforcement due to their ability to improve the overall performance of concrete. Fibers such as polypropylene, coir, and bamboo help in controlling the formation and propagation of cracks, thereby enhancing durability and service life. They increase the flexural strength, toughness, and impact resistance of concrete, making it less brittle and more ductile in behaviour. Unlike steel bars, many fibres are non-corrosive, which makes them suitable for structures exposed to moisture or aggressive environments. Additionally, the use of fibres simplifies construction by reducing the need for complex reinforcement placement and can lower overall costs. However, while fibres significantly enhance crack resistance and durability, they cannot completely replace steel bars in major structural elements, as steel is still required to provide the primary tensile strength and load-bearing capacity.

3. LITERATURE REVIEW

3.1 Grija. S et.al (2016): According to Grija, polypropylene fibers contribute substantially to crack resistance and ductility. Their study demonstrated notable improvements in 28-day compressive, split tensile, and flexural strengths. Moreover, incorporating industrial by-products like hypo sludge enhances sustainability and reduces environmental impact. Despite a slight rise in porosity, the benefits in post-cracking performance make polypropylene-modified concrete ideal for durable construction.

3.2 Shaikh A.S. et.al (2017): Shaikh and colleagues compared curing effects on self-compacting concrete (SCC) and normal vibrated concrete (NVC). Immersion curing yielded superior performance in both types, improving compressive, tensile, and flexural properties. The researchers also highlighted that SCC (M30 grade) outperformed NVC under seawater curing conditions, demonstrating its adaptability for marine and coastal projects.

3.3 Bhushan R. Bhaladhare et.al (2020): Bhaladhare's work reflects that adding fibers (steel, synthetic, or natural) significantly improves tensile strength, flexural strength, impact resistance, and post-cracking energy absorption. The study reiterates that fibers enhance ductility, restrict microcracking, and reduce shrinkage. Although fiber addition cannot fully replace conventional reinforcement, it acts as an effective supplementary mechanism that boosts both static and dynamic performance. This reinforces the idea that hybrid fiber systems offer balanced improvements suitable for varied loading conditions.

3.4 M. Shadheer Ahamed et.al (2021): Ahamed's findings highlight the potential of natural fibers—such as coir, sisal, jute, and bamboo—in improving the mechanical properties of concrete. The researchers observed enhanced ductility, strength, and crack control through natural fibers, particularly at an optimum fiber content of around 1.5%. They emphasized that natural fibres are environmentally friendly, economically feasible, and conducive to sustainable construction, aligning with modern green-building objectives.

3.5 Ammar Anwar et.al (2022): Anwar's research emphasizes that curing is one of the most critical parameters influencing the long-term behavior of concrete. Their findings indicate that continuous moisture availability—such as in ponding—results in higher compressive strength by enabling uninterrupted hydration. Techniques like plastic sheeting and air curing exhibited lower performance due to moisture loss. The authors concluded that the effectiveness of fiber-reinforced concrete is directly dependent on proper curing, as fiber bonding and crack control rely on a fully hydrated matrix.

3.6 Muhammad Auwal Ibrahim et.al (2024): Ibrahim's study outlines that water curing produces the highest compressive and tensile strength due to optimal hydration conditions. Although alternative curing approaches such as steam curing accelerate early strength, they may compromise long-term durability. Hence, choosing a curing method should depend on both performance requirements and environmental constraints. The authors suggest adopting a balanced framework that considers material behavior, project timeline, and sustainability.

4. METHODOLOGY

The methodology involves preparing and testing concrete mixes incorporating hybrid fibers and different curing techniques to evaluate performance improvements. Initially, materials such as cement, fine aggregate, coarse aggregate, water, and fibers (polypropylene, coir, and bamboo) are selected as per standard specifications. Concrete of grade M25 is designed and mixed with varying proportions of hybrid fibers to achieve uniform distribution. Test specimens, including cubes, cylinders, and beams, are cast and compacted properly. After casting, specimens are subjected to different curing methods such as ponding, membrane curing, and wet covering to study the effect of curing conditions. The specimens are then tested at different ages (7, 14, and 28 days) for compressive strength, flexural strength, and split tensile strength. The results obtained are analyzed and compared with conventional concrete to determine the effectiveness of hybrid fibers and optimized curing techniques in enhancing the performance of concrete

5. RESULTS

5.1 Test on Cement:

We perform test on cement like fineness test, standard consistency test, initial and final setting time, soundness test.

