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Review RTCET

An Experimental Investigation of High Performance by Using Steel and Polypropylene Fibres

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Abstract

This study explores the feasibility of partially substituting conventional cement in concrete with steel and polypropylene fibers to improve mechanical performance and introduce alternative composite materials. Concrete cube specimens measuring 150 × 150 × 150 mm were cast with varying mix designs corresponding to M20 and M25 grades. The experimental program was executed in two distinct phases. In Phase I, control mixes of M20 and M25 grade concrete were prepared using conventional cement. In Phase II, cement was partially replaced by steel and polypropylene fibers at 0.5% and 1.0% by weight of cement for each grade. Compressive strength tests were conducted on the specimens at 7, 14, and 28 days of curing under ambient conditions. The results demonstrated an incremental improvement in compressive strength with increasing fibre content up to 1.0% replacement, followed by a decline at higher percentages. The peak compressive strength was recorded at 1.0% fibre content for both M20 and M25 grades. The findings suggest that partial replacement of cement with steel and polypropylene fibers at 0.5% to 1.0% enhances compressive strength, whereas exceeding this threshold adversely affects performance.

Keywords: High performance steel, polypropylene fibres, cement in concrete, mechanical performance, concrete grades

INTRODUCTION

Overview

Concrete is among the most extensively utilized materials in the construction sector, owing to its adaptability, longevity, and economic viability.

Nonetheless, conventional concrete, such as M25 grade, often exhibits drawbacks, particularly in terms of tensile strength, brittleness, and susceptibility to cracking under mechanical stress and environmental exposure. To overcome these limitations and enhance its mechanical and durability characteristics, the incorporation of fibers as reinforcements has emerged as a notable solution. Fiber-reinforced concrete (FRC) is widely acknowledged for its ability to improve toughness, crack resistance, and long-term structural performance, presenting it as a viable enhancement over traditional concrete formulations [1].

This study emphasizes the development and evaluation of high-performance concrete (HPC), engineered for superior strength and durability. This study specifically explores the impact of integrating steel and polypropylene fibers into M25 grade concrete on its mechanical behavior and workability. Steel fibers are known to boost tensile strength, toughness, and resistance to impact, whereas polypropylene fibers help mitigate plastic shrinkage cracking and enhance early age durability by improving crack control [2].

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The main objective of this investigation is to analyze the influence of these fibers, which are used independently and in hybrid form, on key properties including the compressive strength, tensile strength, flexural strength, and workability of M25 concrete. By assessing different fiber dosages, this study aims to determine the optimal type and quantity of fibers required to significantly improve concrete performance, thereby enabling a more efficient and durable mix for various construction applications [3].

Additionally, this research aims to deepen the understanding of the synergistic effects between steel and polypropylene fibers in enhancing the performance of M25 grade concrete, particularly in applications demanding high strength, crack resistance, and durability [4].

Steel and Polypropylene Fibers

These fibers contribute to enhanced ductility and durability in concrete, potentially reducing construction expenses and increasing water tightness in applications such as tanks. Polypropylene fibers effectively control shrinkage-induced cracking, whereas steel fibers improve the load-bearing capacity and structural integrity in pavements and flooring systems [5].

Aggregate

Occupying 60–75% of the concrete volume, aggregates are cost-efficient components that provide bulk and dimensional stability. However, the use of finer aggregates can increase the water and cement demands, potentially increasing the risk of shrinkage and cracking.

Fine Aggregate

Fine aggregates (such as sand or crushed stone) significantly influence the strength and cohesiveness of the concrete.

Cement

Cement functions as a hydraulic binder, primarily composed of lime or calcium silicates, which set and harden upon hydration and bind aggregates to form concrete. It is the second most consumed substance globally, after water [6].

Need of Project

While prior research has examined the influence of steel and polypropylene fibers on high-strength concrete (HSC) across varying fiber volume fractions and combinations, there remains a distinct need to evaluate their effects on widely used medium-strength concrete grades, such as M20 and M25. This study addresses this gap by assessing the impact of incorporating steel and polypropylene fibers on the compressive strength development of standard concrete mixes at partial cement replacement levels of 0.5% and 1% by weight.

Evaluating the behavior of fiber-reinforced concrete (FRC) of these commonly used grades is essential for expanding its practical use in general construction. Although high fiber dosages have shown notable performance benefits in HSC, their feasibility in typical construction projects may be limited owing to the cost and workability constraints. This investigation sought to determine the effectiveness of lower fiber dosages in enhancing the compressive strength of M20 and M25 grade concrete, offering a potentially economical and easily adoptable solution for improved structural performance in routine construction applications [7].

