

Performance Evaluation Of Cellulose Fiber-Engineered Concrete For Structural Applications

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Abstract- Concrete is the most widely used construction material; however, its low tensile strength, brittleness, and susceptibility to cracking limit its performance in structural applications. The incorporation of natural and cellulose-based fibers offers a sustainable and eco-friendly solution to improve the mechanical and durability properties of concrete. This study investigates the influence of various natural fibers (cotton, jute, and sisal) and cellulose-derived fibers (viscose, Tencel, and cellulose acetate) on the performance of M25 grade concrete. Concrete mixes were prepared with fiber contents ranging from 0.1% to 2.0% by weight of cement. The specimens were tested for compressive strength, flexural strength, water absorption, and Ultrasonic Pulse Velocity (UPV) at different curing ages. The experimental results indicated that the incorporation of fibers significantly enhanced the mechanical performance of concrete up to an optimum dosage of approximately 1.25%. Beyond this level, strength gradually decreased due to reduced workability, fiber agglomeration, and increased porosity. Among all the fibers investigated, Tencel fiber exhibited the best overall performance, achieving a maximum 28-day compressive strength of 37.2 MPa and flexural strength of 7.2 MPa at 1.25% fiber content. Sisal and cellulose acetate fibers also demonstrated excellent performance, with compressive strengths of 36.3 MPa and 36.0 MPa, respectively. The addition of fibers improved crack resistance, toughness, and post-cracking behavior of concrete by bridging microcracks and delaying crack propagation. Water absorption increased with increasing fiber content due to the hydrophilic nature of the fibers; however, the increase remained within acceptable limits at optimum dosages. UPV results confirmed good internal quality and homogeneity of the fiber-reinforced concrete, with maximum values of approximately 4.7 km/s observed for Tencel, sisal, and cellulose acetate fiber mixes. The study concludes that natural and cellulose-based fibers can be effectively utilized as sustainable reinforcing materials in concrete. Their incorporation enhances mechanical strength, crack resistance, and durability while promoting environmentally friendly construction practices through the use of renewable and biodegradable resources. Among the fibers studied, Tencel fiber was found to be the most effective in improving the overall performance of concrete.

Keywords: Fiber Reinforced Concrete, Cellulose Fiber, Natural Fiber, Tencel Fiber, Sisal Fiber, Compressive Strength, Flexural Strength, Water Absorption, Ultrasonic Pulse Velocity, Sustainable Construction.

I. INTRODUCTION

Concrete is the most widely used construction material in the world due to its excellent compressive strength, durability, availability, and versatility in various structural applications. Despite these advantages, conventional concrete possesses low tensile strength, limited ductility, and a tendency to develop cracks under mechanical and environmental stresses. These cracks can reduce the service life and durability of concrete structures. To overcome these limitations, researchers have explored the use of fiber reinforcement as an effective method for improving concrete performance.

Natural and cellulose-based fibers have gained significant attention as sustainable alternatives to synthetic fibers because they are renewable, biodegradable, cost-effective, and environmentally friendly. Fibers such as cotton, jute, sisal, viscose, Tencel, and cellulose acetate can enhance the mechanical properties of concrete by controlling crack propagation, improving tensile and flexural strength, and increasing toughness and ductility. In addition, these fibers contribute to sustainable construction by reducing environmental impact and promoting the use of renewable resources.

The present study investigates the influence of different natural and cellulose-based fibers on the mechanical and durability properties of M25 grade concrete. The performance of fiber-reinforced concrete is evaluated through compressive strength, flexural strength, water absorption, and Ultrasonic Pulse Velocity (UPV) tests to determine the optimum fiber type and dosage for improved concrete performance.

II. LITERATURE REVIEW

The incorporation of fibers in concrete has become an effective approach for improving strength, toughness, crack resistance, and durability. Natural and cellulose-based fibers have attracted significant attention due to their biodegradability, renewability, low cost, and environmental sustainability.

Li et al. (2006) investigated the use of natural fibers in cementitious composites and reported that fibers effectively bridge microcracks, enhance flexural strength, and improve post-cracking behavior. Similarly, Toledo Filho et al. (2003) observed that sisal fiber reinforced concrete exhibited enhanced tensile and flexural strength due to improved crack-arresting mechanisms and energy absorption capacity.

Jute fibers have also demonstrated promising performance in concrete applications. Azwa et al. (2013) reported that jute fibers improve toughness and crack resistance while maintaining adequate strength characteristics. However, the long-term durability of natural fibers remains a concern because of their degradation in alkaline cement environments. Savastano et al. (2000) further highlighted that vegetable fibers can significantly reduce concrete brittleness and improve ductility.

