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Optimizing Mechanical Properties of Polypropylene Fibre-Reinforced Coconut Shell Concrete

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Abstract

This study investigates the impact of polypropylene (PP) fibre reinforcement on the mechanical properties of coconut shell (CS) concrete. The compressive strength of CS concrete is primarily governed by the strength of CS aggregates, with early-age failure attributed to poor bonding and later-stage failure influenced by aggregate strength. The incorporation of PP fibres significantly enhanced compressive, tensile, and flexural strength. At 28 days, compressive strength increased by 1.2–3.45% in CSF mixes and 1–4.1% in CSP mixes for 0.25–0.5% fibre content, while excessive fibre additions (0.75–1.0%) led to strength reductions. Splitting tensile strength improved by 11–26% across all fibre-reinforced mixes, and flexural strength showed enhancements of 6–29% in CSF and 4–22% in CSP mixes. The improvements are attributed to the fibre bridging mechanism, which restricts crack propagation and enhances ductility. However, beyond an optimal fibre content, workability issues and strength reductions were observed. This study confirms that PP fibre reinforcement can enhance the structural performance of CS concrete, making it a viable option for sustainable and lightweight construction.

Keywords: Polypropylene fibres, coconut shell concrete, mechanical properties, compressive strength, flexural strength, splitting tensile strength, fibre reinforcement, sustainable construction

INTRODUCTION

Lightweight concrete (LWC) has gained significant attention in the construction industry due to its reduced density, improved thermal insulation, and environmental benefits. Among various lightweight aggregates, coconut shell (CS) has emerged as a sustainable alternative, reducing dependency on conventional aggregates while addressing waste management challenges. However, the mechanical properties of CS concrete are often limited by the weak interfacial bonding between the cement paste and the aggregate, impacting its strength and durability [1–3].

To overcome these limitations, fibre reinforcement has been widely explored as an effective strategy to enhance mechanical performance. Polypropylene (PP) fibres, known for their high tensile strength and durability, have shown promise in improving the compressive, tensile, and flexural properties of concrete by mitigating crack propagation and enhancing energy absorption [4]. However, the optimal fibre dosage remains critical, as excessive fibre content can negatively impact workability and strength [5–8].

This study investigates the influence of PP fibre reinforcement on the mechanical properties of CS concrete, focusing on compressive, splitting tensile, and flexural strength. The findings aim to optimize fibre content for enhanced performance while

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maintaining workability, thus promoting CS concrete as a viable, eco-friendly alternative for sustainable construction [9, 10].

OBJECTIVES

The primary objective of this research is to evaluate the impact of polypropylene (PP) fibre reinforcement on the mechanical properties of coconut shell (CS) concrete. This study aims to assess the compressive strength of CS concrete at different curing ages and determine how fibre incorporation influences the material's durability and structural performance. Additionally, the research investigates the effect of PP fibres on the splitting tensile and flexural strength of CS concrete, identifying improvements in crack resistance and energy absorption. A key focus is to determine the optimal fibre dosage that enhances strength without compromising workability. The study also examines the fibre bridging mechanism, which mitigates crack propagation and improves toughness in CS concrete. Ultimately, this research contributes to developing sustainable, lightweight concrete materials suitable for structural applications, promoting the use of CS as an eco-friendly aggregate alternative in the construction industry [11–13].

MATERIALS

Coconut Shell Aggregate

Coconut shells, sourced from local copra drying yards, are washed to remove iron and processed to eliminate fibres from the convex side before crushing. The shell thickness varies between 2 and 5 mm. Due to high water absorption, they are used in an SSD condition after 24-h water immersion [14–17].

River Sand as Fine Aggregate

Locally sourced river sand (Zone II, specific gravity 2.6) was sieved through a 4.75 mm mesh, ensuring uniformity. Testing was conducted per IS 383-1970.

Coarse Aggregate

Crushed granite (3–12 mm) was used in CSP mixes. Key properties such as bulk density, specific gravity, water absorption, AIV, ACV, and abrasion value were assessed.

Cement

53 Grade OPC (UltraTech) was used, conforming to IS 12269:2013. The specific gravity was 3.15.

Fly Ash

Class F fly ash (specific gravity 2.08) from Mandideep, Madhya Pradesh, was used as a pozzolanic material to enhance durability and reduce OPC content, lowering CO_2 emissions.

Water

Only potable water, free from harmful impurities, was used for mixing and curing to prevent adverse effects on concrete properties [18–22].