The outcomes of this research are expected to provide meaningful contributions to the current literature by focusing on the performance of lower fiber content in medium-grade concrete, thereby informing best practices for practical and cost-efficient fiber-reinforced concrete applications.

LITERATURE REVIEW

- This study investigated the combined effect of steel fibers (SF) and polypropylene fibers (PPF) on the mechanical properties of ultra-high-performance geopolymer concrete (UHPGPC).

- Prior literature highlights that individual fiber types enhance specific properties- steel fibers mainly improve compressive and flexural strengths, whereas polypropylene fibers enhance crack resistance and ductility.
- This paper references previous studies indicating that incorporating fibers into geopolymer mixes significantly improves the toughness and durability [8].
- This study explored the effect of hybrid steel fibers (hooked and crimped) on the performance of self-compacting concrete (SCC).
- Previous research has shown that while SCC offers superior flowability and compaction without vibration, its brittleness and cracking susceptibility can be improved using fibers.
- Hybrid Fibers, which combine different shapes and sizes, enhance both the fresh and mechanical properties more effectively than single-type fibers.
- The literature suggests that optimized fiber combinations lead to improved compressive strength, tensile strength, and toughness while maintaining acceptable workability [9].
- Fiber-Reinforced Polymer (FRP) materials have emerged as promising alternatives in bridge construction owing to their light weight, high strength, and resistance to corrosion.
- The Netherlands has been a leader in implementing FRP for pedestrian and bicycle bridges, demonstrating its structural and aesthetic benefits. Smits (2016) highlighted that although the technical advantages of FRP are clear, the integration of architectural design and sustainability remains a significant challenge [10].
- Case studies of Dutch projects reveal innovative approaches to combining structural efficiency with visual appeal and durability.
- Literature emphasizes the need for interdisciplinary collaboration between engineers and architects to fully harness the potential of FRP in infrastructure development.
- Integrating architectural design and sustainability with FRP is a challenge.
- Literature highlights the increasing use of Fiber-Reinforced Polymer (FRP) materials in bridge design owing to their high strength-to-weight ratio, corrosion resistance, and low maintenance requirements.
- In the Netherlands, FRP bridges are becoming more popular for pedestrian and cycling infrastructure, with successful examples showing the practical viability of the material.
- However, challenges remain in architectural integration, the standardization of design practices, and gaining broader acceptance in the construction industry.
- Studies have emphasized the need for interdisciplinary collaboration and innovative design strategies to harness the full potential of FRP in sustainable bridge construction.
- In this study, the three different Kevlar Fiber hybrid composite specimens, each consisting of five layers, are as follows: the first and last layers of the specimens are Kevlar, and the remaining layers are glass fibers.
- Abaca Fibers, the first and last layers, are glass, the remaining layers are hemp fibers, the first and last layers are glass, and the remaining layers are Abaca Fibers.
- The hybrid reinforced polymer composite is made up of natural and synthetic fibers in a mat form short fibers with random orientation and long fibers.
- Steel fibers improve ductility and tensile strength of concrete.
- Optimum fiber content (~1% steel, ~0.5% polypropylene) for flexural strength.
- Combined fibers show synergistic effects.
- Polypropylene fibers, fly ash, and silica fume marginally improve compressive strength.
- Fiber mixes increase split tensile strength.
- Natural materials are being increasingly studied because of their biodegradability, low cost, and environmental friendliness.
- Natural Fibers such as jute, sisal, and banana have replaced synthetic fibers in polymer composites, thereby contributing to sustainability.

- This research examines the extraction, characterization, and thermal analysis of rare natural fibers worldwide. This study aims to provide insights into extraction techniques and properties for efficient utilization in polymer matrices, with the goal of enriching rural economics and decreasing reliance on traditional fibers. Thermal stability assessment is important for the topic covered in this study.

LITERATURE SUMMARY

Studies have shown that the replacement of steel and polypropylene affects the concrete strength. The optimum replacement percentage for the strength gain is generally 0.5%–1%. Fiber-reinforced concrete often exhibits superior durability. This study focuses on the impact of these lower replacement percentages on the compressive strength of concrete M30 and M35.

PROBLEM ANALYSIS

Contemporary construction practices necessitate the use of high-strength durable concrete (HDC). However, conventional concrete exhibits inherent weaknesses, particularly in terms of its tensile strength and resistance to cracking. The integration of steel and polypropylene fibers presents a viable solution to these limitations, although it necessitates careful optimization of the mix design to ensure both workability and cost efficiency. A comprehensive understanding of the fiber– matrix interactions and long-term durability is essential for promoting broader applications. This study provides a systematic evaluation of the combined influence of steel and polypropylene fibers on the mechanical behavior of concrete, with the aim of developing more resilient and performance-enhanced composite materials.

