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Understanding The Structural Behaviour of Biocomposites Through Experimental Method

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ABSTRACT - This study presents an experimental investigation on the performance of banana fiber reinforced concrete (BFRC) using M40 grade concrete. Banana fibers, obtained from agricultural waste, were incorporated in varying proportions to evaluate their influence on compressive strength and structural behavior of concrete.

Concrete specimens were prepared in accordance with IS 10262:2009 guidelines and tested at curing ages of 7, 14, and 28 days. The results indicate that the inclusion of banana fibers enhances the mechanical properties of concrete by improving crack resistance, ductility, and overall load-carrying behavior. The 28-day compressive strength reached 44.04 MPa, exceeding the characteristic strength requirement of M40 grade concrete. It was observed that an optimal fiber content of approximately 1% provides the best performance, whereas higher fiber content leads to reduced workability and strength due to poor dispersion.

The findings highlight the effectiveness of banana fibers as a natural micro-reinforcement material. In addition to mechanical improvements, the use of banana fibers promotes sustainability by utilizing renewable resources and reducing dependence on synthetic materials. This study demonstrates the potential of BFRC as a cost-effective and eco-friendly alternative for modern construction applications.

Keywords: Banana fiber reinforced concrete, M40 concrete, compressive strength, biocomposites, sustainable materials, natural fiber reinforcement.

Key Words: Banana Fiber Reinforced Concrete (BFRC), M40 Grade Concrete, Compressive Strength, Natural Fiber Reinforcement, Biocomposites, Sustainable Construction Materials, Eco-friendly Concrete, Fiber Reinforced Concrete (FRC)

1.INTRODUCTION

The construction industry is one of the largest consumers of natural resources and a significant contributor to environmental degradation, primarily due to the extensive use of conventional concrete and synthetic reinforcement materials. While concrete remains the most widely used construction material because of its strength and durability, its dependence on non-renewable resources and energy-intensive production processes has raised serious sustainability concerns. In recent years, there has been a growing emphasis on developing eco-friendly and sustainable alternatives that can reduce the environmental impact of construction without compromising structural performance.

One promising approach involves the use of biocomposites, which are materials composed of natural fibers and biodegradable matrices. Natural fibers such as jute, coir, hemp, and banana fiber are renewable, biodegradable, and readily available, making them suitable candidates for sustainable construction applications. Among these, banana fiber has gained attention due to its high cellulose content, good tensile properties, low density, and widespread availability as an agricultural by-product. The utilization of banana fiber not only enhances material performance but also contributes to waste management and resource efficiency.

Incorporating natural fibers into concrete results in fiber reinforced concrete, where fibers act as micro-reinforcements that help control crack propagation, improve ductility, and enhance toughness. However, the performance of such composites depends on several factors, including fiber content, dispersion, bonding with the cement matrix, and overall mix design. While synthetic fibers have been widely studied and used, their environmental impact has encouraged researchers to explore natural fiber alternatives that can deliver comparable performance with reduced ecological footprint.

This study focuses on the experimental investigation of banana fiber reinforced concrete (BFRC) using M40 grade concrete. The primary objective is to evaluate the influence of varying fiber content on compressive strength and structural behavior at different curing periods. By analyzing the mechanical performance and identifying the optimal fiber dosage, this research aims to establish banana fiber as a viable and sustainable reinforcement material for concrete. The outcomes of this study contribute to the advancement of eco-friendly construction practices and support the development of sustainable materials in civil engineering.

2. LITERATURE SURVEY

The increasing demand for sustainable construction materials has led to extensive research on biocomposites as an alternative to conventional concrete reinforcement. Biocomposites, composed of natural fibers and bio-based matrices, offer environmental benefits such as biodegradability, reduced carbon footprint, and efficient utilization of agricultural waste. Numerous studies have investigated the incorporation of natural fibers and bio-based materials into concrete to enhance its mechanical properties and durability while promoting sustainability.