Test Name	Results	Standard Requirements
Fineness test	4.63%	<10%
Standard consistency test	28%	26-33%
Initial	35min	≥ 30 min
Final setting time	520min	≤ 600 min
Soundness test	1.9mm	≤ 10 mm

Table 5.1: Test Results of Cement

Analysis:

- All cement properties are within permissible limits
- Cement is suitable for concrete production
- Proper setting time ensures adequate workability and strength development

5.2 Test on Aggregate:

Property	Value	Limit
Specific Gravity	2.70	—
Water Absorption	0.8%	< 2%
Impact Value	21.6%	< 30%
Abrasion Value	24%	< 30%
Flakiness Index	15%	< 25%
Elongation Index	16%	< 25%

Table 5.2: Test Results of Aggregate

Analysis:

- All values are within acceptable limits.
- Aggregates are strong and durable.
- Suitable for structural concrete.

5.3 Test on Concrete:

5.3.1 Slump Values of Concrete:

The workability of fresh concrete was evaluated using the slump test in accordance with IS 1199.
The test provides an indication of the ease with which concrete can be mixed, placed, and compacted.

Mix Type	Slump Value (mm)	Workability
Normal Concrete	80 mm	Medium
HFRC	55 mm	Low

Table 5.3: Slump Values

Observations:

- Normal concrete exhibited higher workability.
- HFRC showed reduced slump value.
- Concrete became comparatively stiff after fibre addition.

Analysis:

The reduction in slump value in HFRC is due to the presence of fibres, which increase internal resistance and reduce the flowability of concrete.
The slump value of 80 mm for normal concrete indicates good workability, whereas the value of 55 mm for HFRC indicates low workability.

However, the obtained slump value for HFRC is still acceptable for manual compaction with proper handling.

5.3.2: Compression Test Results:

Compressive strength is the most important property of concrete, which determines its ability to resist compressive loads. It is used to assess the quality and structural performance of concrete.
The test was conducted on cube specimens in accordance with IS 516.

Apparatus Used:

Compression Testing Machine (CTM).

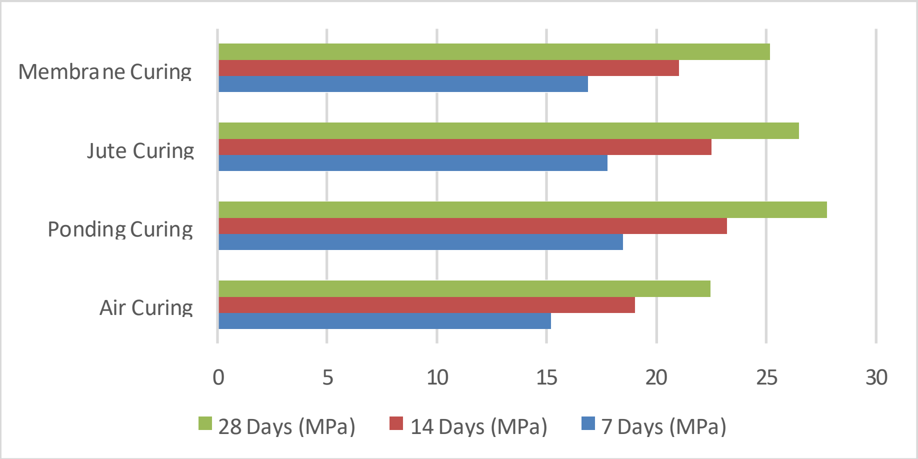
Specimen Details:

- Type: Conventional concrete.
- Shape: Cube.
- Size: 150 mm × 150 mm × 150 mm.
- Number of specimens: 12.
- Curing periods: 7, 14, and 28 days.

Figure5.1: Compression Testing Machine (CTM).

