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Performance Evaluation of High-Performance Fiber Reinforced Concrete Incorporating Fly Ash, Coir Husk Ash, and Hybrid Fibers

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Abstract

High-Performance Fiber-Reinforced Concrete (HPFRC) is an advanced composite material designed to improve the mechanical properties and durability of conventional concrete. This study investigates the effects of fly ash (FA), coir pith ash (CPA), and various fiber reinforcements (polypropylene, coir, and kenaf) on the compressive strength of HPFRC. The research evaluates the influence of natural admixtures, single fiber additions, and hybrid fiber combinations to optimize mix proportions for enhanced structural performance. Experimental results indicate that the M4 mix (5% FA+5% CPA) achieved the highest compressive strength among natural admixture-based mixes, with a 4% increase compared to the control mix (M1). The inclusion of fibers further improved performance, with polypropylene (PP) fiber-reinforced concrete achieving the highest strength due to its low water absorption and high ductility. Conversely, kenaf fiber-reinforced concrete exhibited reduced strength, attributed to its high-water absorption. Hybrid fiber combinations demonstrated significant improvements in mechanical behavior. The M24 (0.75% PP+0.75% CPF) and M29 (1% PP+0.5% CPF) mixes attained the highest compressive strength among hybrid fiber-reinforced concretes. These results highlight the potential of hybrid fiber-reinforced HPFRC in achieving superior performance by balancing tensile and ductile properties. The work concludes that incorporating natural admixtures and hybrid fiber reinforcement enhances the strength, workability, and durability of HPFRC, making it a sustainable and high-performance material for structural applications.

Keywords: High-performance fiber-reinforced concrete, fly ash, coir pith ash, polypropylene fiber, kenaf fiber, hybrid fiber reinforcement, compressive strength, natural admixtures, sustainable concrete, mechanical properties

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INTRODUCTION

High-performance fiber-reinforced concrete (HPFRC) has gained significant attention due to its superior mechanical properties, durability, and sustainability. The integration of mineral admixtures and hybrid fibers further enhances its strength, workability, and long-term performance. This study evaluates the performance of HPFRC incorporating fly ash, coir husk ash, and hybrid fibers, including coir, kenaf, and polypropylene, to improve mechanical properties and environmental sustainability.

Fly ash, a pozzolanic material, enhances the durability and strength of concrete by refining its microstructure. Coir husk ash, derived from agricultural waste, contributes to improved bonding and reduced permeability. The addition of hybrid fibers enhances toughness, crack resistance, and impact strength, making HPFRC suitable for high-performance structural applications. This research aims to assess the effects of these materials on the mechanical and durability properties of HPFRC, providing insights into its potential for sustainable and resilient construction [1–5].

OBJECTIVES

This study aims to evaluate the impact of natural admixtures, such as Fly Ash (FA) and Coir Pith Ash (CPA), on the compressive strength of concrete at varying replacement levels. It further investigates the influence of different fiber types, including polypropylene (PP), coir fiber (CPF), and kenaf fiber, on the mechanical properties of concrete. Additionally, the research compares the compressive strength of concrete reinforced with individual fibers and hybrid fiber combinations to determine the most effective mix proportions for enhanced performance [6, 7].

DEVELOPMENT OF HIGH-PERFORMANCE FIBER-REINFORCED CONCRETE

This study explores the production of high-performance fiber-reinforced concrete (HPFRC) incorporating cement, fine and coarse aggregates, fly ash, coir husk ash, superplasticizers, and fibers (coir, kenaf, and polypropylene). The mix utilizes 53-grade Ordinary Portland Cement (OPC) (IS 8112), locally sourced river sand (Zone-II, IS 383:2016), and 20 mm crushed granite as coarse aggregate. Glenium SP430G, fly ash, and coir husk ash are used as admixtures to enhance performance. Potable water is used for mixing and curing [8–16].

Materials

- *Cement*: 53-grade OPC ensures high strength and consistent paste formation, influencing early-age strength development. Compatibility with chemical and mineral admixtures is crucial for optimal performance [17].
- *Fine aggregate*: River sand (Zone-II, IS 383:2016) is used, free from impurities to maintain workability and strength [18].
- *Coarse aggregate*: Locally available 20 mm crushed granite is selected for improved mechanical performance.

Admixtures

- *Fly ash (class F):* A pozzolanic material with <5% lime content and >70% silica, alumina, and iron, ensuring strength development. The specific gravity is 2.1 [19].
- *Coir husk ash:* Produced by burning coir pith at 400°C, with a specific gravity of 1.9.
- *Superplasticizer (GLENIUM SP 430G):* A high-range water-reducing admixture (HRWRA) that enhances workability, reduces permeability, and ensures a low water-to-cement ratio. It complies with BIS: 9103-1999, BS: 5075 Part 3, and ASTM C 494 standards [20].

Fibers

- *Coir and kenaf (natural fibers):* Procured from Bhopal, Madhya Pradesh.
- *Polypropylene (synthetic fiber):* Sourced from Mandideep, Madhya Pradesh.

These fibers enhance tensile strength, impact resistance, and durability, contributing to the development of HPFRC.

Mix Proportions and Testing

In this study, Mix 1 serves as the control mix, while Mixes M2 to M6 incorporate 5% coir pith ash and 5% fly ash (total 10% replacement of cement). Mixes M7 to M26 include varying proportions of coir, kenaf, and polypropylene fibers. A constant water-binder ratio of 0.30 was maintained for all mixtures [21–24].