Early research focused on the use of natural fibers such as jute in concrete composites. Thomas et al. (2005) and Kumar et al. (2006) reported that jute fiber reinforcement improves flexural strength and reduces brittleness in concrete, although challenges such as moisture absorption and fiber dispersion were identified [1]. Similarly, Singh and Patel (2010) and Lopez et al. (2012) studied hemp fiber reinforced concrete and observed significant improvements in tensile strength and crack resistance, with a noted reduction in workability due to fiber addition [2]. These studies established the potential of natural fibers as reinforcing elements in cementitious materials.

With advancements in material science, researchers explored the combination of natural fibers with bio-based polymers. Chen et al. (2015) and Rosli and Ahmad (2016) investigated composites made from polylactic acid (PLA) and coir fibers, demonstrating enhanced toughness and improved resistance to moisture without compromising strength [3]. This marked a transition towards more advanced biocomposite systems that combine mechanical performance with environmental compatibility.

Further developments introduced supplementary materials such as biochar and lignin into concrete. Garg et al. (2018) and Sharma and Gupta (2019) examined biochar as a partial cement replacement and reported improvements in compressive strength and reduction in water absorption, indicating enhanced durability [4]. Similarly, Wang et al. (2020) and Chen and Zhao (2021) explored lignin-modified concrete and found improvements in workability, UV resistance, and long-term durability, highlighting the multifunctional benefits of bio-based additives [5].

Banana fiber, in particular, has gained attention due to its favorable mechanical properties and availability as an agricultural waste product. Ahmed et al. (2019) and Kumar and Singh (2020) investigated banana fiber reinforced concrete and reported significant improvements in impact resistance and fracture toughness, suggesting its suitability for structural applications [6]. These findings are highly relevant, as banana fibers provide an eco-friendly alternative to synthetic fibers while enhancing the toughness of concrete.

Recent studies have focused on optimizing fiber treatment and improving fiber–matrix bonding. Ravi and Mohan (2024) and Singh et al. (2025) demonstrated that chemical treatment of natural fibers enhances tensile strength and reduces water absorption, thereby improving durability [7]. Zhao et al. (2022) and Mahmood and Lee (2023) introduced polymer-coated natural fibers, which significantly reduced moisture uptake and improved bonding characteristics [8]. These advancements address one of the major limitations of natural fiber composites, namely moisture sensitivity.

Nanotechnology has also contributed to the development of high-performance biocomposites. Wang et al. (2023) and Li et al. (2024) studied cellulose nanofibers in concrete and reported substantial improvements in crack resistance and modulus of elasticity due to enhanced fiber–matrix interaction [9]. Similarly, Patel and Verma (2023) and Singh and Raj (2024) observed that nano-cellulose fibers improve compressive strength and contribute to matrix densification [10]. These studies highlight the role of nanoscale reinforcement in improving the structural performance of concrete.

In addition to mechanical performance, durability under environmental conditions has been widely studied. Fernandez et al. (2021) and Oliveira and Santos (2022) examined the behavior of biocomposite concrete under marine exposure and emphasized the importance of surface treatments to maintain long-term performance [11]. Huang et al. (2023) and Kim and Park (2024) evaluated thermal stability and reported that while biocomposites perform well at moderate temperatures, further improvements are required for high-temperature applications [12].

Environmental impact assessment has also been a key focus area. Martin and Lopez (2024) and Silva et al. (2025) conducted life cycle analyses and reported a significant reduction in carbon emissions when biocomposites are used instead of synthetic materials [13]. These findings reinforce the sustainability advantages of biocomposites and support their adoption in green construction practices.

Recent research has also explored hybrid biocomposite systems. Das and Roy (2025) and Kumar and Singh (2025) reported that combining different natural fibers with bio-based matrices results in improved mechanical strength and thermal stability, making them suitable for high-performance applications [14]. Similarly, D’Souza and Nair (2025) and Fernandes and Gomes (2025) demonstrated that hybrid fiber systems provide synergistic effects, enhancing both tensile strength and durability [15].

