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Enhancing The Strength And Durability Of Concrete Through Hybrid Fiber Reinforcement In Aggressive Environments

Chnadra Prakash Kumawat[1], Ravindra Kumar[2] & Ravi Kant Pareek[3]

[1]M.tech Scholar, Department of Civil Engineering, Vivekananda Global University, Jaipur

[2]Assistant Professor, Department of Civil Engineering, Vivekananda Global University, Jaipur

[3]Associate Professor, Department of Civil Engineering, Vivekananda Global University, Jaipur

Abstract

This research paper investigates the effect of Hybrid Fiber Reinforced Concrete (HFRC) on the strength characteristics of concrete in aggressive environmental conditions. In response to the limitations of conventional concrete in highly aggressive environments, the study explores the incorporation of steel and polypropylene fibers to enhance concrete's ductility, tensile strength, and energy absorption capacity. The research program includes experimental tests on HFRC specimens with varying fiber compositions to evaluate compressive, split tensile, and flexural strengths. Results reveal that the addition of fibers significantly improves concrete strength, with the optimum combination of 75% steel fibers and 25% polypropylene fibers offering the highest increase in compressive, split tensile, and flexural strengths compared to plain concrete. The findings highlight the potential of HFRC as a durable and sustainable construction material for various structural applications in aggressive environments.

Keyword: Hybrid Fiber Reinforced Concrete, HFRC, aggressive environments, steel fibers, polypropylene fibers.

Introduction

Concrete has long been regarded as a durable and reliable construction material. However, in highly aggressive environments such as polluted urban and industrial areas, aggressive marine environments, and coastal regions with harmful sub-soil water, conventional concrete's durability is challenged. The premature failures of structures in such conditions have highlighted the need to explore new approaches to enhance concrete's properties.

In the past, the focus was primarily on the compressive strength of concrete, overlooking its vulnerability in severe environmental conditions. As a result, numerous structures suffered from deficiencies and premature failures. Today, the extensive use of concrete is indispensable in construction, ranging from small buildings to massive structures like bridges and dams. Concrete technology has evolved significantly, with advanced special types of cement, additives, aggregates, and mixing techniques, making it versatile and adaptable to various conditions.

However, normal plain concrete does have inherent weaknesses, such as low tensile strength and the ability to allow strain at fracture due to the presence of micro cracks. To address these limitations, researchers and engineers have turned their attention to modifying the brittle properties of concrete using synthetic fibers.

The introduction of synthetic fibers into concrete has been instrumental in increasing its ductility, energy absorption capacity, and durability. Fibers can manage issues like plastic shrinkage cracking and drying shrinkage cracking by changing the permeability of the concrete, thereby reducing water flow.

Fiber Reinforced Concrete (FRC) has two essential mechanisms at work: spacing mechanism and crack bridging mechanism. The spacing mechanism involves the use of a large number of dispersed fibers to arrest existing micro cracks and prevent further propagation. The crack bridging mechanism relies on larger straight fibers with strong bonding to the concrete, providing additional strength and toughness.

The properties of FRC are influenced by various factors, including the type, aspect ratio, quantity, and orientation of the fibers. Steel fibers are commonly used in FRC due to their high strength, impact resistance, and ability to improve flexural strength. Polypropylene fibers are another option, contributing to increased workability, freeze-thaw resistance, and impact resistance.

Hybrid Fiber Reinforced Concrete (HFRC) is a composite that combines different types of fibers to achieve synergistic benefits. HFRC has gained popularity in applications where weight reduction, improved reinforcement, toughness, and surface finish are crucial.

HFRC finds application in various construction sectors, including architectural panels, noise protection barriers, retrofitting existing structures, and sewer lines. Its lighter weight, sustainable nature, and improved performance make it a promising choice for innovative and durable construction projects.

Literature Conclusion

Hybrid Fiber-Reinforced Concrete (HFRC) has been a subject of extensive research in the construction industry. Studies have explored the effects of incorporating different fibers, such as polypropylene and steel fibers, into concrete girders and structural elements. Results have shown that the addition of even small volumes of fibers significantly enhances the ductility, tensile strength, and flexural behavior of the concrete, with steel fiber-reinforced concrete exhibiting higher energy absorption and deflection at ultimate loads. Several experimental investigations have focused on the mechanical properties of HFRC, demonstrating improvements in compressive and flexural strength, toughness, and energy dissipation capacity. Hybridization of fibers, such as steel and polypropylene, has been studied to optimize strength characteristics. Overall, the research on HFRC has contributed valuable insights into its potential as a promising material for construction applications, offering improved performance and durability compared to traditional concrete.