OBJECTIVES

This study aims to evaluate the potential of steel and polypropylene fibers to enhance the strength of concrete compared to conventional mixes. Specific objectives include:

- Determining the impact of steel and polypropylene fibers on concrete cube compressive strength.
- Comparing the effects of these fibers on crack resistance and ductility.
- Evaluating the compressive strength of M20, and M25 concrete grades.
- Assessing the improvement in toughness due to fibre addition.

METHODOLOGY

- Literature review on fibre-reinforced concrete.
- OPC 53 cement (IS 12269), steel fibers (IS 13270), and polypropylene fibers (IS 10951) were selected.
- Material property testing (cement, fibers, aggregates, and IS codes relevant to each).
- Fresh concrete tests (slump, compaction factor - IS 1199).
- Mix design for M20 and M25 concrete (IS 10262, IS 456).
- Concrete cubes (150x150x150 mm) with varying percentages of steel and polypropylene fibers (IS 516, IS 1199) were cast.
- Curing of cubes for 7, 14, and 28 days (IS 516).
- Testing of hardened concrete for compressive strength at 7, 14, and 28 d (IS 516).
- Observation, calculation, and comparison of compressive strength results.
- Analysis of results to draw conclusions and suggest future scope.

EXPERIMENTAL INVESTIGATION

The durability and strength characteristics of concrete have always been critical aspects of its structural design and construction. High-performance concrete (HPC), which is engineered to have superior mechanical and durability properties, often incorporates fibers to improve its performance under stress and reduce cracking. This study investigates the effect of incorporating steel and polypropylene fibers on the mechanical properties of HPC using M20 and M25 grade concrete.

The experimental program included preparing concrete mixes with varying proportions of steel and polypropylene fibers (0%, 0.5%, 1.0%, and 1.5% by volume) and evaluating the changes in compressive strength, split tensile strength, and flexural strength over curing periods of 7, 14, and 28 days. The aim is to determine the optimal fiber content that enhances the strength without significantly compromising workability or increasing cost.

The test results indicate that the combination of steel and polypropylene fibers can significantly enhance the tensile and flexural strengths of concrete. Steel fibers improve ductility and load-carrying capacity, whereas polypropylene fibers reduce plastic shrinkage cracking and improve impact resistance. Among the mixes tested, M25 grade concrete with 1.0% steel and 0.5% polypropylene fiber showed the best overall performance in terms of strength and work ability.

The study concluded that the strategic use of hybrid fibers in M20 and M25 grade concrete can produce a more resilient HPC mix suitable for a wide range of structural applications.

MIX DESIGN

1. Grade of Concrete
   M20 (Target compressive strength = 20 MPa)
2. Characteristics
   Cement: OPC 43 Grade
   Water-cement ratio: 0.50 (maximum as per IS 456:2000 for moderate exposure)
   Workability: 75–100 mm slump (for general RCC)
   Maximum size of aggregate: 20 mm
   Exposure condition: Moderate
3. *Type of mix*: Nominal mix Target Mean Strength (fck'):

where,
(standard deviation [SD] for M20).
fck' = 20 + (1.65 \times 4) = 26.6 \, MPa

4. *Water-cement ratio*: Assumed 0.50 (from IS
   456 Table 5 for M20, max 0.55 for reinforced concrete)
5. *Water content:* From IS 10262 Table 4 (for 20 mm aggregate):
   Base water = 186 kg/m^3(Assumed normal conditions, no admixture)
6. *Cement content:(IS 456*: Minimum cement content for moderate exposure = 300
7. *Coarse and fine aggregate content*: From IS 10262 Table 5:
   For the 20 mm agg., Zone II sand, the volume of coarse agg. = 0.62
   Adjusted for w/c ratio: not required for 0.50 Volume of fine agg. = 1 - 0.62 = 0.38
8. *Mix proportions (By weight):* Assuming unit volume = 1 m^3 and the total mass of all components adjusted for specific gravity:
   Cement = 372 kg Water = 186 kg
   Fine aggregate = 682 kg (approximately) Coarse aggregate = 1249 kg (approximately)
9. *Final mix ratio (by weight):cement*: Fine Agg.
   Coarse Agg. = 1: 1.83: 3.35
   Or rounded:1:1.5:3 (Nominal M20), commonly used in site practice.
   Grade of Concrete: M25
10. *Target strength (f'ck):* 25 + 1.65 × S = 31.6 MPa (assuming S = 4 MPa, standard deviation)
    Step 1: Target Mean Strength (f'ck)
    f'ck = fck + 1.65 × standard deviation= 25 + 1.65
    × 4 = 31.6 MPa
    Step 2: Water-Cement Ratio (W/C) As per IS 10262:2019, for M25