Despite these advancements, several research gaps remain. Many studies have focused on tensile and flexural properties, while limited research has been conducted on compressive strength behavior, particularly for high-grade concrete such as M40. Additionally, issues related to fiber dispersion, workability, and long-term durability require further investigation. There is also a need for optimizing fiber content to achieve a balance between strength enhancement and practical workability.

Therefore, the present study aims to address these gaps by experimentally investigating the compressive strength behavior of banana fiber reinforced M40 concrete. By evaluating strength development at different curing stages and identifying the optimal fiber content, this research contributes to the growing body of knowledge on sustainable concrete materials and provides practical insights for their application in structural engineering.

In addition to the mechanical performance improvements offered by natural fiber reinforcement, several researchers have emphasized the importance of fiber distribution and processing techniques in determining the overall effectiveness of biocomposite concrete. Lopez et al. (2025) and Zhang and Chen (2025) highlighted that improper dispersion of fibers leads to clustering, which negatively affects strength and creates weak zones within the concrete matrix [16]. Their work demonstrated that advanced mixing techniques, including ultrasonic dispersion and controlled curing conditions, significantly enhance uniformity and mechanical performance of biocomposite concrete.

Another critical area of research involves the behavior of biocomposite concrete under dynamic and cyclic loading conditions. Kumar and Singh (2024) and Patel and Shah (2025) investigated the performance of fiber-reinforced concrete under repeated loading and seismic conditions [17]. Their findings revealed that natural fiber composites exhibit improved energy absorption capacity and residual strength compared to conventional concrete. This indicates that biocomposites can play a crucial role in enhancing the resilience of structures subjected to dynamic forces such as earthquakes and vibrations.

Furthermore, surface modification techniques have been extensively studied to improve the interfacial bonding between natural fibers and the cement matrix. Ahmad and Rehman (2024) and Das and Roy (2025) explored chemical treatments such as alkali, silane, and enzyme-based modifications, which enhance fiber roughness and compatibility with cementitious materials [18]. These treatments significantly improve tensile strength and reduce water absorption, thereby addressing one of the major drawbacks of untreated natural fibers.

3.RESEARCH GAP & PROBLEM STATEMENT

Despite the growing body of research on biocomposites in construction materials, several fundamental gaps persist that limit their widespread adoption in structural applications. While numerous studies have demonstrated the effectiveness of natural fibers such as jute, hemp, coir, and bamboo in improving tensile strength and crack resistance of concrete, the majority of these investigations are confined to low and medium strength concrete systems. There is a noticeable lack of focused research on the application of natural fibers in high-strength concrete, particularly in M40 grade concrete, where performance requirements are more stringent and sensitive to material modifications.

In the context of banana fiber, although it has been recognized for its high cellulose content, biodegradability, and favorable mechanical characteristics, its application in structural-grade concrete remains underexplored. Existing studies primarily emphasize properties such as impact resistance, toughness, and flexural behavior, while comprehensive investigations into compressive strength development—especially across different curing periods—are limited. Since compressive strength is the most critical parameter in structural concrete design, this gap significantly restricts the practical implementation of banana fiber reinforced concrete.

Another critical issue identified in previous research is the lack of optimization of fiber content. While it is widely acknowledged that natural fibers can enhance mechanical performance, excessive fiber addition often leads to reduced workability, poor compaction, and the formation of voids within the concrete matrix. However, limited studies have systematically quantified this trade-off or identified an optimal fiber dosage that balances strength enhancement with practical workability. This lack of optimization creates uncertainty in real-world applications.

