

EXPERIMENTAL STUDY ON THE M20 GRADE CONCRETE BY PARTIAL REPLACEMENT OF CEMENT WITH POLYPROPYLENE FIBER AND DIFFERENT ADMIXTURES

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Abstract— Based on the document, the study investigates the performance of polypropylene fiber-reinforced concrete (PPRC) incorporating quarry dust (QD) and fly ash (FA) as supplementary materials to improve the mechanical properties of conventional concrete while promoting sustainable construction practices. M20 grade concrete mixes were prepared using varying proportions of polypropylene fibers combined with quarry dust and fly ash. Experimental evaluation was carried out through workability, compressive strength, split tensile strength, and flexural strength tests conducted at curing periods of 7, 14, and 28 days. The results demonstrated that the inclusion of polypropylene fibers with mineral admixtures significantly enhanced the strength characteristics of concrete compared to ordinary reinforced concrete. The optimum combination for quarry dust-based concrete was identified as 3% polypropylene fiber with 0.3% quarry dust, whereas 4% polypropylene fiber with 0.4% fly ash produced the best performance among fly ash mixes. Although the addition of fibers reduced workability, substantial improvements were observed in compressive, tensile, and flexural strengths. The findings indicate that the combined use of polypropylene fibers and industrial by-products can effectively improve concrete performance, reduce dependence on natural resources, and support environmentally sustainable construction. The proposed approach offers a practical solution for producing durable and high-strength concrete suitable for modern infrastructure applications.

Keywords: Polypropylene Fiber Reinforced Concrete (PPRC), Quarry Dust, Fly Ash, Compressive Strength, Split Tensile Strength, Sustainable Concrete.

I. INTRODUCTION

Concrete is the most widely utilized construction material in the world due to its versatility, durability, and cost-effectiveness. It plays a crucial role in the development of infrastructure such as buildings, bridges, pavements, dams, and transportation systems. Despite its excellent compressive strength, conventional concrete exhibits relatively low tensile and flexural strength, making it susceptible to cracking under various loading and environmental conditions. These limitations often affect the long-term durability and service life of concrete structures. Therefore, researchers and engineers continuously explore innovative materials and techniques to enhance the mechanical performance and sustainability of concrete.

The increasing demand for natural resources in the construction industry has led to concerns regarding environmental degradation and resource depletion. Simultaneously, large quantities of industrial by-products such as fly ash and quarry dust are generated every year, creating disposal and environmental challenges. Fly ash, a by-product of thermal power plants, possesses pozzolanic

properties that can improve concrete performance, while quarry dust, produced during the crushing of rocks, can serve as a partial replacement for natural fine aggregates. The utilization of these materials in concrete not only reduces environmental pollution but also promotes sustainable construction practices by minimizing the consumption of natural resources.

Fiber reinforcement has emerged as an effective method for improving the behavior of concrete under tensile and flexural loading conditions. Among the various fibers available, polypropylene fibers have gained significant attention due to their low cost, high chemical resistance, lightweight nature, and ability to control crack propagation. The incorporation of polypropylene fibers in concrete enhances ductility, impact resistance, toughness, and post-cracking performance. These fibers act as crack arresters within the concrete matrix, reducing the formation and growth of microcracks and thereby improving the overall structural integrity of concrete elements.

In recent years, researchers have investigated the combined use of fibers and supplementary cementitious materials to develop high-performance and eco-friendly concrete. The synergistic effect of polypropylene fibers with fly ash and quarry dust can significantly improve the mechanical and durability characteristics of concrete. Fly ash contributes to better particle packing and long-term strength development through pozzolanic reactions, while quarry dust improves the density and interlocking properties of the concrete matrix. When used together with polypropylene fibers, these materials can produce concrete with enhanced compressive strength, tensile strength, flexural strength, and durability characteristics compared to conventional concrete.

The present study focuses on evaluating the performance of polypropylene fiber reinforced concrete incorporating quarry dust and fly ash as supplementary materials. Different proportions of polypropylene fibers combined with quarry dust and fly ash were used to prepare concrete specimens, which were subsequently tested for workability, compressive strength, split tensile strength, and flexural strength at different curing periods. The objective is to identify the optimum dosage of fibers and admixtures that can maximize the mechanical properties of concrete while promoting sustainable utilization of industrial by-products. The outcomes of this study are expected to contribute to the development of durable, economical, and environmentally friendly concrete for modern construction applications.