Curing Method	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
Air Curing	15.2	19.0	22.5
Ponding Curing	18.5	23.2	27.8
Jute Curing	17.8	22.5	26.5
Membrane Curing	16.9	21.0	25.2

Table5.4: Compression Test Results



Graph5.1: Compression Test Results

Observations:

- Strength increases with curing age for all methods.
- Ponding curing shows highest strength at all ages.
- Air curing gives the lowest strength.
- Jute curing performs close to ponding curing.
- Membrane curing shows moderate performance.

Analysis of Results:

The strength variation is mainly due to the availability of moisture during curing:

- **Ponding curing** provides continuous water → maximum hydration → highest strength.
- **Air curing** leads to moisture loss → incomplete hydration → lowest strength.
- **Jute curing** maintains surface moisture → good strength development.
- **Membrane curing** reduces evaporation → moderate strength

Strength Growth Trend:

- Rapid strength gain from 7 to 14 days.
- Gradual increase from 14 to 28 days.

Method	Strength	Efficiency	Method	Strength
Ponding	Highest	Best	Ponding	Highest
Jute	High	Good	Jute	High
Membrane	Medium	Moderate	Membrane	Medium
Air	Low	Poor	Air	Low

Table5.5: Comparison Table

5.3.3: Flexural Strength Test Results:

Flexural strength test was conducted to determine the bending resistance of concrete. This test is particularly important for evaluating the performance of Hybrid Fibre Reinforced Concrete (HFRC), as fibres mainly improve crack resistance and ductility.
The test was carried out as per IS 516**.**

Specimen Details:

- Shape: Beam
- Size: 150 mm × 150 mm × 500 mm
- Number of specimens: 3

Types of Beams:

1. **Conventional Concrete Beam** (without fibres)
2. **HFRC Beam-1** (Steel fibre + Coconut fibre + Micro fibre)
3. **HFRC Beam-2** (Bamboo fibre + Polypropylene fibre + Micro fibre)

Apparatus Used:

- Flexural Testing Machine / Universal Testing Machine (UTM)
- Beam moulds
- Measuring scale
- Curing tank

Formula:

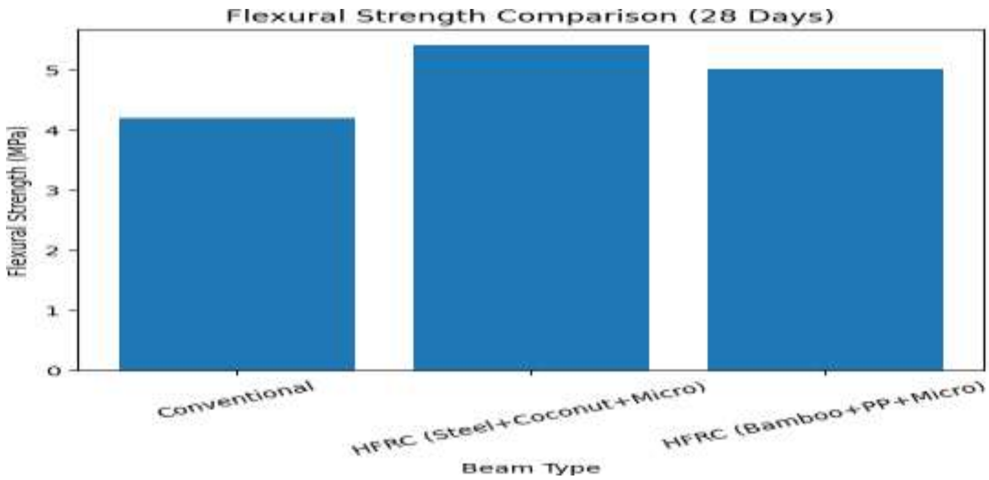
$$f_r = \frac{3PL}{2bd^2}$$

Where:

- f_r= Flexural strength (MPa)
- P= Load at failure (N)
- L= Span length (mm)
- b= Width of beam (mm)
- d= Depth of beam (mm)

Beam Type	Fiber Combination	Flexural Strength (MPa)
Conventional Concrete	No fiber	4.2 MPa
HFRC Beam-1	Steel + Coconut + Micro	5.4 MPa
HFRC Beam-2	Bamboo + Polypropylene + Micro	5.0 MPa

Table5.6: Flexural Strength Test Results



Graph5.2: Flexural Strength Test Results

Observations:

- HFRC beams showed higher flexural strength compared to conventional concrete.
- Beam with steel fibre combination showed maximum strength.
- Crack formation was gradual in HFRC beams.
- Conventional beam fails suddenly.