Superplasticizer

Conplast SP430 (sulfonated naphthalene polymer) was added to improve workability, allowing water reduction and strength enhancement. The optimal dosage was 1.2% of the binder content.

Fibres

The study utilized fibrillated multidimensional polypropylene fibres with a length of 20 mm and a diameter of 40 µm. These fibres exhibit an aspect ratio of 500 and possess a specific gravity of 0.91. Additionally, they demonstrate a high tensile strength of 550 MPa, making them suitable for enhancing the mechanical properties of concrete.

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RESULTS

Compressive Strength

The compressive strength of CS concrete is significantly influenced by the strength of the CS aggregates. At an early age, failure in CS concrete primarily results from inadequate bonding between the cement paste and CS aggregates, while at later stages, failure is predominantly due to the inherent strength of the CS aggregates [23–25].

In this study, the incorporation of polypropylene (PP) fibres generally enhanced the compressive strength of CS concrete. Under compressive loading, cracks initiate and propagate until they reach the fibres, which then act as a barrier by bridging the cracks. This bridging effect prevents further crack propagation by distributing stress along the fibre-mortar interface [26–28].

The compressive strengths of all the mixes at 28 and 56 days are detailed in Table 1 and graphically represented in Figure 1. A notable improvement in compressive strength was observed with the inclusion of 0.25 and 0.5% PP fibres in both the CSF and CSP series. Specifically, in the CSF series, compressive strength at 28 days increased by 1.2 and 3.45% for 0.25 and 0.5% fibre content, respectively. Similarly, in the CSP series, the strength improvement was recorded at 1 and 4.1% for the same fibre additions. This enhancement can be attributed to the high tensile strength of PP fibres (600 MPa) [29, 30].

However, when the fibre content was increased to 0.75 and 1.0%, a decline in compressive strength was observed in both CSF and CSP series. The reduction was particularly significant in the CSF100 and CSP100 mixes, indicating that excessive fibre content may adversely impact the compressive strength of CS concrete.

Splitting Tensile Strength Result

Incorporating fibres into concrete significantly enhances its mechanical properties, including tensile strength, flexural strength, impact resistance, ductility, and flexural toughness in the hardened state . Previous research has demonstrated that fibre reinforcement substantially improves the splitting tensile strength of lightweight aggregate concrete.

In this study, the addition of polypropylene (PP) fibres to coconut shell lightweight concrete positively influenced both flexural and splitting tensile strengths. The values for these properties across all mixes are presented in Table 2. Figures 2 and 3 illustrate the split tensile strength of PP fibre-reinforced CSF and CSP mixes, respectively. The inclusion of PP fibres at volume fractions ranging from 0.25 to 1.0% resulted in an increase in split tensile strength by 11–22% in the CSF series and 11–26% in the CSP series compared to the control mix.

Table 1. Compressive strength of CS concrete reinforced with polypropylene fibres.

Mix Designation	Compressive strength (MPa)		
	7 Days	28 Days	56 Days
CSF10	28.04	37.38	41.90
CSF10P25	29.51	37.80	43.89
CSF10P50	27.83	38.64	45.57
CSF10P75	24.57	36.12	41.58
CSF10P100	21.42	30.66	35.28
CSP10	26.57	40.74	44.84
CSP10P25	32.13	41.16	47.36
CSP10P50	32.66	42.42	49.67
CSP10P75	26.04	40.11	46.94
CSP10P100	26.04	35.81	41.58

