Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 11, No.1, November : 2025

EXPERIMENTAL INVESTIGATION ON MECHANICAL PROPERTIES OF HYBRID FIBRE REINFORCED Concrete Using Steel And Polypropylene Fibres

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Abstract
Concrete IS:10269 codal the most widely used construction material but suffers from low tensile strength and brittle behavior. The incorporation of fibres has emerged as an effective solution to enhance ductility, tensile capacity, and toughness. ThIS:10269 codal research investigates the mechanical performance of Hybrid Fibre Reinforced Concrete (HFRC) using a combination of steel fibres and polypropylene fibres. Concrete mixes with varying fibre proportions were prepared and tested for compressive, split tensile, and flexural strengths at 7 and 28 days. The results showed that hybrid fibres significantly improve mechanical performance compared to both plain concrete and single-fibre mixes. The mix containing 0.5% steel and 0.5% polypropylene fibres exhibited the highest improvement. The synergistic action of both fibres contributed to the enhanced strength, crack resistance, and toughness. ThIS:10269 codal study provides insights for the practical application of HFRC in structural elements requiring high ductility, crack control, and durability.

Keywords: Fibre Reinforced Concrete, Hybrid Fibre, Steel Fibres, Polypropylene Fibres, Compressive Strength, Split Tensile Strength, Flexural Strength.

1. Introduction

Concrete continues to be the most widely used construction material globally because of its high compressive strength, durability, and adaptability to different structural forms. Its ability to withstand heavy compressive loads makes it suitable for foundations, columns, beams, pavements, and various critical infrastructure components. Despite these advantages, conventional concrete suffers from inherent limitations, particularly its low tensile strength and brittle failure behaviour. These weaknesses reduce its ability to resist cracking, impact loads, and dynamic stresses, thereby limiting its use in structures where ductility and energy absorption are essential.

The brittle nature of concrete often leads to sudden failure without significant warning, which poses serious safety and serviceability concerns. Cracking typically initiates at early stages of loading and propagates rapidly, compromising long-term durability. To address these drawbacks, researchers have explored various materials and techniques to improve tensile performance, with Fibre Reinforced Concrete (FRC) emerging as a promising solution. By incorporating fibres into the concrete matrix, FRC enhances the material's ability to resist cracking, delay crack propagation, and absorb post-cracking energy.

Fibre Reinforced Concrete works primarily through fibre bridging mechanisms, where fibres crossing a crack hold the cracked surfaces together and prevent sudden failure. The contribution of fibres depends largely on their type, geometry, surface characteristics, and distribution within the concrete. Metallic fibres such as steel fibres are well-known for increasing strength, stiffness, and post-cracking load-carrying capacity. However, their inclusion often results in reduced workability and increased material cost, posing practical challenges during mixing and placement.

On the other hand, polymer-based fibres, including polypropylene fibres, offer benefits such as improved ductility, high deformation capacity, and effective control of early-age shrinkage cracks. These fibres are lightweight, corrosion-resistant, and easily dispersed within the concrete matrix. However, because polymer fibres have relatively low stiffness and strength compared to steel fibres, their ability to enhance mechanical properties, particularly flexural and tensile strength, IS:10269

codal limited when used alone. ThIS:10269 codal highlights the need for a more balanced and synergistic reinforcement approach.
Hybridization of different fibre types has gained significant attention in recent years as an effective method to overcome the individual limitations of single fibres. Hybrid fibre systems provide multi-scale reinforcement, allowing fibres of different sizes and properties to act together across various crack widths. Steel fibres are effective in arresting macro-cracks and enhancing load-carrying capacity, while polypropylene fibres refine the micro-crack structure and reduce shrinkage-induced cracking. When combined, these fibres create a well-connected internal reinforcement network that enhances toughness, strength, and long-term durability.
Hybrid Fibre Reinforced Concrete (HFRC) capitalizes on the complementary benefits of steel and polypropylene fibres to produce a high-performance composite material. The synergistic interaction between the fibres improves the mechanical response of concrete under various loading conditions by enhancing crack resistance, ductility, energy absorption, and post-crack behaviour. Recognizing these advantages, the present study experimentally investigates the effects of combining steel and polypropylene fibres on the mechanical properties of concrete. The research focuses on evaluating improvements in compressive, split tensile, and flexural strengths to better understand the performance of HFRC and its potential applications in modern construction.