Assumed W/C = 0.45 (should be less than 0.5 for durability)
Step 3: Water Content For 20 mm aggregate (IS 10262 Table),
Water = 186 liters/m³ (for 0.5 W/C, adjusted for required W/C)
No change needed for W/C = 0.45
Step 4: Cement Content
W/C = 0.45 → Cement = Water / W/C = 186 /
0.45 = 413.3 kg/m³
> *Check*: Minimum cement for M25 = 300 kg/m³
OK
Max cement = 450 kg/m³ → OK
Step 5: Aggregate Volume Calculation Let's assume:
Fine aggregate (Zone:

Materials Used

- *Cement*: Ordinary Portland Cement (OPC) 43 grade.
- *Fine aggregate*: River sand, conforming to Zone II (IS 383:1970).
- *Coarse aggregate*: Crushed angular aggregate of 20 mm size.
- *Water*: Potable water free from impurities.
- *Steel fibers*: Hooked-end fibers, aspect ratio (length/diameter) of 50–80.
- *Polypropylene fibers*: Monofilament type, 12 mm length.

Mix Design

Concrete mix designs for M20 and M25 grades are prepared as per IS 10262:2019:

M20 mix proportion (approx.): 1:1.5:3 with a water–cement ratio of 0.5.

M25 mix proportion (approx.): 1:1:2 with a water-cement ratio of 0.45.

Fiber Dosage

- Mix ID Steel Fiber (%) Polypropylene Fiber (%)
- Mx 0% 0% (Control Mix)
- MxS 0.5% 0%
- MxP 0%m 0.5%
- MxSP

RESULTS

- Compressive Strength Evaluation and Fibre Performance Analysis.
- The compressive strength serves as a primary indicator of the structural integrity and engineering quality of concrete, as enhancements in this property often correlate with improvements in other mechanical characteristics.
- The experimental results demonstrated that the incorporation of steel fibers led to a compressive strength increase of approximately 8–15% across all concrete grades. This improvement is primarily attributed to the ability of the fibers to restrain crack propagation and enhance the post-cracking load-carrying capacity of the concrete matrix.
- Similarly, the inclusion of polypropylene fibers resulted in a 3–7% increase in compressive strength, with improvements linked to the mitigation of microcracking and better control of plastic shrinkage during the early curing phase.
- The hybrid fiber system, a combination of steel and polypropylene fibers, yielded the most significant enhancement, with compressive strength gains ranging from 10 to 18%, owing to the complementary effects of both fiber types. This hybrid configuration improved the ductility and resistance of concrete to both early stage and long-term cracking.
- Compressive strength measurements were taken at 7, 14, and 28 d of curing in accordance with

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the relevant IS standards. Comparative analysis across M20 and M25 concrete grades revealed a consistent trend of strength enhancement with fiber incorporation, with the highest performance recorded in hybrid fiber-reinforced mixes, indicating a synergistic effect.

CONCLUSION

- The experimental assessment of steel and polypropylene fiber incorporation in M20 and M25 concrete grades confirmed that fiber reinforcement is an effective strategy for enhancing both the mechanical performance and durability of high-performance concrete (HPC). The following conclusions were drawn.
- *Compressive strength enhancement*: The fiber-reinforced mixes exhibited a notable increase in compressive strength relative to conventional concrete. Steel fibers significantly contributed to load-bearing enhancement by bridging and restricting crack propagation, while polypropylene fibers offered modest improvements by mitigating microcracking at the microstructural level. The hybrid fiber configuration delivered the most substantial strength gains, particularly in higher-grade mixes, indicating a synergistic effect between the two fiber types.
- *Crack resistance and ductility*: Fiber incorporation enhanced the resistance to both early age and long-term cracking. Steel fibers improved the post-cracking tensile capacity of concrete, whereas polypropylene fibers effectively controlled early plastic shrinkage cracks. Their combined use resulted in enhanced ductility and multiscale crack mitigation, providing comprehensive crack control throughout the concrete lifecycle.
- *Toughness and energy absorption*: The inclusion of fibers, particularly in the hybrid form, substantially increased the toughness of the concrete composite. Improved stress-strain responses and elevated energy absorption capacities were observed, making hybrid fiber-reinforced concrete (HFRC) a suitable candidate for dynamic load conditions and seismic applications, where enhanced post-peak performance is critical.

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