Research on cellulose-based fibers has shown considerable potential for sustainable concrete production. Woodings (2001) reported that regenerated cellulose fibers improve cohesion and crack resistance in cementitious materials. Kalia et al. (2011) observed that cellulose fibers such as viscose and Tencel possess excellent mechanical properties and compatibility with cement matrices. Bledzki and Gassan (1999) found that Tencel fibers provide high tensile strength, dimensional stability, and effective stress transfer, leading to improved concrete performance. Furthermore, Edgar et al. (2001) reported that cellulose acetate fibers exhibit lower water absorption and better chemical resistance than many natural fibers.

Several studies have concluded that fiber addition improves compressive and flexural strengths up to an optimum dosage, generally between 0.5% and 1.5% by weight of cement. Beyond this limit, workability decreases due to fiber agglomeration and increased internal friction, resulting in reduced strength. Although many researchers have investigated individual fiber types, comparative studies involving cotton, jute, sisal, viscose, Tencel, and cellulose acetate fibers under identical conditions remain limited. Therefore, the present study aims to compare these fibers and

identify the most effective sustainable reinforcement for M25 grade concrete.

III. METHODOLOGY

3.1 Materials

M25 grade concrete was prepared using Ordinary Portland Cement (OPC 53 Grade), natural river sand as fine aggregate, crushed coarse aggregate of maximum size 20 mm, and potable water. Six different fibers, namely cotton, jute, sisal, viscose, Tencel, and cellulose acetate, were used as reinforcing materials. The fibers were incorporated into concrete at varying contents of 0.1%, 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5%, 1.75%, and 2.0% by weight of cement.

3.2 Mix Design

The concrete mix was designed according to IS 10262:2019 for M25 grade concrete. The control mix proportion was 1:1.65:3.10 (cement aggregate aggregate) with a water-cement ratio of 0.45. For 1 m³ of concrete, the quantities of materials were 400 kg cement, 660 kg fine aggregate, 1240 kg coarse aggregate, and 180 liters of water.

3.3 Preparation of Fiber Reinforced Concrete

Dry mixing of cement and aggregates was carried out initially, followed by the gradual addition of fibers to ensure uniform dispersion. Water was then added, and mixing continued until a homogeneous concrete mix was obtained. Concrete specimens were cast in standard molds and compacted properly to eliminate entrapped air.

3.4 Curing and Testing

After 24 hours, the specimens were demolded and cured in water for 7 and 28 days. Compressive strength tests were conducted on 150 mm cube specimens as per IS 516, while flexural strength tests were performed on prism specimens using the two-point loading method. Durability was evaluated through water absorption tests, and concrete quality was assessed using the Ultrasonic Pulse Velocity (UPV) test. The experimental results were compared to determine the optimum fiber type and dosage for enhancing the mechanical and durability performance of concrete.

IV. RESULTS AND DISCUSSION

4.1 Mechanical Properties

The experimental results demonstrated that the incorporation of natural and cellulose-based fibers significantly influenced the mechanical performance of M25 grade concrete. Table 1 summarizes the optimum 28-day compressive strength, flexural strength, and UPV values obtained for different fiber types, while Figure 1 illustrates the comparative performance of all fibers.

The compressive and flexural strengths increased with increasing fiber content up to an optimum dosage of 1.25%. Beyond this level, strength decreased due to reduced workability, fiber agglomeration, and the formation of additional voids. Among all fibers, Tencel fiber exhibited the highest performance, achieving a compressive strength of 37.2 MPa and flexural strength of 7.2 MPa at 1.25% fiber content. Sisal and cellulose acetate fibers also showed significant improvements, with compressive strengths of 36.3 MPa and 36.0 MPa, respectively.

Table 1. Comparative Performance of Different Fibers at Optimum Content

Fiber Type	Compressive Strength (MPa)	Flexural Strength (MPa)	UPV (km/s)
Cotton	—	4.5	4.2
Jute	35	6.7	4.6
Sisal	36.3	7	4.7
Viscose	35.6	6.8	4.6
Tencel	37.2	7.2	4.7
Cellulose Acetate	36	6.9	4.7

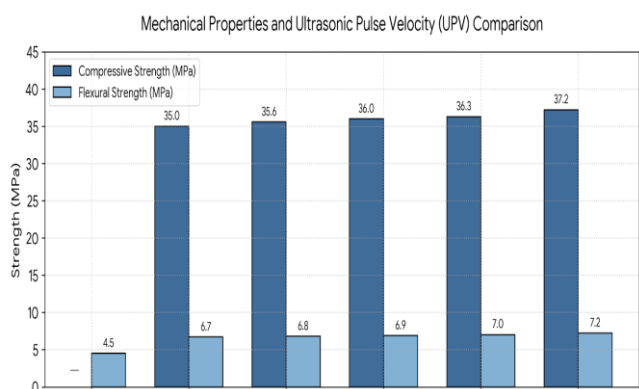


Figure 1. Comparative mechanical testing performance of different fibers at optimum dosage.

