ENHANCING FLEXURAL STRENGTH IN CONCRETE ONE-WAY SLABS OF BUILDING THROUGH COTTON FIBER REINFORCEMENT

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Abstract- Concrete inherent brittleness and low tensile strength and require reinforcement in flexural members like one-way slabs, to mitigate cracking and structural failures under flexural loading. Steel is mostly used as reinforcement to enhance flexural strength of concrete. The manufacturing of steel reinforcement produces significant carbon emissions which causes environmental pollution. The purpose of this study is to make sustainable concrete with fiber reinforcement and reduce steel usage. By using pure Cotton fiber, it seeks to develop an ecofriendly composite that balances structural stability with environmental sustainability. After obtaining Cotton fiber from reliable resource, 2-inch-long fiber was made. Different trials were done to avoid balling effect in concrete, best was to place material in layers for proper mixing. 5 layered concrete mix was found better with water to binder ratio 0.55. Beamlets are made for testing purpose. Cotton fiber reinforced concrete presented 17% to 73% more flexural strength as compared to the plain cement concrete. With results from flexural strength of beamlet, one-way slab can be designed analytically. There is substantial potential for further research into cotton fibers with longer fiber lengths, as well as the use of textile waste to achieve more sustainable outcomes.

Keywords- Cotton Fiber, Flexural Strength, Modulus of Rupture, Plain Cement Concrete, Textile Waste Fiber

1 Introduction

Concrete, the most widely used construction material globally, is inherently brittle and weak in tension, leading to sudden failure under flexural or tensile loads. Especially in one-way slabs with long spans have flexural cracks at bottom even due to self-loads. To address this limitation, in addition to other research works researchers have also explored the incorporation of fibers into concrete matrices to enhance ductility, toughness, and crack resistance. Synthetic fibers, such as steel, polypropylene, and glass fibers, have been extensively studied for their ability to improve mechanical properties. For instance, steel fibers are known to increase tensile strength and post-crack energy absorption, while polypropylene fibers reduce plastic shrinkage cracks. Studies by Chousidis [1]demonstrated that adding steel fibers and carbon nanotubes could elevate the modulus of rupture (MOR) as compared to plain concrete. Similarly, research by Statkauskas et al. [2] highlighted that polypropylene fibers enhance toughness by bridging microcracks during early loading stages. However, synthetic fibers often entail high production costs and environmental concerns, prompting interest in sustainable alternatives like natural fibers. Despite the benefits of natural fibers[3], challenges such as fiber-matrix compatibility and long-term durability in alkaline environments remain critical areas of investigation.

In recent years, natural fibers have gained traction as eco-friendly reinforcements due to their low cost, renewability, and reduced carbon footprint. Fibers such as jute[4], sisal[5], coir[6], banana[7] and wheat straw[8] have shown promise in improving concrete's ductility and fracture resistance. Among natural fibers, cotton—a widely available agricultural byproduct—has emerged as a new contender. For example, Bartulovic et al. [9] examined the influence of cotton knitted fabric waste on concrete properties. They had used 1.7% to 3.5% cotton knitted fabric waste in 10 different mixes with same amount of cement. It was found that flexural strength was increased 38% but compressive strength decreased to 20%. Natural fibers also introduce challenges, including variability in fiber geometry, hydrophilicity, and susceptibility to degradation in moist conditions. To mitigate these issues, treatments such as alkali immersion or coatings are often applied. Recent work by Sadrolodabaee et al. [10] did experimental study of textile waste fiber reinforced concrete by adding 6-10% short random fibers and non-woven fabric in 6-7 layers as textile waste reinforcement. The best composite was recognized to be the one reinforced with 6 layers of non-woven fabric, with flexural strength of 15.5 MPa and a toughness of 9.7 KJ/m3. Some researchers improved concrete[11] properties[12, 13] by improving[14] mix[15] design[16, 17] and aggregate[18, 19] properties[20-22] . These findings underscore the need for systematic studies to optimize cotton fiber-reinforced concrete (CFRC) for structural applications.