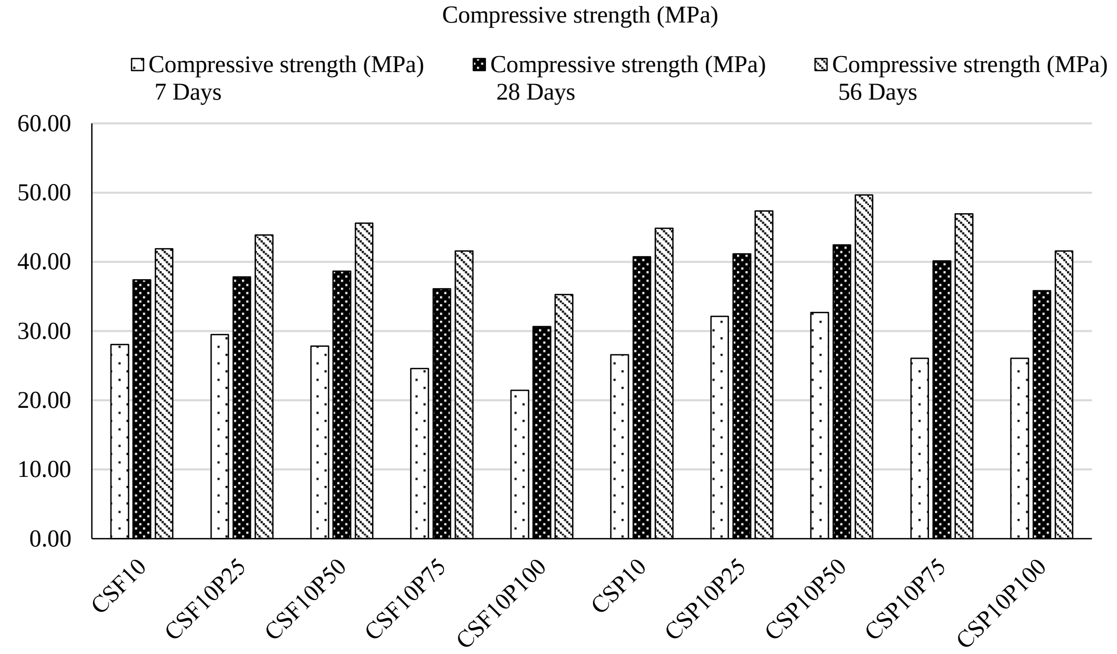

Figure 1. Compressive strength variation in CS concrete with polypropylene fibre addition.

Table 2. Splitting tensile strength of polypropylene fibre-reinforced coconut shell concrete.

Mix Designation	Split Tensile strength (MPa) 28 days
CSF10	2.85
CSF10P25	3.3
CSF10P50	3.39
CSF10P75	3.42
CSF10P100	3.14
CSP10	3.55
CSP10P25	4.05
CSP10P50	4.34
CSP10P75	4.3
CSP10P100	3.68

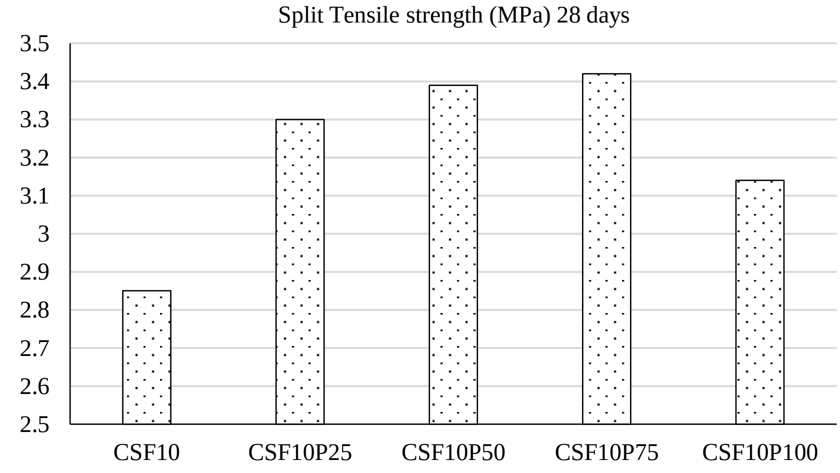

Figure 2. Splitting Tensile Strength of PP Fibre-Reinforced CSF Mix.

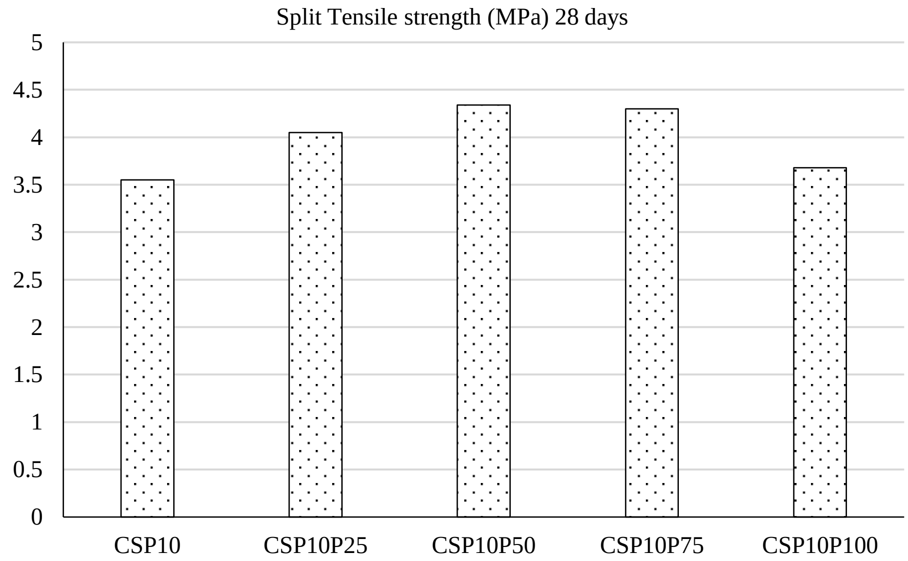

Figure 3. Splitting tensile strength of PP fibre-reinforced CSP mix.