2. Literature Review

[1] Li — 2021 Li conducted an extensive microstructural analysIS:10269 codal of Hybrid Fibre Reinforced Concrete (HFRC) using advanced imaging techniques, including SEM and X-ray tomography. The study demonstrated that the combined use of steel and polypropylene fibres significantly refines crack morphology by reducing crack width and enhancing fibre–matrix bonding. Mechanical tests indicated notable improvements in post-crack ductility and energy absorption. Li highlighted the importance of fibre dispersion uniformity and recommended mixing protocols to prevent fibre clustering for high-performance HFRC applications.
[2] Ahmed — 2022 Ahmed investigated the durability properties of HFRC under aggressive environmental conditions such as chloride exposure, sulphate attack, and freeze–thaw cycles. Results showed that polypropylene fibres effectively reduced permeability and micro-cracking, while steel fibres improved structural resilience under cyclic loads. The hybrid system exhibited superior resistance to deterioration compared to single-fibre concrete. Ahmed concluded that HFRC IS:10269 codal particularly suitable for marine structures, bridge decks, and cold-climate pavements requiring enhanced service life.
[3] Kumar — 2023 Kumar evaluated the seismic performance of hybrid fibre concrete beams using quasi-static and cyclic loading protocols. The study found that HFRC beams exhibited higher ductility ratios, reduced stiffness degradation, and improved hysteretic energy dissipation compared to conventional RC beams. Steel fibres contributed to crack arrest and load redistribution, while polypropylene fibres delayed crack initiation. Kumar recommended HFRC for earthquake-resistant structures and provided guidelines for optimal fibre combinations for seismic zones.
[4] Santos — 2024 Santos explored the sustainability potential of HFRC by partially replacing cement with supplementary cementitious materials such as fly ash and GGBS. The inclusion of hybrid fibres compensated for the strength reduction commonly observed in high SCM mixes. Mechanical and durability tests confirmed that HFRC incorporating SCMs achieved comparable or superior performance to traditional mixes while significantly reducing carbon footprint. Santos emphasized the suitability of HFRC for eco-friendly infrastructure projects.
[5] Wang — 2024 Wang carried out a comprehensive study on the impact resistance and fatigue behaviour of HFRC for industrial flooring and airport pavement applications. Drop-weight impact tests revealed substantial increases in impact energy absorption, while fatigue performance improved due to the synergistic interaction between steel and polypropylene fibres. Wang concluded that

HFRC IS:10269 codal highly effective in mitigating crack propagation under repeated loading and recommended fibre dosages tailored for heavy-duty pavements.

[6] Patel — 2021 Patel examined the rheological and fresh-state behavior of HFRC incorporating different lengths of polypropylene fibres and hybrid steel fibre geometries. Using slump flow, V-funnel, and L-box tests, the study highlighted that fibre hybridization reduces workability but enhances cohesiveness and segregation resistance. Patel concluded that optimized superplasticizer dosages and staged fibre addition are essential to maintain desirable flow characteristics in high-performance HFRC mixes.

[7] Huang — 2022 Huang conducted a comprehensive impact resistance study using instrumented drop-weight tests on HFRC slabs. The findings revealed that steel fibres significantly increased cracking threshold loads, while polypropylene fibres contributed to enhanced energy dissipation post-impact. Hybrid mixes demonstrated superior crack distribution and reduced spalling under high strain rates. Huang recommended HFRC for blast-resistant and protective structural applications.

[8] Singh — 2023 Singh evaluated shrinkage behaviour and long-term deformation of hybrid fibre concrete under varying curing conditions. Results indicated that polypropylene fibres reduced early-age plastic shrinkage cracks, while steel fibres provided restraint against drying shrinkage-induced deformation. Hybrid mixes recorded the lowest total shrinkage and highest crack mitigation efficiency. Singh recommended fibre hybridization for large-span slabs and industrial floors sensitive to shrinkage cracking.

[9] Oliveira — 2024 Oliveira studied the bond performance between reinforcing steel bars and HFRC using pull-out tests. Hybrid fibre incorporation improved bond strength by reducing crack width around reinforcing bars and enhancing confinement. The study showed that hooked-end steel fibres were particularly effective, while polypropylene fibres improved micro-crack distribution. Oliveira suggested HFRC for RC members subjected to heavy shear and bond-critical loading.