This study focuses on evaluating the mechanical performance of cotton fiber-reinforced concrete, particularly its flexural strength (MOR) and toughness, compared to plain cement concrete (PCC). While prior research has explored synthetic [23], Basalt fiber[24] and other natural fibers[25, 26], cotton[27] remains understudied despite its potential as a low-cost, sustainable reinforcement. The current work addresses gaps in understanding the interplay between cotton fibers and fresh concrete properties, such as workability, and their influence on hardened-state performance. Previous investigations on fiber reinforcement presents potential flexural strength improvements. By adopting a layered mixing technique to minimize balling, the research aims to optimize fiber dispersion. Cotton fibers (2-inch length) were incorporated into concrete using a layered mixing method to prevent balling, with a 0.55 water-binder ratio and 5-layer material placement ensuring uniform dispersion. Flexural tests on beamlets revealed that the cotton fiber-reinforced concrete exhibited a 16% higher modulus of rupture than plain concrete, demonstrating enhanced crack resistance. Findings reveal that CFRC exhibits higher first-crack stress, improved ductility, and enhanced toughness due to fiber bridging, positioning cotton as a viable reinforcement for sustainable construction. One-way Slab can be designed analytically with results from beamlets flexural test results. This work contributes to advancing green concrete technologies while addressing practical challenges in fiber-concrete compatibility.

2 Research Methodology

2.1 Raw Material

Threaded cotton fibres were obtained as shown in figure 1(a), (b). Ahmed et al. [28] investigated coir fibre reinforced concrete with 25mm, 50mm and 75mm lengths and found best results with 50mm length. With these findings cotton fibre length for cotton fibre reinforced concrete was made 50mm (2-inches). Threaded fibres were cut in 2-inches with the help to steel cutters accurately as shown in figure-1. The diameter of threaded cotton fibre was 10µm. Concrete is made with ratio 1:2:4, cement, sand and aggregate respectively. Ordinary Portland cement was used for the mix. Coarse sand was used with Fineness Modulus 2.7 from river bed of Jhelum River for making a proper mix. Well graded aggregates from query near Abbottabad was taken using ½" thick down aggregate for good quality and better strength. OPC is mainly used cement in concrete slabs to achieve standard strength required for slabs. Coarse sand from Jhelum River bed is specially used for concrete works in Pakistan central and northern areas.

(a) (b)

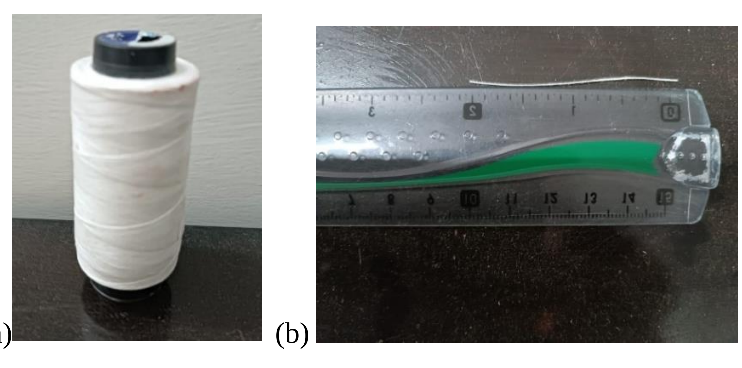


Figure 1: Cotton Fiber, (a). fibre length (b).

2.2 Mix Design and Casting

For mix design preparation cement sand, aggregates and cottons fibres are assessed. PCC and CFRC are casted in ratio 1:2:4 (cement: sand: aggregate) concrete. Plain cement concrete was made with 1:2:4 (cement: sand: aggregate) to achieve required strength in slab by using cement, sand and aggregates as mentioned. For cotton fibre reinforced concrete cement, sand and aggregates are used in same 1:2:4 to match same strength. Cotton fibres are then added by cement weight. To achieve a proper mix cotton fibres were used 1% by weight of cement in concrete mix to avoid balling and collating. To minimize balling effect cement mix was made by spreading each component in layers, 5 layers of cement sand aggregate and cotton fibre was placed in mixer machine. After mixing in mixture machine for 5 minutes with 0.55 water binder ratio, concrete is placed for slump test and beamlet filling. Slump was found to be 2-inches which showed lesser workability, slight bulging effect was observed as shown in figure 2-b. 2 inches slump is enough for small area slabs. Three beamlets were poured for flexural testing and were put in curing tank after a day. Similarly Plain cement concrete of ratio 1:2:4 was made for 3 beamlets. Slump was found to be collapsed and 5-inches as shown in figure-2a. Which showed a highly workable concrete. Water to binder ratio was 0.5 in case of Plain cement concrete. It was observed that slump value was reduced after cotton fibre reinforcement showing low workability. It was also observed during mixing that due to cotton fibres, mix needed more water and water to binder ratio was increased. That is why water to cement ratio was increase in cotton fibre reinforced concrete.

(a) 

(b) 

Figure 2:(a). Slump test PCC (b). Slump test CFRC

Following table 1 is made for comparison between plain cement concrete and cotton fibre reinforced concrete. Table 1 clearly showed different behaviour of both type of concretes during mixing and placing. Both had different mixing techniques and showed different test results in workability.