Analysis of Results:

Flexural strength increased by approximately:

- **~28%** (Steel + Coconut + Micro)
- **~19%** (Bamboo + PP + Micro)

Combined effect results in improved bending performance.

Beam Type	Behavior
Conventional	Brittle failure
HFRC (Steel mix)	Highest strength + ductile
HFRC (Bamboo mix)	Moderate strength + ductile

Table5.7: Comparison Table

6. CONCLUSION

From the experimental study, it can be concluded that the incorporation of hybrid fibers along with proper curing techniques significantly enhances the performance of concrete. The addition of fibers such as polypropylene, coir, and bamboo improves the mechanical properties by increasing compressive strength, flexural strength, and tensile strength, while also enhancing ductility and resistance to cracking. Hybrid fiber combinations were found to be more effective than single fiber usage due to their ability to control both micro and macro cracks.

Furthermore, curing methods play a crucial role in strength development. Water-based curing methods, especially ponding and wet covering, resulted in higher strength compared to air and membrane curing, as they ensure adequate moisture for proper hydration of cement. The combined effect of hybrid fibers and optimized curing leads to improved durability, reduced brittleness, and better overall structural performance.

Thus, the study confirms that the use of hybrid fibers along with efficient curing practices is a practical and effective approach for producing high-performance and durable concrete. However, while fibers enhance many properties, they should be used as a supplement rather than a complete replacement for conventional reinforcement in structural applications.

Another important observation from the study is the change in failure behavior. Conventional concrete exhibited brittle failure with sudden crack formation, whereas HFRC specimens showed gradual crack development and ductile behavior. The fibres acted as crack arresters, holding the concrete matrix together even after initial cracking, thereby preventing sudden failure and improving structural safety.

The workability of concrete was found to decrease with the addition of fibres due to increased internal resistance; however, it remained within acceptable limits for practical applications. The study also highlighted the importance of proper curing, as specimens subjected to adequate curing conditions showed better strength development compared to improperly cured specimens. The synergistic interaction of diverse fiber types facilitates a substantial enhancement in mechanical properties, particularly in terms of tensile strength, flexural performance, ductility, and resistance to crack initiation and propagation. Simultaneously, the implementation of controlled and efficient curing regimes ensures optimal hydration, leading to a refined microstructure and improved durability characteristics.

Furthermore, this integrated approach contributes to the mitigation of structural deterioration caused by environmental and loading conditions, thereby extending the service life of concrete structures. The combined effect not only elevates the functional performance of concrete but also promotes sustainability by reducing maintenance requirements and resource consumption over time.
Thus, the strategic utilization of hybrid fibers alongside advanced curing techniques emerges as a highly promising and transformative solution in modern construction practices, paving the way for the development of resilient, durable, and high-performance infrastructure systems.

In conclusion, the use of hybrid fibres in concrete not only improves strength but also enhances post-cracking behavior, toughness, and durability. The results indicate that HFRC can be effectively used in structural elements subjected to bending and cracking, such as beams, pavements, and slabs. Therefore, hybrid fiber reinforced concrete presents a promising and efficient alternative to conventional concrete in modern construction practices.

7. FUTURE SCOPE

1. Study can be extended by using different percentages of fibres to determine the optimum fibre content.

2. Effect of fibres on compressive strength, tensile strength, and durability can be investigated in detail.

3. Use of other natural fibres (jute, sisal, coir, etc.) can be explored for sustainable construction.

4. Long-term durability studies such as chemical attack, sulphate attack, and corrosion resistance can be carried out.

5. Behaviors of HFRC under extreme conditions like fire and high temperature can be studied.

6. Use of industrial waste materials like fly ash, silica fume, and GGBS along with fibres can be investigated.

7. Advanced properties such as impact resistance, fatigue behaviors, and fracture mechanics can be analysed.

8. Application of HFRC in real structures like pavements, bridges, and industrial floors can be studied.

9. Use of admixtures (superplasticizers) to improve workability of fibre reinforced concrete can be explored.

10. Large-scale field studies and cost analysis can be performed to check practical feasibility.

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