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RESULTS

Compressive Strength of High-Performance Fiber-Reinforced Concrete (HPFRC)

This section examines the compressive strength of concrete at 28, 56, and 90 days (Table 1). The compressive strength trends for mixes M1 to M32 were plotted to determine the highest strength achieved (Figure 1). Among these, mixes M12, M15, M21, M24, and M29 exhibited the highest compressive strengths, reaching 70.39, 72.10, 70.04, 70.04, and 70.68 N/mm² at 28 days, respectively [24–27].

Compared to the control mix (M1), M15, containing 1.8% polypropylene fiber, demonstrated a 15% increase in compressive strength. Additionally, mixes M12, M21, M24, and M29 showed a 12% improvement over M1. These findings highlight that polypropylene fiber-enhanced mixes achieved superior compressive strength, whereas mixes incorporating kenaf fiber exhibited lower strength. The reduction in compressive strength in kenaf fiber mixes is attributed to its higher water absorption capacity, which negatively impacts the concrete's overall strength [28–30] (Figure 1).

Table 1. Compressive Strength.

Mix designation	Compressive strength (MPa)		
	28 Days	***56 Days***	***90 Days***
M1	63.86	68.18	69.93
M2	64.41	68.76	70.52
M3	59.08	63.08	64.69
M4	66.04	70.50	72.32
M5	65.77	70.22	72.02
M6	62.23	66.44	68.14
M7	67.98	72.57	74.44
M8	64.75	69.12	70.89
M9	68.24	72.85	74.72
M10	68.96	73.62	75.51
M11	61.16	65.29	66.97
M12	70.39	75.15	77.07
M13	68.50	73.13	75.00
M14	58.71	62.68	64.29
M15	72.10	76.97	78.95
M16	57.90	61.81	63.40
M17	45.44	48.51	49.76
M18	62.09	66.28	67.99
M19	66.44	70.93	72.75
M20	56.65	60.48	62.04
M21	70.04	74.78	76.69
M22	59.74	63.78	65.42
M23	61.80	65.98	67.67
M24	70.04	74.78	76.69
M25	65.37	69.79	71.59
M26	60.30	64.38	66.02
M27	69.72	74.44	76.34
M28	64.46	68.81	70.59
M29	70.68	75.46	77.39
M30	67.98	72.57	74.44
M31	61.80	65.98	67.67
M32	67.84	72.42	74.28

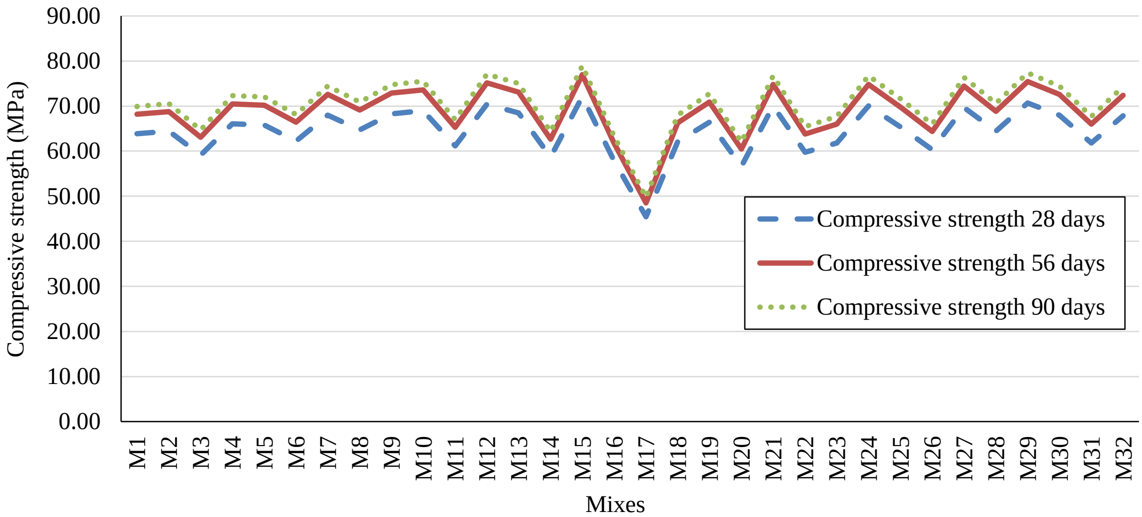

Figure 1. Compressive strength trends at 28, 56, and 90 days.

CONCLUSION

- The inclusion of fly ash (FA) and coir pith ash (CPA) improved compressive strength by reducing capillary voids and enhancing particle packing.
- The M4 mix (5% FA+5% CPA) exhibited superior compressive strength, making it the optimal mix among natural admixture-based concretes.
- Polypropylene (PP) fiber-reinforced concrete achieved the highest compressive strength due to its low water absorption and high ductility.
- Kenaf fiber resulted in lower compressive strength due to its high water absorption, affecting the mix's overall performance.
- Hybrid fiber combinations significantly improved mechanical properties by leveraging the tensile and ductile strengths of different fibers.
- The M24 (0.75% PP+0.75% CPF) and M29 (1% PP+0.5% CPF) mixes demonstrated maximum compressive strength among hybrid fiber-reinforced concretes.
- The study confirms that using natural admixtures and hybrid fiber reinforcement can enhance strength, durability, and sustainability in HPFRC applications.

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