II. LITERATURE SURVEY

The performance of conventional concrete is often restricted by its low tensile strength, brittle behavior, and susceptibility to cracking. To overcome these limitations, researchers have explored the incorporation of natural fibers, synthetic fibers, and industrial by-products into concrete mixtures. Among the various reinforcement techniques, fiber-reinforced concrete has gained significant attention because fibers enhance crack resistance, toughness, durability, and post-cracking behavior. Additionally, the utilization of waste materials and mineral admixtures contributes to sustainable construction practices by reducing environmental pollution and conserving natural resources.

Agrawal et al. [1] investigated the use of coconut fibers in concrete to improve strength characteristics while producing lightweight concrete. Their study demonstrated that the inclusion of coconut fibers enhanced the structural performance of concrete by reducing crack formation and increasing toughness. The authors concluded that natural fibers can serve as an effective reinforcement material while simultaneously reducing the self-weight of concrete elements. The research highlighted the potential of sustainable fiber materials in modern construction applications.

Kanalli et al. [2] carried out a comparative study between polymer fiber reinforced concrete and conventional concrete pavement. Their experimental results indicated that polymer fibers significantly improved pavement performance by increasing resistance to cracking and deformation. The study revealed that fiber-reinforced pavements exhibited greater durability and load-carrying capacity under repeated traffic loading. The authors suggested that polymer fibers could effectively enhance the service life of rigid pavement structures.

Selina Ruby et al. [3] examined the influence of hybrid fibers on reinforced concrete and reported considerable improvements in mechanical properties. Their findings showed that the combination of different fiber types produced a synergistic effect that enhanced compressive, tensile, and flexural strengths. The study emphasized that hybrid fiber reinforcement improves energy absorption capacity and controls crack propagation more effectively than single-fiber systems. The researchers concluded that hybrid fiber concrete offers superior structural performance and durability.

Nadgouda [4] evaluated the behavior of coconut fiber reinforced concrete and observed improvements in toughness, ductility, and crack resistance. The investigation demonstrated that fibers act as bridging elements across developing cracks, thereby delaying crack growth and increasing the energy absorption capacity of concrete. The study also highlighted the environmental advantages of utilizing renewable natural fibers as reinforcing materials in construction.

The use of synthetic fibers has been extensively investigated due to their durability and compatibility with cementitious materials. Ahsana Fathima [5] conducted a behavioral study on steel fiber and polypropylene fiber reinforced concrete and reported that polypropylene fibers

effectively improved tensile and flexural performance. The study observed a reduction in crack width and an increase in ductility when fibers were incorporated into concrete mixtures. Furthermore, polypropylene fibers were found to provide enhanced resistance against shrinkage cracking, making them suitable for structural and pavement applications.

Murahari [6] investigated the effects of polypropylene fibers on fly ash-based concrete. The study revealed that the combined use of fly ash and polypropylene fibers significantly improved compressive strength, split tensile strength, and flexural strength compared to conventional concrete. The pozzolanic action of fly ash contributed to a denser concrete matrix, while polypropylene fibers enhanced crack resistance and load distribution. The author concluded that the integration of industrial by-products and fiber reinforcement can lead to sustainable and high-performance concrete.

A comprehensive review on polypropylene fiber reinforced concrete was presented by Madhavi [7], who summarized the effects of fiber addition on fresh and hardened concrete properties. The review highlighted that polypropylene fibers improve impact resistance, abrasion resistance, durability, and post-cracking behavior. It was also reported that fibers reduce plastic shrinkage cracking and enhance the long-term performance of concrete structures exposed to harsh environmental conditions. The author emphasized that polypropylene fibers are among the most effective synthetic fibers available for concrete applications.

Ramujee [8] conducted an experimental investigation on the strength properties of polypropylene fiber reinforced concrete. The results demonstrated that the addition of polypropylene fibers increased compressive, tensile, and flexural strengths when compared with ordinary concrete. The study identified the existence of an optimum fiber dosage beyond which workability decreases and strength gains become marginal. The research further confirmed that polypropylene fibers improve crack control and contribute to the development of durable concrete structures.

