COTTON FIBERS FOR IMPROVED CONCRETE TENSILE STRENGTH AND CRACK RESISTANCE IN SLABS

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Abstract- Concrete is one of the most used materials in construction because of its high compressive strength. However, it tends to perform poorly under tensile stress, often resulting in cracks and reduced service life of structures. In this study, experimental investigation is done to explore whether adding cotton fiber repurposed from post-industrial textile waste can help improve the tensile behavior of concrete. This approach not only targets mechanical enhancement but also introduces an environmentally conscious alternative to conventional synthetic fibers. To evaluate this, cylindrical specimens of both plain cement concrete (PCC) and cotton fiber-reinforced concrete (CFRC) were prepared, with 0.5% cotton fiber added by weight in the CFRC mix. After 28 days of water curing, the samples were tested using a Universal Testing Machine (UTM) as per ASTM C496 standards. The performance was assessed based on tensile strength. Interestingly, while CFRC samples showed a slightly lower tensile strength (0.8 MPa) compared to PCC (0.9 MPa), they demonstrated much better ductility and crack control. The cotton fibers acted as internal bridges, slowing down crack formation and allowing the material to absorb more energy before failure increasing toughness up to 7 times. These results suggest that CFRC, despite a modest reduction in peak tensile strength, could be a strong candidate for use in applications where long-term durability and crack resistance are key priorities.

Keywords- Tensile Strength, Cotton Fibers, Crack Resistance, Sustainable Concrete

1 Introduction

Concrete is universally acknowledged as one of the most important and extensively utilized construction materials due to its exceptional compressive strength, durability, and versatility. It forms the essential structural element in a vast array of infrastructure projects, ranging from residential and commercial buildings to complex transportation networks such as highways, tunnels, and bridges. The material's ability to withstand heavy compressive loads has made it indispensable in modern construction practices [1][2] [3]. However, despite these advantages, concrete exhibits an inherent lack in its tensile strength. This weakness becomes particularly critical in applications where tensile forces are unavoidable, leading to the initiation and propagation of cracks. Early age cracking, often occurring within days or weeks after placement, can severely compromise the structural integrity, serviceability, and longevity of concrete components. These cracks not only allow deleterious agents such as moisture, chlorides, and carbon dioxide to penetrate the matrix but also facilitate corrosion of embedded steel reinforcement, which can accelerate deterioration processes and jeopardize structural safety [4][5]. Consequently, tensile cracking remains a persistent challenge faced by engineers aiming to ensure both the safety and durability of concrete structures over their expected design life. Addressing this limitation is essential to enhance the performance of concrete, especially in applications exposed to dynamic loads, aggressive environmental conditions, or long-term service demands [1][2].

Fiber reinforcement has emerged as a widely accepted and highly effective strategy to mitigate the intrinsic brittleness and limited tensile capacity of plain concrete. The incorporation of discrete fibers into the cementitious matrix transforms the material into fiber-reinforced concrete (FRC), a composite engineered to enhance crack resistance, post-cracking ductility, and overall tensile performance [10][14]. These fibers, which may be composed of steel, synthetic polymers, or natural materials, serve as micro-reinforcements that arrest crack initiation and propagation by bridging across micro- and macro-cracks as they develop. This bridging mechanism facilitates a more uniform distribution of tensile stresses within the matrix, thereby reducing localized stress concentrations at crack tips and improving the composite's ductility and toughness [9][4][14][15]. The fibers absorb and redistribute tensile loads that plain concrete is unable to bear, effectively increasing the material's tensile strength and energy absorption capacity. Furthermore, fibers significantly reduce concrete's inherent brittleness by allowing it to sustain mechanical loads even after the formation of initial cracks, a post-crack load-carrying capacity that is particularly vital in structural elements subjected to dynamic loading, fatigue, or cyclic stresses [3][10][14]. Consequently, the application of fiber reinforcement extends the service life of concrete structures, minimizes repair and maintenance demands, and promotes economic efficiency and environmental sustainability by prolonging infrastructure durability [16]. Considering increasing global emphasis on sustainable construction practices and the urgent need to reduce environmental impacts, research has progressively shifted toward the exploration of natural fibers as eco-friendly alternatives to traditional synthetic and steel fibers.

