Experimental Investigation of Mechanical Properties and Durability Characteristics of Polypropylene Fibre Reinforced Concrete

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Abstract

This experimental study investigates the mechanical properties and durability characteristics of M30 grade concrete reinforced with polypropylene (PP) fibres, which belong to the broader category of polymers and composites used in modern construction materials. The research determines the optimum fibre dosage by testing varying percentages (0.5%, 1.0%, 1.5%, 2.0%, and 2.5% by volume) and evaluates comprehensive mechanical properties including compressive strength, split tensile strength, flexural strength, and modulus of elasticity. Non-destructive testing methods including rebound hammer and ultrasonic pulse velocity tests were employed alongside durability assessments through water absorption and sorptivity tests. Results indicate that 1.5% PP fibre dosage yields optimal performance, showing compressive strength improvements of 8.08% at 7 days and 6.48% at 28 days compared to control concrete. Split tensile strength increased by 13.86% at 28 days, while flexural strength improved by 11.87% at 7 days. Durability parameters demonstrated superior performance with 25–33% reduction in water absorption. The study confirms that PP fibre reinforcement, as an effective polymer composite additive, significantly enhances both mechanical properties and long-term durability of concrete structures.

Keywords: Polymers and composites, Polypropylene fibres, Fibre reinforced concrete, Mechanical properties, Durability, Compressive strength, Non-destructive testing

1. INTRODUCTION

Concrete remains the most widely used construction material globally due to its versatility, strength, and durability. However, conventional concrete exhibits inherent weaknesses including low tensile strength, brittleness, and susceptibility to cracking from plastic shrinkage and temperature variations. These limitations necessitate the development of enhanced concrete systems that address these deficiencies while maintaining economic viability.

Fibre reinforced concrete (FRC) has emerged as an innovative solution, incorporating discrete fibres uniformly distributed throughout the concrete matrix. Among various fibre types, polypropylene fibres have gained significant attention due to their cost-effectiveness, chemical resistance, and ability to control plastic shrinkage cracking. Polypropylene fibres are synthetic polymeric fibres with excellent tensile strength, low elastic modulus, and superior resistance to alkaline environments characteristic of concrete.

The addition of polypropylene fibres addresses multiple concrete deficiencies: reduction of plastic shrinkage cracking, improved crack control, enhanced ductility, increased impact resistance, and reduced permeability. Unlike steel fibres, polypropylene fibres are corrosion-free, lighter, and exhibit superior chemical resistance to acids and alkalis. These properties make PP fibre reinforced concrete particularly suitable for applications requiring enhanced durability and crack control.

2. REVIEW OF LITERATURE

2.1 Historical Development

The concept of fibre reinforcement in construction materials dates back over 4500 years, with ancient civilizations using straw in mud bricks. Modern development of fibre reinforced concrete accelerated in the

1960s, when engineers recognized the potential of discontinuous fibres to address concrete's brittleness and low tensile strength. Polypropylene fibres, developed through petrochemical and textile industries, emerged as viable reinforcement materials due to their high tensile strength despite low elastic modulus.

2.2 Recent Research Findings

Thipparthi et al. (2022) demonstrated that 1% PP fibre addition improved compressive strength by 29.8%, flexural strength by 4.92%, and splitting tensile strength by 3.21%. Their work emphasized the role of superplasticizers in achieving better workability and uniformity in fibre distribution. Blazya and Blazy (2021) highlighted PP fibres' crucial role in reducing plastic shrinkage cracks while noting that excessive fibre content can deteriorate workability, emphasizing the importance of optimal dosage determination.

Wang et al. (2021) reviewed durability aspects, confirming that PP fibres reduce water transmission and harmful media penetration, though noting that fibre spreading and cement bonding present challenges. They suggested surface modification using nano-materials (nano-SiO_2 and nano-$CaCO_3$) to enhance bond performance. Kilmartin-Lynch et al. (2021) explored sustainable applications, demonstrating that 0.20% volume of shredded face mask fibres (polypropylene-based) increased mechanical properties while addressing pandemic waste management.

Yuan and Jia (2020) compared glass and polypropylene fibre reinforced concrete, finding that water/binder ratio significantly affects optimal fibre content. At 0.30 water/binder ratio, 1.35% glass fibre reduced water absorption from 3.49% to 1.99%, while 0.45% PP fibre reduced it to 3.12%. Chaturvedi and Singh (2020) investigated hybrid systems combining steel and polypropylene fibres, reporting enhanced fire-resistant capability without affecting elastic modulus.

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Cement

Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269 was used. The cement exhibited specific gravity of 3.13, normal consistency of 31%, fineness of 6%, initial setting time of 105 minutes, and final setting time of 440 minutes.

3.1.2 Aggregates

Fine aggregate (river sand) conforming to IS 383-2016, Zone-II classification, with specific gravity 2.65, fineness modulus 2.74, and bulk density 1610 kg/m³ was utilized. Coarse aggregate consisted of crushed granite stone with nominal maximum size 20mm, comprising 60% 20mm and 40% 12.5mm fractions. Properties included specific gravity 2.61, water absorption 0.23%, fineness modulus 7.15, and bulk densities of 1430 kg/m³ (20mm) and 1550 kg/m³ (12mm).