4.2 Durability Characteristics

The water absorption results indicated that fiber addition increased the water absorption capacity of concrete. This behavior is mainly attributed to the hydrophilic nature of

natural and cellulose fibers. However, moderate fiber contents improved crack resistance and toughness by restricting the propagation of microcracks.

Tencel, sisal, and cellulose acetate fibers exhibited relatively lower water absorption compared to other fibers at similar dosages, indicating better durability performance. The results suggest that optimum fiber addition can enhance mechanical properties without causing excessive deterioration in durability.

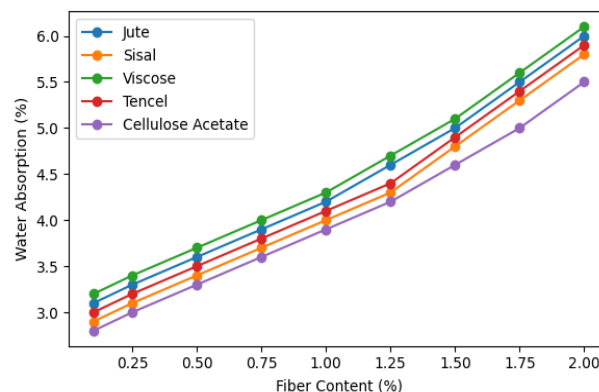


Figure 2. Effect of Fiber Content on Water Absorption of concrete

The trend shown in Figure 2 indicates a gradual increase in water absorption with increasing fiber content for all fiber types. The increase became more pronounced beyond 1.25% fiber dosage.

4.3 Ultrasonic Pulse Velocity (UPV)

UPV measurements were used to evaluate the quality and homogeneity of concrete. The results showed that UPV values increased with fiber content up to the optimum dosage and then decreased slightly at higher fiber percentages. The highest UPV values of approximately 4.7 km/s were recorded for Tencel, sisal, and cellulose acetate fiber reinforced concrete, indicating dense and high-quality concrete with fewer internal defects.

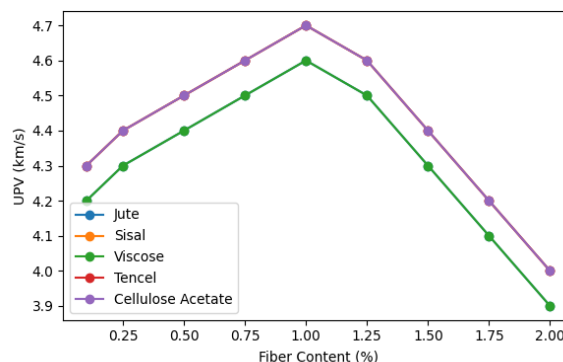


Figure 3. Effect of Fiber Content on UPV of Concrete

The results confirm that the incorporation of fibers improved the internal structure of concrete by controlling crack formation and enhancing matrix integrity. However, excessive fiber addition reduced compaction efficiency, leading to a slight decline in UPV values.

4.4 Discussion

The overall results indicate that natural and cellulose-based fibers effectively enhance the mechanical and durability performance of concrete. The improvement is primarily attributed to the crack-bridging action of fibers, which delays crack initiation and propagation. Among all fibers investigated, Tencel fiber exhibited the best overall performance due to its high tensile strength, superior bonding characteristics, and dimensional stability. Therefore, Tencel fiber can be considered the most suitable fiber for developing sustainable and high-performance concrete.

V. CONCLUSION

This study evaluated the influence of natural fibers (cotton, jute, and sisal) and cellulose-based fibers (viscose, Tencel, and cellulose acetate) on the mechanical and durability properties of M25 grade concrete. The experimental results demonstrated that fiber incorporation significantly improved the performance of concrete up to an optimum dosage of 1.25% by weight of cement.

The addition of fibers enhanced compressive strength, flexural strength, crack resistance, and overall toughness of concrete. Among all the fibers investigated, Tencel fiber exhibited the best performance, achieving a maximum 28-day compressive strength of 37.2 MPa and flexural strength of 7.2 MPa. Sisal and cellulose acetate fibers also showed notable improvements in strength and durability characteristics. The improvement in mechanical properties was mainly attributed to the crack-bridging action of fibers, which delayed crack propagation and improved stress distribution within the concrete matrix.

Water absorption increased with increasing fiber content due to the hydrophilic nature of the fibers; however, the values remained within acceptable limits at optimum fiber dosages. Ultrasonic Pulse Velocity (UPV) results confirmed good internal quality and homogeneity of the fiber-reinforced concrete, with the highest values observed for Tencel, sisal, and cellulose acetate fibers.

Overall, the findings indicate that natural and cellulose-based fibers can be effectively utilized as sustainable reinforcing materials in concrete. Their incorporation not only enhances mechanical and durability properties but also supports environmentally friendly construction practices through the use of renewable and biodegradable resources.

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