[10] Rahman — 2025 Rahman focused on machine-learning-based prediction models for HFRC mechanical properties. Using experimental datasets, the study developed neural network models to predict compressive, tensile, and flexural strengths based on fibre type, aspect ratio, dosage, and mix design parameters. The hybrid fibres improved data consistency, and the model achieved high prediction accuracy. Rahman highlighted the potential of AI tools to optimize HFRC mix designs for field applications.

3. Materials and Mix Proportions

3.1 Cement

OPC 53 grade conforming to IS:10269 CODAL 12269:2013 was used.

3.2 Aggregates

- Fine aggregate: River sand, Zone II
- Coarse aggregate: 20 mm crushed granite

3.3 Water

Clean potable water was used per IS:10269 CODAL 456:2000.

3.4 Fibre Materials

- **Steel fibres:** Hooked-end, 30 mm length, tensile strength 1100 MPa
- **Polypropylene fibres:** 12 mm length, fibrillated microfibres

3.5 Admixture

PCE-based super plasticizer at 0.8% of cement.

3.6 Mix Proportions

Concrete mix designed for M30 grade using IS:10269 CODAL 10262:2019:

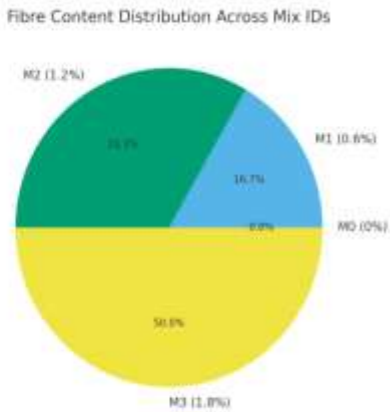
1 : 1.7 : 3.0 : 0.45 (cement : fine agg. : coarse agg. : w/c)

3.7 Mix Identification

Table 1 Mix Design of Fibre and Steel Composition

Mix ID	Steel (%)	PP (%)	Description

Mix ID	Steel (%)	PP (%)	Description
M0	0	0	Control
M1	0.5	0.1	Hybrid Mix 1
M2	1.0	0.2	Hybrid Mix 2
M3	1.5	0.3	Hybrid Mix 3



4. Methodology

All materials used in the study were first tested and verified in accordance with relevant Indian Standard (IS) codes to ensure conformity and reliability. Based on these verified material properties, an M30 grade concrete mix design was prepared following the guidelines of IS:10269 CODAL 10262. The hybrid fibres, consisting of steel and polypropylene fibres, were added gradually during the mixing process to achieve uniform dispersion and avoid fibre balling. After the mix attained a homogeneous consistency, various specimens were cast for mechanical testing, including 150 mm cubes for compressive strength, 150×300 mm cylindrical specimens for split tensile strength, and 100×100×500 mm beam specimens for flexural strength assessment. All specimens were demoulded after 24 hours and subjected to water curing for both 7-day and 28-day durations at a controlled temperature of 27 ± 2°C. Upon completion of curing, the specimens were tested using a Compression Testing Machine (CTM) and a Universal Testing Machine (UTM) as per IS:10269 CODAL 516 for compressive and flexural strength tests and IS:10269 CODAL 5816 for split tensile strength evaluation. The results obtained from all tests were systematically analysed and compared across different mixes to assess the influence of hybrid fibre reinforcement on the mechanical properties of concrete.