Natural fibers offer a range of environmental advantages, including renewability, biodegradability, lower embodied energy, and a reduced carbon footprint when compared to their synthetic counterparts [17][18]. Their adoption aligns with the principles of sustainable development by minimizing dependence on finite resources and encouraging circular economy approaches through waste valorization and material reuse [19]. Among natural fibers, cotton has gained considerable interest due to its abundance as a byproduct of the textile and agricultural industries, especially when recycled from discarded textile waste streams. These recycled cotton fibers provide an economically viable and environmentally responsible reinforcement option, transforming what would otherwise be landfill waste into a valuable construction resource [5][6][20]. Cotton fibers possess a unique combination of advantageous physical properties including light weight, high aspect ratio, and sufficient tensile strength that enable effective integration into conventional concrete mixes without adversely impacting fresh concrete workability or compaction [21]. The fibrous morphology of cotton allows it to act as a mechanical barrier that inhibits crack opening and deflects crack propagation paths, thereby enhancing the toughness and crack control capabilities of the concrete matrix [22]. Incorporating cotton fibers into concrete not only improves the mechanical and durability performance of the composite but also addresses critical environmental imperatives by mitigating textile waste accumulation and lowering the ecological footprint of construction materials [23]. This convergence of performance enhancement and environmental stewardship underscores the promising role of cotton fiber-reinforced concrete (CFRC) as a sustainable and practical material solution for modern green construction and infrastructure applications [24]. The present study is dedicated to investigating the potential of CFRC to enhance the tensile behavior of concrete through a series of controlled laboratory experiments focusing on split tensile strength. Split tensile strength is a critical mechanical property that reflects concrete's resistance to tensile forces and its ability to delay crack formation [25].

2 Methodology

2.1 Raw Materials

The materials used in this study were selected to ensure both standard concrete performance and sustainability through fiber reinforcement. Ordinary Portland Cement (OPC) was employed as the primary binder due to its widespread availability and reliable development [25]. Natural river sand, conforming to ASTM C33 grading requirements, served as the fine aggregate, providing adequate particle size distribution and cleanliness to optimize workability and matrix cohesion [26]. Crushed stone with a nominal size of 20 mm was used as coarse aggregate, offering the necessary hardness and angularity to enhance compressive strength and stability [27]. Clean tap water, free from harmful impurities, was utilized for both mixing and curing to ensure proper hydration and durability of the concrete [28]. The study's innovative aspect involved the incorporation of recycled post-industrial cotton fibers derived from textile waste, which were carefully processed and cleaned to achieve consistent fiber length and quality [29][30]. These natural fibers, characterized by their lightweight, tensile strength, and fibrous morphology, were integrated into the mix to improve crack resistance, tensile behavior, and energy absorption while supporting circular economy principles by reducing textile waste [31][32].

Collectively, these materials were combined with attention to compatibility and performance, aiming to produce a fiber-reinforced concrete composite that balances mechanical enhancement with environmental responsibility

Figure 1: Raw materials used for samples preparation (Left) and microscopic view of Cotton Fibre Thread (Right)

2.2 Mix Design, Preparation, and Casting

The concrete mix was carefully designed based on a conventional 1:2:4 proportion by weight for cement, sand, and coarse aggregate, respectively, ensuring a balanced combination to achieve adequate strength and workability. A water-cement ratio of 0.48 was maintained throughout the mixing process to optimize hydration while controlling porosity and durability characteristics. Recycled cotton fibers were added to the mix at 0.5% by volume of concrete, as determined from preliminary trials and literature support. Initially, all the dry ingredients were thoroughly blended to ensure homogeneity before the gradual addition of clean water, which was introduced in measured increments to obtain a consistent and workable mixture without causing segregation or excessive slump. To incorporate the recycled cotton fibers effectively, cotton fibers were carefully introduced into the mix in multiple thin layers during mixing, a technique aimed at promoting uniform dispersion and minimizing the risk of fiber agglomeration or clumping, which could adversely affect the composite's mechanical performance and workability. Cylindrical specimens with dimensions of 100 mm diameter and 200 mm height were cast in precision-engineered steel molds to ensure dimensional accuracy and repeatability of test samples. After casting, the specimens were left undisturbed for 24 hours to allow initial setting and sufficient strength gain for demolding. Subsequently, the specimens were demolded carefully to prevent damage and transferred to a curing tank where they were submerged in clean water for a standard curing period of 28 days. This water curing environment provided ideal moisture conditions to promote continuous hydration of the cementitious matrix, ensuring optimal strength development and durability consistent with ASTM guidelines [34].