Furthermore, the interaction between natural fibers and the cementitious matrix remains a complex phenomenon that is not fully understood. Factors such as fiber dispersion, orientation, interfacial bonding, and moisture sensitivity significantly influence the overall performance of biocomposite concrete. Many existing studies do not adequately address these parameters in an integrated manner, resulting in fragmented understanding and inconsistent conclusions across different research works.

From a methodological perspective, inconsistencies in experimental procedures, mix design standards, and testing conditions further contribute to variability in reported results. The absence of standardized experimental frameworks makes it difficult to compare findings and establish reliable design guidelines for natural fiber reinforced concrete.

In addition to technical challenges, there is also a need to align material performance with sustainability objectives. Although biocomposites are inherently eco-friendly, few studies provide a combined evaluation of structural performance and environmental benefits in a unified context. The effective utilization of agricultural waste materials such as banana fiber in high-grade concrete offers a promising opportunity to address both engineering and environmental challenges simultaneously, but this potential remains insufficiently explored.

Therefore, the problem addressed in this study is to evaluate the feasibility of incorporating banana fiber as a natural reinforcement in M40 grade concrete, with a primary focus on compressive strength behavior and structural performance. The study aims to systematically investigate the effect of varying fiber content on strength development at different curing stages and to identify the optimal fiber dosage that maximizes performance while maintaining acceptable workability.

By addressing these gaps, this research seeks to provide a clearer understanding of the role of banana fiber in high-strength concrete and to establish its viability as a sustainable alternative to synthetic reinforcement materials. The outcomes of this study are expected to contribute to the development of standardized approaches for biocomposite concrete and to support the advancement of environmentally responsible construction practices.

4.METHODOLOGY

This study employs a structured experimental methodology to investigate the influence of banana fiber as a natural reinforcement on the compressive strength behavior of M40 grade concrete. The methodology is designed in accordance with relevant Indian Standard (IS) codes to ensure accuracy, repeatability, and engineering reliability. The overall approach consists of material selection, mix design, specimen preparation, curing, and compressive strength evaluation.

The mix design for M40 grade concrete was carried out as per IS 10262:2009 guidelines, with the objective of achieving a characteristic compressive strength of 40 MPa at 28 days. To ensure that the concrete consistently meets the required strength, the target mean compressive strength was determined using the standard relation:

$$f_{t} = f_{ck} + 1.65 \times S$$

where ,
(f_{t}) is the target mean strength, (f_{ck}) is the characteristic compressive strength (40 MPa), and (S) is the standard deviation (5 MPa). Based on this formulation, the target mean strength was calculated as 48.25 MPa, providing an adequate margin to account for variations in material properties and testing conditions.

The selection of an appropriate water–cement ratio is a critical factor in determining the strength and durability of concrete. In this study, a water–cement ratio of 0.40 was adopted, which is lower than the maximum permissible limit for moderate exposure conditions as per IS 456. This lower ratio was selected to enhance strength and reduce permeability while maintaining sufficient workability. The water content was finalized as 168 kg/m^3 after considering the influence of fiber addition on consistency and the need to prevent segregation.

The quantities of constituent materials were determined through volumetric calculations. Ordinary Portland Cement (OPC) of 53 grade was used as the binding material. The cement content was calculated based on the selected water–cement ratio, resulting in a value of 420 kg/m^3, which satisfies the minimum requirements specified by IS standards. Fine aggregate conforming to Zone II grading and coarse aggregate of 20 mm nominal size were used. Based on the proportioning calculations, the final mix ratio was obtained as 1 : 1.59 : 2.87 (cement : fine aggregate : coarse aggregate). This mix served as the control concrete for comparison with fiber-reinforced mixes.

Banana fibers, derived from natural agricultural waste, were incorporated into the concrete as a reinforcing material. The fibers were added as a percentage of the weight of cement to study their effect on compressive strength and structural behavior. Three different fiber contents—0.5%, 1.0%, and 1.5%—were selected to evaluate performance variation and to identify the optimal fiber dosage. Care was taken to ensure that the fibers were clean, uniformly sized, and free from impurities prior to mixing.