Table 1 Comparison of PCC and CFRC during concrete

Properties	**Plain Cement Concrete**	**Cotton Fiber reinforced concrete**
Mix Ratio	1:2:4	1:2:4
Water / Binder ratio	0.5	0.55
Mixing Layers	1	5
Slump test	5 inches	2 inches
Balling effect	No	Yes

2.3 Testing

The beamlets were removed from curing tank after 28 days and dried. The objective is to determine flexural strength (Modulus of Rupture) of cotton fiber reinforced concrete under the third point loading. It is required to assess how cotton fiber affect crack control and ductility. Standard testing method for flexural strength of concrete is performed using simple beam with three-point loading. A 3-point loading test apparatus in a servo-hydraulic testing machine applies a controlled bending load to a specimen using a central loading nose and two fixed supports as shown in figure 3-a. The servo-hydraulic system precisely regulates load rate, displacement, or strain via closed-loop feedback. This setup is standardized in tests like (concrete beams) or (fiber-reinforced plastics), ensuring repeatable evaluation of bending performance under quasi-static or cyclic conditions. Real-time data acquisition captures load-deflection curves, critical for calculating parameters like the Flexural Toughness Index (FTI) in materials such as fiber-reinforced concrete or composites. Three-point mechanism is made in servo hydraulic testing machine and plain cement concrete beamlets were placed for flexural testing. Load and displacement with time was presented by testing machine. Similarly, Cotton fiber reinforced concrete beamlet was placed in servo hydraulic testing machine and observed first crack stress was more than plain cement concrete. It was also observed that cotton fiber reinforced concrete showed more toughness than plain cement concrete. It is also observed that cotton fiber provided bridging effect in cracked surface and showed ductile behavior. Plain cement concrete on other hand cracked and showed brittleness.

a) 

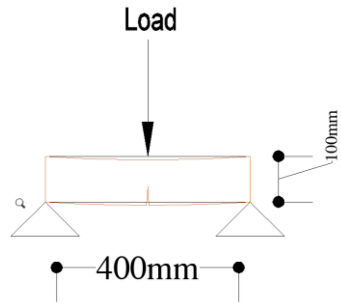
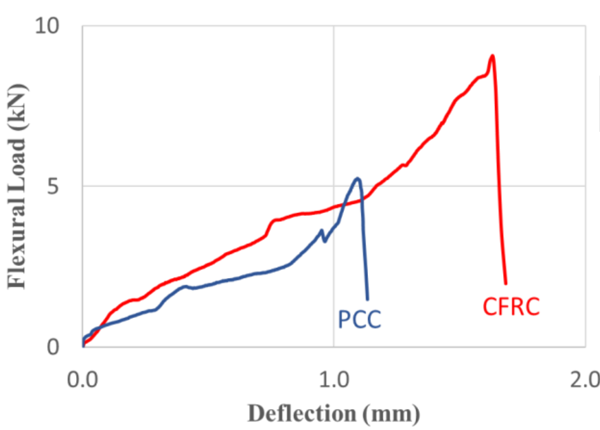
b) 

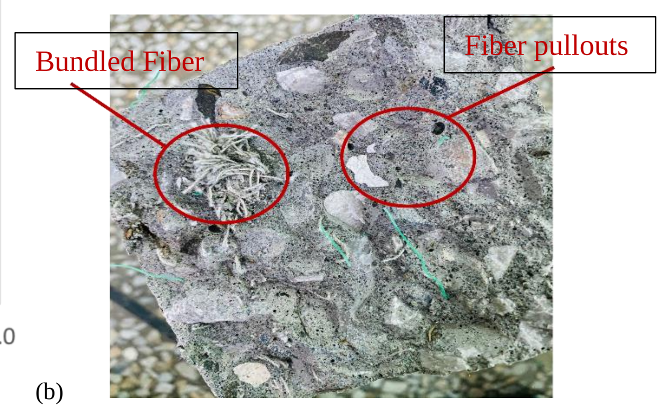
Figure 3: (a)CFRC sample in testing machine (b) Schematic Diagram

3 Results

Load and deflection graph were made for cotton fiber reinforced samples Figure-4(a). The x-axis ("Deflection (mm)") ranges up to 2.0 mm, while the y-axis likely represents load (kN) with a peak near 10 kN. CFRC shows enhanced post-crack ductility (gradual load drop) compared to PCC, which exhibits brittle failure (sharp decline after cracking). As clearly seen from the graph below that cotton fiber reinforced concrete has shown significantly high loads before fracture as compared to Plain cement concrete. Noticeable point is that cotton fiber reinforced concrete has not shown better toughness. As compared to plain cement concrete, cotton fiber reinforced concrete didn't show much improvement in toughness. That is mainly because of the shorter length of the fiber which is not able to bridge cracks for longer period. Second reason is density of the fiber, which is much less, thicker and longer fiber should be used for future research to have better results in toughness. Figure-4 (b) shows bundled and pulled out fibers of fractured surface of beamlet. Bundled fibers are the main cause of the low toughness in cotton fiber reinforced concrete.