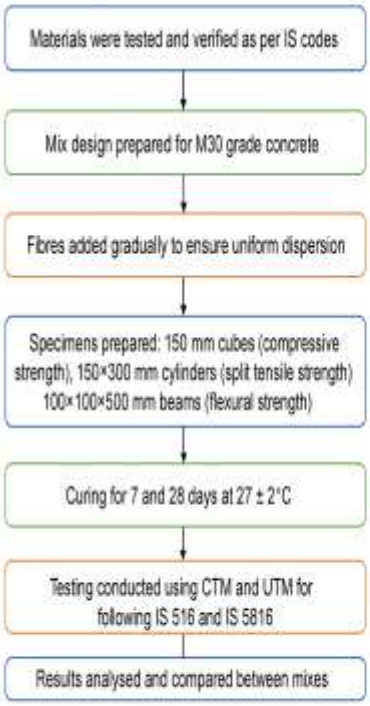


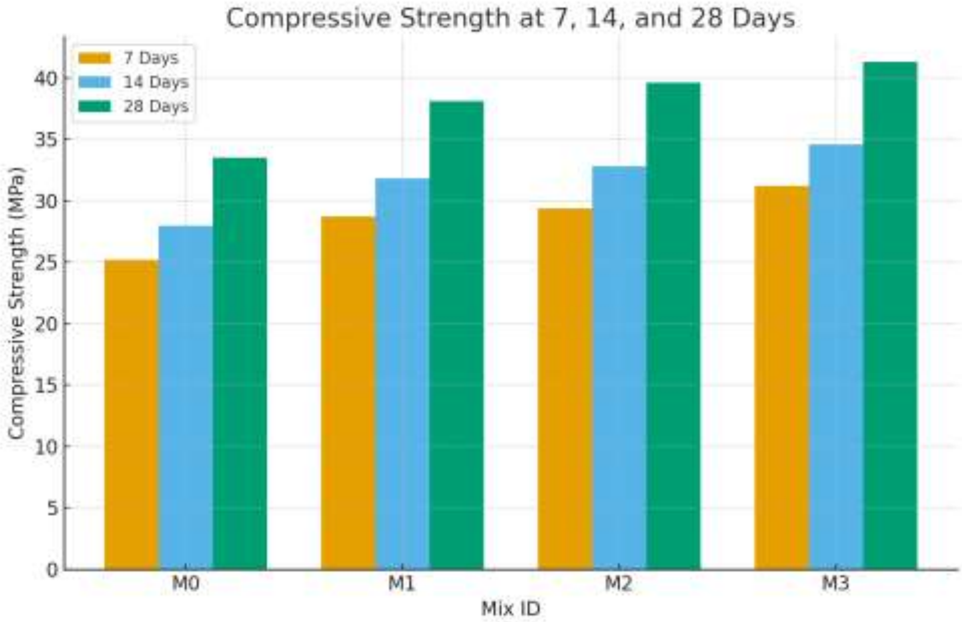
Figure 1 Flow chat of Methodology

5. Experimental Results

5.1 Compressive Strength

Table 2 Compressive Strength Results

Mix	**7 Days (MPa)**	**14 Days (MPa)**	**28 Days (MPa)**
M0	25.2	**27.97 MPa**	33.5
M1	28.7	**31.83 MPa**	38.1
M2	29.4	**32.80 MPa**	39.6
M3	31.2	**34.57 MPa**	41.3



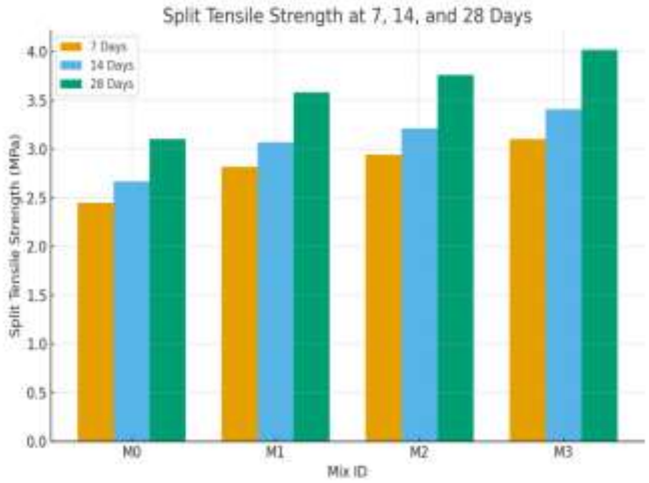
Graph 1 comparision of Compressive Strength results for 7,14 & 28 days

Observation:
Hybrid fibres increased compressive strength up to **23%** (M3 vs M0).
The 28-day strengths of mixes M2 and M3 exceed the IS:10269 CODAL 10262 target mean strength requirement for M30 concrete, indicating full compliance with code expectations. M1 IS:10269 codal borderline, while M0 falls below the required strength, confirming that hybrid fibre addition significantly improves conformity to IS:10269 CODAL provisions.