Methodology

Hybrid Fiber Reinforced Concrete (HFRC) is a composite material that combines Portland cement, aggregate, steel fibers, and polypropylene fibers. Unlike conventional concrete, HFRC overcomes its brittleness and weak tensile strength by incorporating randomly distributed irregular fibers, which help fill cracks and enhance its strength. The materials required for making HFRC include cement, fine sand, coarse aggregates, and hybrid fibers.

To investigate the effect of hybrid fibers on concrete strength, an experimental program was devised. It aimed to determine the compressive, flexural, and direct tensile strengths of HFRC with various fiber contents. The study compared the strength of plain mortar and HFRC to assess the influence of fiber addition. The specimens were tested at 7, 28, and 56 days in wet conditions.

The experimental program included the following steps:

1. Materials used in manufacturing HFRC were collected and tested for their properties, including cement, fine aggregates, coarse aggregates, superplasticizer, and fibers.
2. Concrete mix design for M40 grade concrete was adopted as per IS 10262:2009, with a mix ratio of 1:1.81:2.91 (cement: fine aggregates: coarse aggregates). Fibers were added to the mix at a volume fraction of 0.75%.
3. Six groups of specimens were prepared with varying fiber compositions: control (0% fibers), 100% polypropylene fibers, 25% steel fibers and 75% polypropylene fibers, 50% each of steel and polypropylene fibers, 75% steel fibers and 25% polypropylene fibers, and 100% steel fibers.
4. Cubical molds (150mm x 150mm x 150mm), beam molds (150mm x 150mm x 700mm), and cylinder molds (150mm diameter x 300mm height) were used for casting specimens.
5. Hand mixing was carried out to ensure a homogeneous mixture of all ingredients, and the required amount of superplasticizer was added to maintain workability.
6. The concrete mix was poured into the molds and compacted using a vibrating table.
7. After 24 hours, the specimens were demolded and transferred to curing tanks, where they were allowed to cure for 28 days.
8. At the ages of 7 and 28 days, the specimens were tested for compressive strength using a Universal Testing Machine (UTM).
9. At 28 days, flexural strength tests were conducted on beam specimens using a flexural testing machine.
10. At 28 days, split tensile strength tests were performed on cylinder specimens using a split tensile testing machine.

11. The average values of each type of strength were recorded and analyzed to determine the effect of hybrid fibers on the strength characteristics of HFRC

Result and Discussion

The results and discussions of the experimental program are as follows:

Compressive Strength: The compressive strength tests were conducted on 36 specimens with six different mixes of steel and polypropylene fibers. The results showed that the introduction of 100% polypropylene fibers led to a reduction in compressive strength by approximately 10%. However, an increase in compressive strength was observed with the addition of steel fibers, reaching its maximum value when using 75% steel fibers and 25% polypropylene fibers. In general, the addition of fibers to the concrete mix increased the compressive strength by 6% to 18%, with the optimum combination being 75% steel fibers + 25% polypropylene fibers, resulting in an 18% increase over plain concrete. Notably, the mix containing 50% steel fibers and 50% polypropylene fibers exhibited higher compressive strength than the mix with 100% steel fibers.

Split Tensile Strength: The split tensile strength tests were conducted on the same 36 specimens with different fiber combinations. When 100% polypropylene fibers were introduced, the split tensile strength increased by approximately 18%. Similar to the compressive strength, an increase in split tensile strength was observed with the addition of steel fibers, and the maximum strength was achieved with 100% steel fibers. The overall increase in split tensile strength ranged from 18% to 160% when fibers were added to the concrete mix. The optimum combination was found to be 100% steel fibers without polypropylene fibers, resulting in a significant 160% increase over plain concrete.

Flexural Strength: The flexural strength tests were carried out on the same set of specimens. Like the compressive and split tensile strengths, the flexural strength of concrete with 100% polypropylene fibers was lower compared to plain concrete, showing a decrease of about 16%. However, as steel fibers were gradually introduced to replace polypropylene fibers, the flexural strength increased up to the combination of 75% steel fibers + 25% polypropylene fibers, showing an increase of 68% compared to plain concrete. Beyond this combination, with 100% steel fibers, the flexural strength decreased. The overall increase in flexural strength varied from 30% to 70% for different fiber combinations. The optimal mix was found to be 75% steel fibers + 25% polypropylene fibers, resulting in a 68% increase in flexural strength compared to plain concrete.

Conclusion

In conclusion, the experimental investigation confirmed that HFRC with hybrid fibers offers enhanced concrete properties, providing higher strength and ductility. The optimum fiber composition of 75% steel fibers and 25% polypropylene fibers demonstrated superior performance in various strength tests. This research underscores the potential of HFRC as a promising construction material with broad applicability in diverse structural applications.

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