(a)



(b)

Figure 4: a) Load/deflection Graphs, b) Fractured surface

Cracked and failed surface showed the fibers were bundled together. Test results confirmed the observations made during testing that cotton fiber reinforced concrete showed better results as compared to the plain cement concrete. Table 2 shows detail of different results obtained from testing. Table 2 shows it clearly that Cotton fiber reinforce concrete in stronger than plain cement. Cotton fiber flexural strength is more than plain cement concrete by 73%. Load taken by cotton fiber to failure is much more than plain cement concrete. Overall cotton fiber reinforced concrete performance is much better than plain cement concrete.

Table 2 Flexural test results

Properties	Cotton fibre Reinforced concrete	Plain Cement concrete
Load (KN)	9.056 (±1.78)	5.248 (± 2.5)
Displacement (mm)	1.63 (±0.02)	1.092 (± 0.48)
Stress (MPa)	6.13 (± 1.2)	3.54 (± 1.7)
Strain	0.0048 (± 0.0001)	0.0032 (± .0015)
Modulus of Rupture (MPa)	6.130 (± 1.2)	3.540 (± 1.7)
E (J/m^3)	9.2×10^9	8.1×10^9
E1 (J/m^3)	5.6×10^9	5.2×10^9
E2 (J/m^3)	1.8×10^9	1.9×10^9
FTI	2	1.67

4 Practical Implementation

Cotton fiber-reinforced concrete (CFRC) offers unique advantages due to its improved ductility, crack resistance, and sustainability. Cotton fiber-reinforced concrete (CFRC) is increasingly utilized in one-way slab construction due to its unique benefits. In residential flooring, CFRC slabs reduce shrinkage cracks and enhance impact resistance, ideal for high-traffic areas like living spaces. Its improved ductility makes it suitable for lightweight roof slabs, minimizing structural weight while maintaining strength. For sustainable housing, CFRC slabs integrate eco-friendly materials, lowering carbon footprints. In industrial settings, CFRC's crack resistance extends the lifespan of warehouse or factory floors exposed to heavy loads. Agricultural storage slabs benefit from its resistance to thermal stress and moisture when properly sealed. Rural projects use CFRC for cost-effective, locally sourced flooring in sheds or pathways. Decorative interior slabs with exposed cotton fibers add aesthetic texture to modern designs. Retrofitting aging concrete slabs with CFRC overlays repairs surface cracks and reinforces structural integrity. Insulated slabs combining CFRC with foam or cork improve thermal efficiency in eco-homes. Soundproofing slabs in apartments leverage cotton fibers' sound-dampening properties. Temporary event pavements use CFRC for easy installation and recyclability. Fire-resistant treated CFRC slabs enhance safety in garages or utility rooms. Urban landscaping employs CFRC for durable, low-maintenance pavements or garden benches. Educational or community centers adopt CFRC slabs for sustainable, resilient flooring. By addressing moisture vulnerability through coatings or additives, CFRC slabs offer versatile, eco-conscious solutions across residential, commercial, and industrial applications.

5 Conclusion

Cotton fiber reinforcement is provided to concrete with 2 inches length and 1% by weight of cement to get better flexural strength. Following conclusions can be drawn from the conducted study:

1 Cotton fiber reinforcement improves concrete's flexural strength (modulus of rupture) by providing crack-bridging effects, delaying brittle failure, and enhancing post-crack ductility, as demonstrated in flexural tests.
2 While cotton fibers reduce slump and increase water demand, optimized mixing techniques (e.g., layered mixing) and adjusted water-to-binder ratios can mitigate balling and maintain practical usability. Cotton fiber reinforced concrete has increased flexural strength. Toughness can be increased with long sized fibers of 4 to 5 inches length. Textile waste fiber can also be used for sustainable solution.
3 Cotton fiber reinforced concrete is low-cost agricultural product (cotton fibers), aligning with eco-friendly construction goals and offering potential for non-structural applications like architectural elements, lightweight panels, partition walls and small one-way slabs.

Future research should concentrate on: Evaluating the enduring impact of fiber reinforced under various environmental conditions and loading circumstances. Performing comparative studies to determine the best combinations of different fiber kinds and novel concrete formations to increase flexural strength.

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