Collectively, the reviewed studies demonstrate that both natural and synthetic fibers significantly enhance the engineering properties of concrete. Natural fibers such as coconut fibers improve sustainability and toughness, whereas polypropylene fibers provide superior crack resistance, durability, and mechanical performance. Moreover, the incorporation of fly ash contributes to strength development and environmental sustainability. Although numerous researchers have examined fiber-reinforced concrete and fly ash-based concrete independently, limited studies have focused on evaluating polypropylene fiber reinforced concrete incorporating both quarry dust and fly ash under identical experimental conditions. Therefore, the present investigation aims to assess the combined influence of polypropylene fibers, quarry dust, and fly ash on the workability, compressive strength, split tensile strength, and flexural strength of concrete to determine the optimum mix proportions for sustainable and high-performance construction applications.

III. PROPOSED METHODOLOGY

The present study investigates the mechanical performance of Polypropylene Fiber Reinforced Concrete (PPRC) incorporating Quarry Dust (QD) and Fly Ash (FA) as supplementary materials. The experimental methodology was designed to evaluate the influence of varying proportions of polypropylene fibers on the workability and strength characteristics of concrete. The investigation focused on determining compressive strength, split tensile strength, and flexural strength while comparing the performance of quarry dust-based and fly ash-based concrete mixtures. The methodology was structured to identify the optimum mix combination capable of producing durable, sustainable, and high-strength concrete suitable for structural applications.

A. Material Selection and Mix Design

Ordinary Portland Cement (OPC), natural river sand, coarse aggregate, quarry dust, fly ash, polypropylene fibers, and potable water were used in this investigation. All materials were selected according to relevant Indian Standard specifications. Quarry dust obtained from stone crushing industries was used as a partial replacement material, while fly ash collected from thermal power plants served as a supplementary cementitious material. Polypropylene fibers were incorporated to improve crack resistance and tensile behavior.

Concrete was designed for M20 grade using standard mix design procedures. Two experimental groups were considered. In the first group, polypropylene fibers were combined with quarry dust at different percentages. In the second group, polypropylene fibers were combined with fly ash at varying proportions. A conventional concrete mix without fibers or supplementary materials was prepared as the control specimen. The selected proportions enabled the evaluation of individual and combined effects of polypropylene fibers, quarry dust, and fly ash on concrete performance.

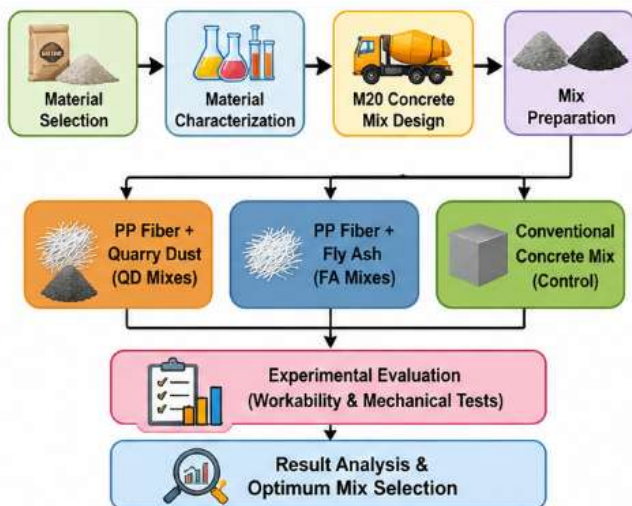


Fig. 1. Experimental Methodology Framework

B. Specimen Preparation and Curing

After proportioning the materials, dry mixing of cement, fine aggregate, coarse aggregate, quarry dust, and fly ash was performed to ensure uniform distribution. Polypropylene fibers were gradually added to avoid fiber clustering and to achieve homogeneous dispersion throughout the concrete matrix. Water was subsequently introduced, and mixing was continued until a workable and uniform concrete mixture was obtained.

Fresh concrete was subjected to a slump cone test to assess workability. The prepared concrete was then cast into standard molds. Cube specimens of dimensions 150 mm × 150 mm × 150 mm were prepared for compressive strength testing. Cylindrical specimens measuring 150 mm × 300 mm were cast for split tensile strength evaluation. Prism specimens of size 100 mm × 100 mm × 500 mm were prepared for flexural strength testing. After 24 hours, the specimens were demolded and cured in water for 7, 14, and 28 days to facilitate proper hydration and strength development.



Fig. 2. Concrete Preparation and Curing Process

C. Mechanical Testing and Performance Evaluation

After the completion of curing periods, the specimens were subjected to compressive strength, split tensile strength, and flexural strength tests. The obtained results were compared with those of conventional concrete to determine the effectiveness of polypropylene fibers, quarry dust, and fly ash in enhancing mechanical performance.