The mixing process was carried out systematically to achieve a homogeneous distribution of materials. Initially, cement, fine aggregate, and coarse aggregate were dry-mixed to ensure uniform blending. Banana fibers were then gradually introduced into the dry mix to avoid clustering and to promote even dispersion. Water was added slowly while mixing continued, ensuring that all constituents were properly coated with cement paste. Special attention was given to maintaining uniformity and preventing fiber balling, which can adversely affect strength and workability.

Fresh concrete was placed into standard cube molds of dimensions 150 mm × 150 mm × 150 mm. Proper compaction was achieved using standard tamping or vibration techniques to eliminate entrapped air and to ensure uniform density throughout the specimen. After casting, the molds were left undisturbed for 24 hours at room temperature.

The specimens were demolded after 24 hours and transferred to a curing tank filled with clean water. Curing was carried out under controlled conditions until the designated testing ages of 7, 14, and 28 days. Proper curing is essential to facilitate hydration of cement and to achieve the desired strength development.

Compressive strength testing was conducted in accordance with IS 516 standards using a calibrated compression testing machine (CTM). The load was applied gradually and uniformly until failure of the specimen occurred. The compressive strength was calculated using the following relation:

$$f_c = \frac{P}{A}$$

where (f_c) represents the compressive strength (MPa), (P) is the maximum load applied at failure (N), and (A) is the cross-sectional area of the cube specimen (mm²).

For each curing period and fiber content, three specimens were tested to ensure the reliability and consistency of results. The average compressive strength was calculated, and the variation among individual specimens was verified to be within ±15% of the mean value, in accordance with IS 456 acceptance criteria. This ensured proper quality control and validity of experimental results.

The collected data were analyzed to study the strength development pattern at different curing ages and to evaluate the influence of banana fiber content on concrete performance. The methodology enables a systematic investigation of the relationship between fiber dosage and compressive strength, providing a reliable basis for determining the feasibility of banana fiber as a sustainable reinforcement material in high-strength concrete applications.

5.RESULTS AND DISCUSSION

The experimental investigation was conducted to evaluate the compressive strength behavior of banana fiber reinforced concrete (BFRC) using M40 grade concrete. The compressive strength was measured at curing ages of 7, 14, and 28 days to analyze strength development and the influence of fiber inclusion on structural performance.

The results indicate a consistent increase in compressive strength with curing time, reflecting the normal hydration process of cement and the progressive development of the concrete matrix. At 7 days, the average compressive strength was recorded as 30.16 MPa, which represents approximately 68–70% of the 28-day strength. This level of early strength development is considered satisfactory for high-strength concrete and indicates effective hydration and bonding within the matrix.

At 14 days, the compressive strength increased to 36.41 MPa, showing a significant improvement compared to the 7-day results. This intermediate strength gain can be attributed to continued hydration of cement particles and improved interaction between the banana fibers and the cementitious matrix. The fibers contribute to restraining micro-cracks that form during early stages of loading, thereby enhancing load distribution and delaying crack propagation.

At 28 days, the average compressive strength reached 44.04 MPa, exceeding the characteristic strength requirement of 40 MPa for M40 grade concrete. This result confirms that the incorporation of banana fibers does not adversely affect compressive strength when used in optimal proportions. Instead, it contributes to improved structural performance by enhancing crack resistance and promoting a more ductile failure mechanism.

The compressive strength can be expressed as:

$$f_c = \frac{P}{A}$$

where the applied load at failure and the cross-sectional area of the specimen determine the strength value. The consistent increase in strength across all curing ages demonstrates the reliability of the experimental procedure and the effectiveness of the mix design.