2.3 Testing Procedure

After the completion of the 28-day curing period, the split tensile strength of the specimens was evaluated in accordance with the standardized ASTM C496 testing procedure [13]. Each cylindrical specimen was positioned horizontally as shown in Figure 2 in a Universal Testing Machine (UTM) where diametral compression was applied through loading strips to induce tensile stresses perpendicular to the applied load. This indirect tensile test method effectively simulates tensile failure by generating tensile stresses across the vertical diameter of the specimen, which are otherwise difficult to measure directly in concrete. The loading was applied at a controlled, constant rate to ensure uniform stress distribution and to capture precise mechanical behavior up to the point of failure. During the test, load and displacement data were continuously recorded to generate load-displacement curves, which provide insight into the elastic and post-cracking response of the material. Observations of failure patterns were also documented to understand crack initiation and propagation mechanisms influenced by the fiber reinforcement. The split tensile strength was then calculated using the maximum load sustained by the specimen prior to failure, following the formula prescribed by ASTM C496, which relates the load, specimen dimensions, and tensile strength. This method allowed for a consistent and reproducible assessment of the tensile performance enhancement imparted by the incorporation of cotton fibers [13].

Figure 2: Split Tensile Test Setup

3 Results and Discussion

3.1 Slump Results

The slump test results for both plain concrete (PCC) and cotton fiber-reinforced concrete (CFRC) are presented in Table 1. It is observed that the CFRC exhibits a noticeably lower slump value compared to the PCC, indicating reduced workability. Table 1 provides a comparison of the water-cement (w/c) ratios for both concrete types along with their corresponding slump values. The reduction in slump for the cotton fiber-reinforced concrete can primarily be attributed to the high water absorption capacity of the cotton fibers, which effectively reduces the free water available in the mix [10]. This absorption limits the lubricating effect of water, resulting in a stiffer and less workable mixture. Consequently, the presence of cotton fibers influences the fresh concrete's rheological behavior, necessitating careful mix design adjustments to maintain adequate workability without compromising fiber dispersion or mechanical performance.as we can observe in Figure 1 CFRC showed true slump.

Figure 1: Slump test

Table 1. show the slump values noted for the both PCC and CFRC. The values for CFRC decreased by 25 mm showing the balling effect and congestion created by the fibers.

Table 1: Slump test of PCC and cotton fibres

Concrete Type	Observed Slump (mm)
PCC	75
Cotton Fiber	50

3.2 Load vs Deformation

The load-deformation behavior, as illustrated in Figure 2, clearly shows how PCC and CFRC perform differently under tensile stress. In case of PCC, the load increases sharply and then dropped abruptly once the peak is reached, this points to a typical brittle failure with no ability to carry load afterward. On the other hand, the CFRC curve rises more steadily and continues even after reaching its peak load. This indicates that the cotton fibers help the concrete retain its integrity even as cracks start to form [9]. These fibers act like tiny bridges inside the material, holding it together and slowing down the cracking process. As a result, CFRC doesn't just carry more load but also absorbs more energy before failing, making it a more dependable option when resistance to cracking is important.