The compressive strength of concrete cubes was determined using:

$$[f_c = \frac{P}{A}] \quad (1)$$

where:

(f_c) = Compressive strength (MPa)

(P) = Ultimate load applied (N)

(A) = Cross-sectional area of cube specimen (mm²)

The split tensile strength of cylindrical specimens was calculated as:

$$[f_{\{st\}} = \frac{2P}{\pi DL}] \quad (2)$$

where:

$(f_{\{st\}})$ = Split tensile strength (MPa)

(P) = Applied load (N)

(D) = Diameter of cylinder (mm)

(L) = Length of cylinder (mm)

The flexural strength of prism specimens was determined using:

$$f_r = \frac{PL}{bd^2} \quad (3)$$

where:

(f_r) = Flexural strength (MPa)

(P) = Failure load (N)

(L) = Effective span length (mm)

(b) = Width of specimen (mm)

(d) = Depth of specimen (mm)



Fig. 3. Mechanical Testing and Analysis Framework

The experimental results obtained from all tests were analyzed systematically to evaluate the influence of polypropylene fibers, quarry dust, and fly ash on concrete performance. Comparative analysis was carried out between quarry dust-based and fly ash-based concrete mixtures to identify the optimum combination capable of producing maximum compressive, tensile, and flexural strengths. The adopted methodology provides a reliable framework for developing sustainable and high-performance concrete suitable for modern structural applications.

IV. EXPERIMENTAL RESULTS

The experimental investigation was conducted to evaluate the influence of polypropylene fibers combined with quarry dust and fly ash on the mechanical properties of concrete. The performance of the developed concrete mixes was assessed through workability, compressive strength, split tensile strength, and flexural strength tests. The obtained results were compared with conventional concrete to determine the effectiveness of the proposed materials in improving structural performance. The experimental observations indicate that the incorporation of polypropylene fibers significantly enhanced crack resistance and strength characteristics, while quarry dust and fly ash contributed to improved particle packing and matrix densification.

A. Workability Characteristics

The slump test was performed to evaluate the workability of fresh concrete mixtures. The results indicated that workability gradually decreased with increasing polypropylene fiber content. This reduction can be attributed to the large surface area of fibers, which increases internal friction within the concrete matrix and reduces flowability. However, all mixes exhibited workable consistency suitable for casting and compaction operations.

Table 1. Slump Values of Concrete Mixes

Mix ID	Slump (mm)
Control	82
QD1	78
QD2	74
QD3	70

QD4	66
FA1	80
FA2	76
FA3	72
FA4	68
FA5	64

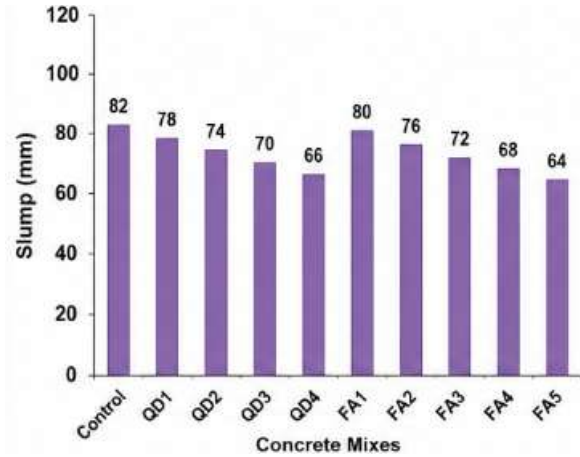


Fig. 4. Slump Values of Different Concrete Mixes

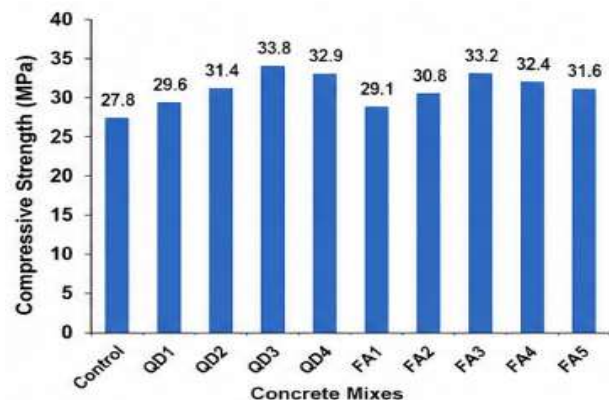
The results reveal that the control mix exhibited the highest slump value, whereas mixes containing higher fiber contents showed reduced workability. The decrease in slump remained within acceptable limits, indicating that polypropylene fibers can be incorporated without causing significant difficulties during construction.