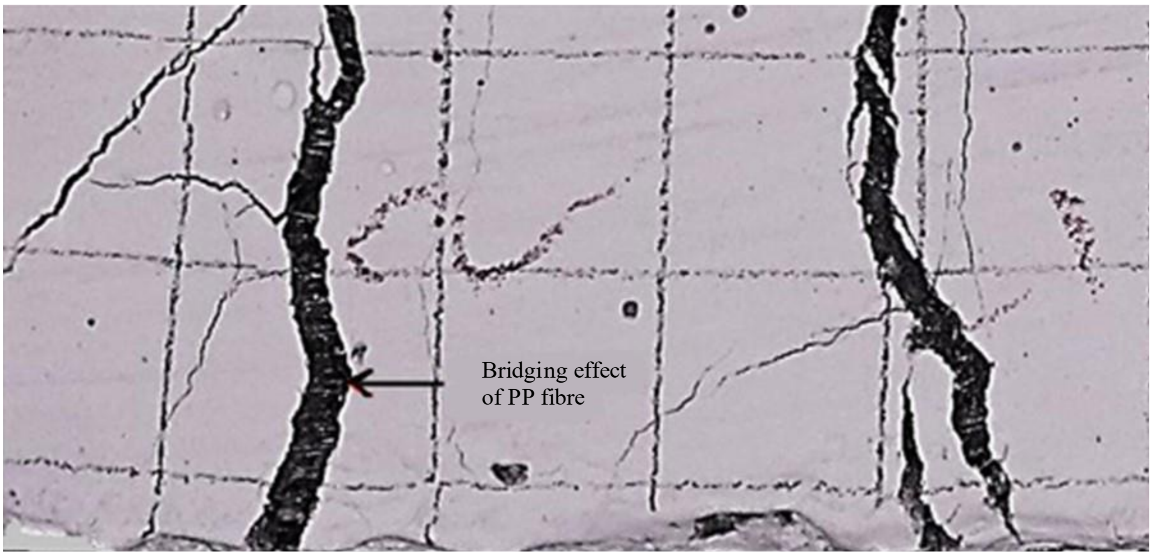

Figure 4. Bridging effect of PP fibres across flexural cracks.

Flexural strength results indicate a consistent improvement across all fibre-reinforced mixes at 28 days compared to the control mix. The 28-day flexural strength corresponds to 6–29% of the 28-day compressive strength in CSF mixes and 4–22% in CSP mixes. The rate of increase in flexural strength was observed to be 25, 29, 23, and 6% for CSF25, CSF50, CSF75, and CSF100 mixes, respectively, while CSP25, CSP50, CSP75, and CSP100 mixes exhibited increases of 16, 22, 15, and 4%, respectively. The effect of PP fibres on flexural strength was more pronounced in CSF mixes than in CSP mixes. This improvement is attributed to the fibre bridging mechanism, as demonstrated in Figure 4 for the CSP50 mix.

CONCLUSION

The findings of this study indicate that the compressive strength of coconut shell (CS) concrete is significantly influenced by the strength of CS aggregates, with early-age failure primarily attributed to weak bonding between the cement matrix and CS aggregates, while later-stage failure is governed by the aggregate's inherent strength. The incorporation of polypropylene (PP) fibres generally enhanced the compressive strength, with peak improvements observed at 0.25 and 0.5% fibre content. However, excessive fibre additions beyond 0.75% resulted in reduced compressive strength, suggesting an optimal fibre dosage for performance enhancement.

The study also demonstrated notable improvements in the splitting tensile and flexural strengths of CS concrete with PP fibre reinforcement. The inclusion of PP fibres increased split tensile strength by 11–22% in the CSF series and 11–26% in the CSP series. Similarly, flexural strength improvements ranged from 6–29% for CSF mixes and 4–22% for CSP mixes, with the enhancement being more pronounced in CSF mixes. These improvements are attributed to the fibre bridging mechanism, which effectively restricts crack propagation and enhances ductility.

Overall, the study confirms that PP fibre reinforcement enhances the mechanical performance of CS concrete, with an optimal fibre content balancing strength gains and workability.

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