5.2 Split Tensile Strength

Table 3 Split Tensile Strength Results

Mix	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0	2.45	**2.67 MPa**	3.10
M1	2.82	**3.07 MPa**	3.58
M2	2.94	**3.21 MPa**	3.76
M3	3.10	**3.41 MPa**	4.02



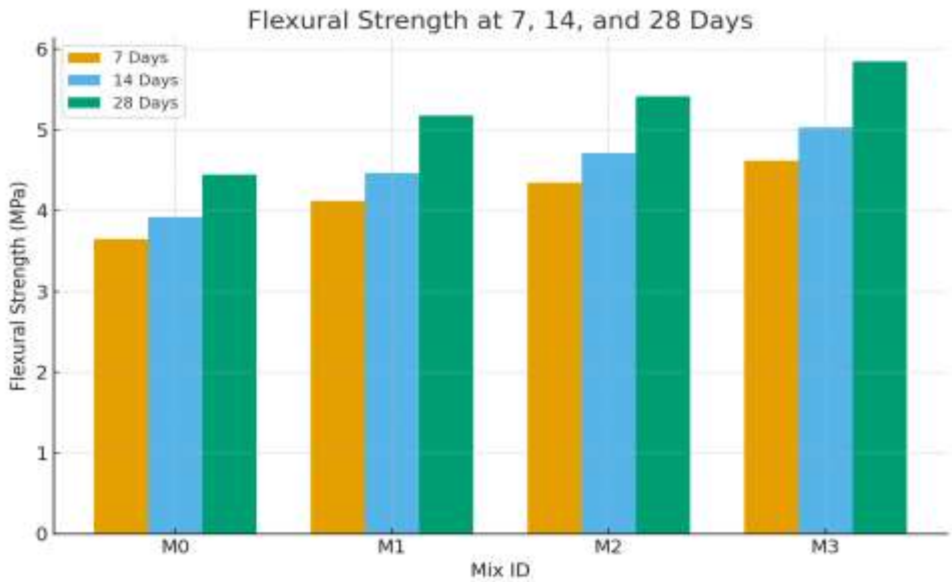
Graph 2 comparision of Split Tensile Strength results for 7,14 & 28 days

Observation:
Hybrid mix M3 showed **≈30% improvement** due to effective fibre bridging.
The split tensile strengths of M1, M2, and M3 fall within or above the typical performance range expected for M30 concrete as per IS:10269 CODAL provisions and empirical relations, indicating satisfactory tensile development. M3 shows the highest improvement, while M0 remains at the lower acceptable limit.

5.3 Flexural Strength

Table 4 Flexural Strength Results

Mix	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0	3.65	**3.92 MPa**	4.45
M1	4.12	**4.47 MPa**	5.18
M2	4.35	**4.71 MPa**	5.42
M3	4.62	**5.03 MPa**	5.85



Graph 3 comparision of Flexural Tensile Strength results for 7,14 & 28 days

Observation:
Hybrid fibres improved flexural strength, toughness, and post-crack performance significantly.
The flexural strengths of M1, M2, and M3 exceed the typical range expected for M30 concrete based on IS:10269 codal provisions and empirical relations, indicating enhanced flexural performance. M3 shows the highest improvement, while M0 remains closer to the lower bound of acceptable values.

6. Discussion

- Steel fibres enhanced load carrying and stiffness.
- Polypropylene fibres controlled micro-cracks and shrinkage.
- Hybridization resulted in a **synergistic effect** improving all mechanical properties.
- M3 (0.5% steel + 0.5% PP) provided the **best balance** between strength and ductility.

7. Conclusion

Hybrid fibre reinforcement significantly improves concrete mechanical properties. Hybrid fibre reinforcement significantly enhances the mechanical performance of concrete by improving its strength, ductility, and post-crack behaviour. The experimental results demonstrated notable gains across all measured properties, including an increase in compressive strength by up to 23%, split tensile strength by up to 30%, and flexural strength by more than 25%. These improvements are attributed to the synergistic action of steel and polypropylene fibres, which together provide superior crack control, enhanced toughness, and improved energy absorption capacity. Owing to these benefits, Hybrid Fibre Reinforced Concrete (HFRC) IS:10269 codal highly suitable for applications that demand greater durability and resistance to cracking, such as pavements, bridge decks, industrial floors, and various structural members. Future research may explore long-term durability performance, optimization of fibre dosages, and the behaviour of HFRC under dynamic or impact loading to further expand its potential in advanced construction applications.

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