B. Compressive Strength Analysis

Compressive strength is one of the most important parameters governing the structural performance of concrete. Cube specimens were tested after 7, 14, and 28 days of curing.

Table 2. Compressive Strength Results (MPa)

Mix ID	7 Days	14 Days	28 Days
Control	18.2	23.5	27.8
QD1	19.5	24.8	29.6
QD2	20.8	26.1	31.4
QD3	22.3	28.0	33.8
QD4	21.7	27.2	32.9
FA1	19.2	24.4	29.1
FA2	20.5	25.8	30.8
FA3	22.0	27.5	33.2



FA4	21.3	26.8	32.4
FA5	20.6	25.9	31.6

Fig. 5. Comparison of 28-Day Compressive Strength

The results demonstrate that all modified concrete mixes achieved higher compressive strength than conventional concrete. The maximum strength was observed for QD3 and FA3 mixes. The increase in strength is attributed to improved bonding, reduced microcracking, and enhanced particle packing within the concrete matrix. Beyond the optimum dosage, a slight reduction in strength was observed due to reduced workability and possible fiber agglomeration.

C. Split Tensile Strength Analysis

The split tensile strength test was conducted on cylindrical specimens to evaluate resistance against indirect tensile stresses.

Table 3. Split Tensile Strength Results (MPa)

Mix ID	7 Days	14 Days	28 Days
Control	1.95	2.45	3.12
QD1	2.15	2.68	3.42
QD2	2.28	2.84	3.67
QD3	2.48	3.12	4.01
QD4	2.39	3.01	3.88
FA1	2.10	2.62	3.35
FA2	2.24	2.81	3.61
FA3	2.43	3.06	3.95
FA4	2.34	2.95	3.82
FA5	2.25	2.83	3.65

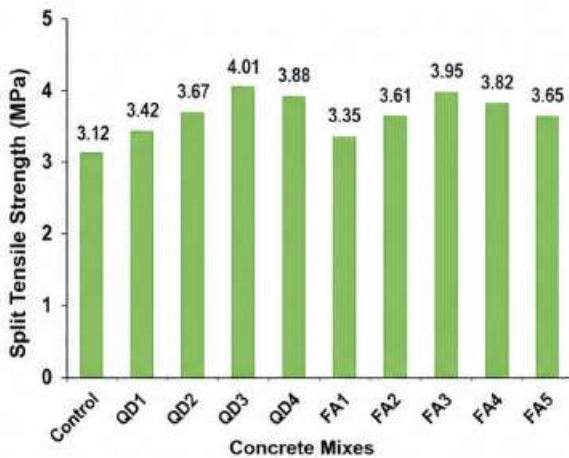


Fig. 6. 28-Day Split Tensile Strength Comparison

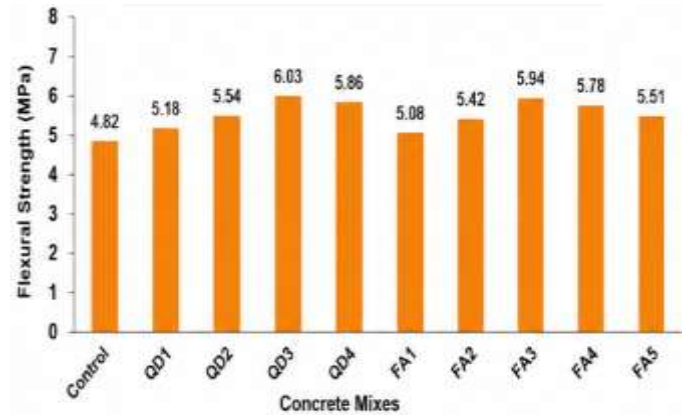
The incorporation of polypropylene fibers considerably improved tensile performance. The fibers acted as crack-bridging elements that delayed crack propagation and enhanced load transfer mechanisms. QD3 and FA3 mixes again exhibited the highest tensile strength values, confirming the effectiveness of moderate fiber content.