3.1.3 Water and Admixture

Potable tap water with pH 7.76, chloride content 160 mg/l, and sulphate content 110 mg/l was used for mixing and curing. Conplast SP430, a sulphonated naphthalene polymer-based superplasticizer with specific gravity 1.220-1.225, was incorporated to enhance workability while reducing water content.

3.1.4 Polypropylene Fibre

Bajaj Fibre Guard polypropylene fibres with fibrillated design were employed. Key properties include: 100% virgin polypropylene material, diameter 30-50 micron, cut lengths 20/12/6mm, elongation 10-15%, specific gravity 0.91, melting point 160-165°C, aspect ratio 400-666.67, with excellent alkali and acid resistance and nil water absorption.

3.2 Mix Design

M30 grade concrete was designed according to IS 10262:2019 with cement:fine aggregate:coarse aggregate ratio optimized for target strength. The mix incorporated superplasticizer at 0.5-2.0 liters per 100 kg cement to maintain workability with fibre addition.

4. RESULTS AND DISCUSSION

4.1 Optimum Dosage Determination

Table 2: Compressive Strength for Various Fibre Percentages

Fibre Percentage	7 Days Strength (N/mm²)	28 Days Strength (N/mm²)
0.50%	22.58	33.47
1.00%	24.64	36.71
1.50%	27.67	39.37
2.00%	25.64	37.12
2.50%	22.49	34.56

Results demonstrate that 1.5% PP fibre content yields maximum compressive strength at both 7 and 28 days, establishing this as the optimum dosage. Beyond 1.5%, strength decreases due to inadequate fibre dispersion and increased void content, consistent with findings from previous research. This optimum dosage was used for all subsequent testing.

4.2 Compressive Strength Development

Table 3: Comparative Compressive Strength (N/mm²)

Curing Age (days)	Control Concrete	1.5% PP FRC	Improvement (%)
3	21.1	22.67	7.44
7	25.61	27.67	8.08
28	39.37	41.92	6.48
56	41.93	43.40	3.51
90	47.43	49.67	4.72

The data reveals consistent strength improvement with PP fibre addition across all curing ages. Maximum percentage improvement (8.08%) occurs at 7 days, indicating PP fibres' effectiveness in early-age crack control and matrix strengthening. At 28 days, FRC achieved 109.59% of design strength compared to 102% for control concrete, demonstrating superior performance. The continued strength gain through 90 days suggests ongoing hydration benefits from improved microstructure.

4.3 Concrete Core Test Results

Table 4: Core Test Compressive Strength Comparison (N/mm²)

Curing Age (days)	Control Concrete	1.5% PP FRC	Improvement (%)
7	24.88	26.93	8.24
28	38.76	41.38	6.76
56	41.54	42.89	3.25
90	47.25	49.32	4.38

Core test results validate cube test findings, confirming PP FRC's superior in-situ strength. The slightly lower absolute values compared to cube tests are attributed to extraction damage and size effects, consistent with standard practice. Strong correlation between cube and core results across all ages confirms reliability of both testing methods.

4.4 Split Tensile Strength

Table 5: Split Tensile Strength Results (N/mm²)

Curing Age (days)	Control Concrete	1.5% PP FRC	Improvement (%)
7	2.77	2.90	4.69
28	3.03	3.45	13.86
56	3.17	3.81	20.19
90	3.92	4.12	5.10

Split tensile strength shows remarkable improvement, particularly at 56 days (20.19%), demonstrating PP fibres' effectiveness in crack bridging and tensile stress distribution. The substantial 28-day improvement (13.86%)

indicates fibres' role in preventing crack propagation under tensile loading. This enhanced tensile performance translates to improved crack control in structural applications.

4.5 Flexural Strength

Table 6: Flexural Strength Comparison (N/mm²)

Curing Age (days)	Control Concrete	1.5% PP FRC	Improvement (%)
7	5.56	6.22	11.87
28	6.69	7.13	6.58

Flexural strength improvements confirm PP fibres' effectiveness in bending applications. The 11.87% increase at 7 days demonstrates early-age performance benefits, crucial for rapid construction scenarios. Enhanced flexural capacity results from fibres' crack-arresting mechanism and improved ductility.

5. CONCLUSIONS

Based on comprehensive experimental investigation, the following conclusions are drawn:

1. **Optimum Dosage:** 1.5% polypropylene fibre content by volume represents the optimum dosage for M30 grade concrete, yielding maximum mechanical properties and durability enhancement.

2. **Compressive Strength:** PP FRC demonstrates 6.48-8.08% compressive strength improvement over control concrete, with consistent enhancement across all curing ages from 3 to 90 days.

3. **Tensile Performance:** Split tensile strength shows remarkable improvement of 13.86% at 28 days and 20.19% at 56 days, demonstrating PP fibres' exceptional effectiveness in tensile stress applications.

4. **Flexural Capacity:** Flexural strength increases by 11.87% at 7 days and 6.58% at 28 days, indicating enhanced bending resistance suitable for structural applications.

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