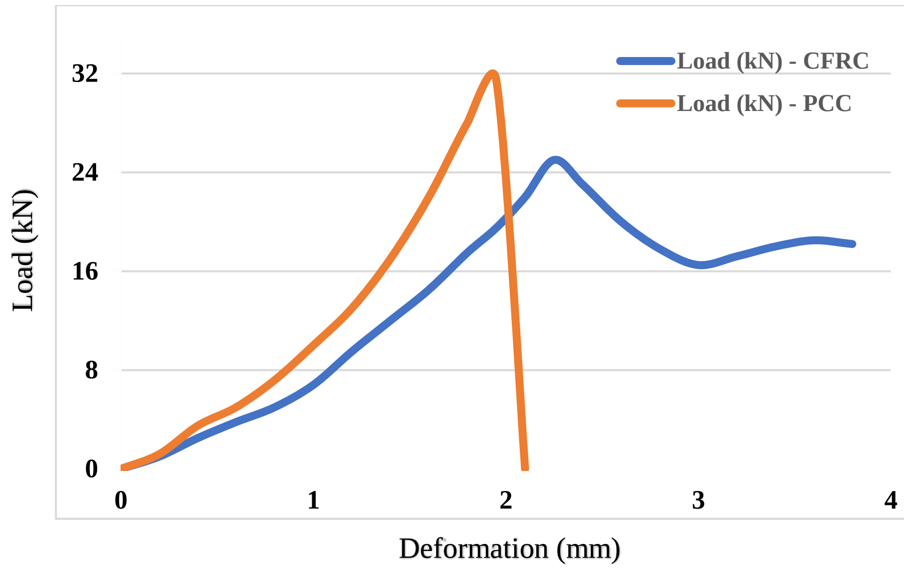

Figure 2: Load deformation curve

3.3 Split Tensile Results

As shown in Table 2, the average tensile strength of PCC was calculated to be 0.9 MPa, whereas the CFRC specimen registered a slightly lower strength of 0.8 MPa. This minor decrease is may be due to challenges like uneven fiber distribution or slight disruption in the matrix continuity caused by fiber inclusion. Still, the behavior of CFRC during failure was notably different, it failed more gradually and exhibited improved toughness. Rather than snapping abruptly like PCC, the CFRC held together longer under stress, showing visible signs of crack resistance. This makes CFRC a valuable option for applications where, reducing sudden failure and enhancing long-term durability is more critical than maximizing peak tensile strength [7].So this more energy obsorbtion by CFRC shows increse in toughness up to 7 times as compared to PCC.

Table 2: Comparative performance of Plain Concrete with Cotton Fiber

Concrete Type	Peak Load (KN)	Tensile Strength (MPa)	E1(Nm)	E2(Nm)	E(Nm)	TI
PCC	30	0.9	14.7	0	14.7	1
CFRC	28	0.8	15	87.9	102.9	6.96

3.4 Compression Results

The compressive test results presented in Table 3 show that CFRC achieved a higher peak load (150.91 kN) compared to PCC (86.47 kN), along with a slightly increased peak position and a notable rise in initial stiffness (4.99 kN/mm for CFRC versus 3.83 kN/mm for PCC). This behavior suggests that the inclusion of cotton fibers not only slightly enhances the mix's capacity to resist compressive loads but also delays microcrack propagation, allowing the composite to sustain higher loads before failure. The cotton fibers likely act as internal bridges, improving the bond within the cement matrix and resisting early crack formation. This mechanism contributes to increased stiffness because the fibers restrict localized deformation, distributing stress more uniformly across the section. As a result, CFRC demonstrates a stiffer and tougher response under compressive loading, indicating its potential for applications where both crack control and compressive load capacity are critical. This outcome aligns with the broader aim of leveraging natural fibers to create concrete that is not only sustainable but also mechanically resilient in multiple stress conditions.

Table 3: Comparative performance of PCC with CFRC in Compression

Material	Peak Load (kN)	Peak Position (mm)	Initial Stiffness (kN/mm)
PCC	86.47	4.45	3.83
CFRC	150.91	4.86	4.99

4 Practical Implementation

Cotton fiber-reinforced concrete (CFRC) presents a viable solution for advancing sustainable construction practices by integrating mechanical performance with environmental considerations. Its incorporation into structural elements, such as slabs, offers multiple functional benefits. Among these are enhanced thermal insulation, reduced susceptibility to crack formation, and improved long-term durability under service loads. Due to the fibrous matrix's ability to distribute stresses more uniformly, CFRC is particularly advantageous in applications demanding increased flexural strength, such as base slabs and pavement overlays. Additionally, its utility extends to erosion control on embankments and inclined surfaces, where crack mitigation and surface integrity are critical. From an architectural perspective, the natural texture imparted by cotton fibers supports the development of aesthetically pleasing and eco-conscious finishes, making it suitable for decorative and surface-visible applications.. The growing adoption of CFRC is underpinned by rigorous laboratory testing to ensure compliance with structural and durability standards. As research into natural fiber composites continues, it is anticipated that new application domains will emerge, further, positioning CFRC as a material of choice for both structural and sustainable innovation in the construction industry.

5 Conclusion

In an experimental investigation to assess the impact of cotton fibers on the mechanical properties of concrete, the following conclusions were drawn from the results obtained:

- The slump of cotton fiber-reinforced concrete (CFRC) decreased compared to plain concrete (PCC), due to water absorption and congestion created by the cotton fibers.
- Split tensile strength of CFRC decreased slightly by 11.1% relative to PCC.
- CFRC demonstrated significantly improved ductility and crack resistance, absorbing more energy before failure compared to PCC showing up to 7 times more toughness.

Despite the slight reduction in tensile strength, CFRC shows promise for applications where enhanced crack control and durability are critical.

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