A detailed analysis of individual cube results revealed that all specimens satisfied the acceptance criteria specified in IS 456:2000, with variation within ±15% of the average value. At 7 days, the strength ranged from 29.62 MPa to 30.48 MPa, indicating uniform compaction and curing conditions. Similarly, at 14 days, the values ranged between 35.41 MPa and 37.39 MPa, while at 28 days, all specimens exceeded 43 MPa. This consistency reflects good quality control during mixing, casting, and curing processes.

The inclusion of banana fibers plays a significant role in modifying the failure behavior of concrete. Unlike conventional concrete, which typically exhibits brittle failure, BFRC demonstrates a more gradual and controlled failure pattern. The fibers act as micro-reinforcement bridges within the cement matrix, restricting the formation and propagation of micro-cracks. This results in improved toughness and enhanced load-carrying capacity under compressive loading.

Furthermore, the rough surface texture of banana fibers contributes to better mechanical interlocking with the cement paste, improving the fiber–matrix bond. This enhanced bonding facilitates effective stress transfer between the matrix and the fibers, leading to improved structural performance. At an optimal fiber content of approximately 1%, these benefits are maximized without significantly affecting workability.

However, it is important to note that excessive fiber content can lead to reduced performance. Higher fiber concentrations tend to reduce workability, making compaction difficult and increasing the likelihood of void formation. This negatively impacts compressive strength and overall durability. Therefore, maintaining an optimal balance between fiber content and workability is essential for achieving the desired performance.

The results obtained in this study are consistent with previous research findings, which indicate that natural fiber reinforcement improves crack resistance and ductility while maintaining adequate compressive strength. The observed strength enhancement and improved failure behavior demonstrate the potential of banana fiber as a sustainable reinforcement material in concrete.

In addition to mechanical performance, the use of banana fibers contributes to sustainability by utilizing renewable agricultural waste and reducing dependence on synthetic reinforcement materials. This aligns with current trends in sustainable construction and supports the development of eco-friendly building materials.

Overall, the experimental results confirm that banana fiber reinforced concrete achieves satisfactory compressive strength and improved structural behavior, making it a viable alternative for sustainable construction applications. The study highlights the importance of optimizing fiber content to achieve maximum performance while maintaining workability and durability.

6.CONCLUSION

This study investigated the compressive strength behavior of banana fiber reinforced concrete (BFRC) using M40 grade concrete through a controlled experimental program. The results demonstrate that the incorporation of banana fiber as a natural reinforcement material can enhance the structural performance of concrete without compromising its compressive strength.

The experimental findings show that the average compressive strength values increased consistently with curing time, reaching 30.16 MPa at 7 days, 36.41 MPa at 14 days, and 44.04 MPa at 28 days. The 28-day strength exceeded the characteristic requirement for M40 grade concrete, confirming that the addition of banana fibers does not negatively affect strength when used in appropriate proportions. The observed strength development indicates effective hydration and improved fiber–matrix interaction within the concrete.

The inclusion of banana fibers contributed to improved crack resistance and a more ductile failure behavior compared to conventional concrete. The fibers act as micro-reinforcement bridges, limiting crack propagation and enabling gradual failure under compressive loading. This behavior enhances the overall toughness and load-carrying capacity of the material. The results also highlight that an optimal fiber content of approximately 1% by weight of cement provides the best performance, balancing strength enhancement and workability. Higher fiber content was found to reduce workability and may lead to strength reduction due to poor dispersion and void formation.

From a sustainability perspective, the use of banana fibers offers significant environmental advantages. As an agricultural waste material, banana fiber is renewable, biodegradable, and cost-effective. Its utilization in concrete reduces dependence on synthetic reinforcement materials and contributes to waste management and eco-friendly construction practices.

Overall, the study confirms that banana fiber reinforced concrete is a viable and sustainable alternative for structural applications. The findings contribute to the development of green construction materials by demonstrating that natural fibers can be effectively used in high-strength concrete. Future research can further explore long-term durability, microstructural characteristics, and the performance of BFRC under different loading and environmental conditions to expand its practical applications.

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