D. Flexural Strength Analysis

Flexural strength testing was performed to evaluate the behavior of concrete under bending loads.

Table 4. Flexural Strength Results (MPa)

Mix ID	7 Days	14 Days	28 Days
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Control	3.15	3.95	4.82
QD1	3.42	4.26	5.18
QD2	3.65	4.58	5.54
QD3	3.98	4.95	6.03
QD4	3.86	4.81	5.86
FA1	3.36	4.18	5.08
FA2	3.58	4.46	5.42
FA3	3.91	4.88	5.94
FA4	3.80	4.72	5.78
FA5	3.67	4.55	5.51

Fig. 7. 28-Day Flexural Strength Comparison

The flexural strength results showed a substantial improvement over conventional concrete. The addition of polypropylene fibers improved crack resistance and enhanced energy absorption capacity under bending loads. The highest flexural strength was recorded for the QD3 mix, followed closely by the FA3 mix.

E. Comparative Performance Evaluation

Table 6. Percentage Improvement over Conventional Concrete (28 Days)

Mix ID	Compressive (%)	Tensile (%)	Flexural (%)
QD3	21.58	28.53	25.10
FA3	19.42	26.60	23.24

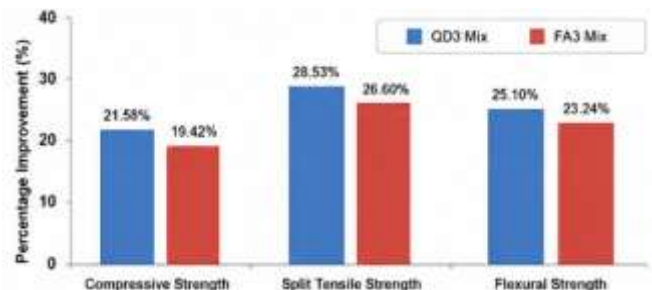


Figure 8. Performance Improvement of Optimum Mixes

The comparative analysis clearly indicates that the incorporation of polypropylene fibers with quarry dust and fly ash significantly enhanced the mechanical performance of concrete. Among all investigated mixes, the QD3 mixture exhibited the highest compressive, split tensile, and flexural

strengths. The superior performance is primarily attributed to improved particle packing, effective crack arresting action of polypropylene fibers, and enhanced interfacial bonding within the cementitious matrix.

Overall, both quarry dust and fly ash proved to be effective supplementary materials for producing sustainable concrete. However, quarry dust-based concrete exhibited slightly higher strength values than fly ash-based concrete under similar fiber dosages. The findings confirm that the combined use of polypropylene fibers and industrial by-products can successfully produce high-performance concrete suitable for structural and infrastructure applications.

V. CONCLUSION

The present study investigated the mechanical performance of Polypropylene Fiber Reinforced Concrete (PPRC) incorporating Quarry Dust (QD) and Fly Ash (FA) as supplementary materials. Experimental results demonstrated that the inclusion of polypropylene fibers significantly improved the compressive strength, split tensile strength, and flexural strength of concrete when compared with conventional concrete. The addition of quarry dust and fly ash contributed to better particle packing, improved bonding characteristics, and enhanced overall structural performance. Among the investigated mixtures, the optimum fiber dosage produced superior strength characteristics due to effective crack-bridging action and improved stress distribution within the concrete matrix. The results further indicated that quarry dust-based concrete exhibited slightly higher strength values than fly ash-based concrete under similar conditions. Therefore, the combined utilization of polypropylene fibers, quarry dust, and fly ash can be considered an effective approach for developing sustainable, durable, and high-performance concrete suitable for modern construction applications.

Future research can be extended by investigating the long-term durability characteristics of polypropylene fiber reinforced concrete under aggressive environmental conditions such as sulfate attack, chloride exposure, acid attack, and freeze-thaw cycles. The behavior of the developed concrete under elevated temperatures, impact loading, fatigue loading, and seismic conditions may also be explored to assess its suitability for critical infrastructure applications. Furthermore, optimization studies involving different fiber lengths, fiber contents, and combinations of supplementary cementitious materials can be carried out to achieve enhanced mechanical and durability performance. Advanced analytical techniques such as microstructural analysis, scanning electron microscopy (SEM), and machine learning-based strength prediction models may also be employed to gain deeper insights into the behavior of sustainable fiber reinforced concrete and support its large-scale implementation in future construction projects.

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