Evaluating the Mechanical Properties of Concrete with the use of Coconut Fiber

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ABSTRACT

Coconut fiber is readily available, it is a good substitute for steel fiber in concrete. Additionally, it offers coconut farmers a new revenue stream as demand from the construction sector increases. These natural fibers can be a cost-effective way to dispose of coir mattress waste and, being environmentally friendly, they can significantly reduce environment pollution from burning it. However, it is crucial to assess whether the use of these fibers affects the strength of concrete, determining their suitability for widespread use in the construction industry or identifying potential concerns.

This study aims to compare the strength of reinforced concrete without coconut fiber to that with coconut fiber reinforced concrete at various fiber concentrations. Tests were conducted with different fiber percentages (1%, 3%, and 5% by weight of cement) to evaluate the compressive, split tensile, and flexural strength of coconut fiber reinforced concrete. The results indicate that coconut fiber enhances both the flexural and compressive strength of concrete, along with improving its ductile behavior.

Keywords : *Tensile strength, Compressive strength, Flexural strength, Coconut Fiber.*

1. INTRODUCTION

Coconut fiber, an agricultural byproduct from processing various coconut products, is abundant in tropical regions like Africa, Asia, and America. Often discarded as waste, coconut fiber can be repurposed into valuable products such as floor mats, doormats, brushes, and cushions. This repurposing helps reduce the accumulation of coconut coir waste in soil and water resources.

In the construction industry, coconut fiber is gaining attention as a building material. Researchers have demonstrated its potential in cementitious composites, offering advantages over synthetic fibers, which can suffer from poor fire resistance, decreased workability, and reduced shear strength (Khan et al., 2017).

While the use of fibers in reinforced concrete can be debated due to issues like exposure to rainfall and random fiber orientation, fiber-reinforced concrete (FRC) presents a cost-effective solution for affordable housing and secondary structures, especially in developing countries. The construction industry is evolving with innovative materials like high-performance concrete (HPC), which are environmentally friendly. Consequently, research on fibers, matrix materials, and production techniques has intensified.

FRCs, known for their high tensile strength-to-weight ratio and weather resistance, can be molded into various forms and used in secondary structures and offshore platforms (Thomas and Ramaswamy, 2007). Studies indicate that FRC offers significant opportunities for low-cost, non-traditional building materials (Olanipekun et al., 2006; Nor et al., 2010). Coconut fiber in particular, reduce crack in concrete (Adeyemi, 1998; Zain et al., 2010), providing an environmentally compliant disposal method for industrial coconut waste.

Recent research highlights the suitability of coconut fiber-reinforced concrete (CFRC) and coconut-fiber ropes in earthquake-resistant construction. CFRC has shown greater load resistance and reduced disintegration under seismic loading compared to conventional concrete, making it ideal for seismic-resistant structures (Kirandeep, 2023; Ali, 2016; Ali, 2014). Additionally, the biodegradable and non-toxic nature of coconut fibers promotes sustainability, reducing environmental impact (Martinelli et al., 2023; Ahmad et al., 2022). These fibers enhance the mechanical properties of concrete, including tensile, flexural, shear, and torsional strength, while preventing crack formation, improving load-bearing capacity, and increasing energy absorption (Martinelli et al., 2023; Ahmad et al., 2022).

Coconut fibers present a cost-effective alternative to synthetic fibers for use in construction materials (Ahmad et al., 2020; Agrawal et al., 2014). When treated with substances like sodium hydroxide, these fibers enhance the durability of concrete and resist decay (Martinelli et al., 2023; Naamandadin et al., 2020). Research indicates that an optimal fiber content of around 3% by weight significantly improves mechanical properties while maintaining a balance between workability and compressive strength (Ahmad et al., 2022; Naamandadin et al., 2020).

Choosing the optimal fiber content can improve torsion, toughness and tensile strength of concrete (Yalley & Kwan, 2009; Agrawal et al., 2014; Ahmad et al., 2022; Naamandadin et al., 2020). The use of coconut fiber-reinforced concrete (CFRC) as high-strength concrete is beneficial for its mechanical properties, energy absorption, and toughness indices. Additionally, CFRC fibers with lengths of 50 mm and 75 mm significantly enhance flexural and shear strength, making them suitable for paving block mixtures (Mudiyono & Sudarno, 2019).

This study focuses on the intrinsic use of coconut fiber in concrete, exploring its impact on mechanical properties and the effect of different fiber proportions on concrete strength.

2. MATERIALS AND METHODS

This study focuses on a comparative analysis of the strength of CFRC and normal concrete, as well as the impact of fiber length on concrete properties. Rabma, S et al. (2020) achieved optimal compressive and flexural strength with 5% coconut fiber compared to 10% and 15%. Similarly, Dharmik et al. (2021) found that concrete with 1% coconut fiber by weight of cement showed an increase in compressive strength. Consequently, processed coconut fibers of 3 cm length were used in experiments with fiber levels of 1%, 3%, and 5% by weight of cement. The suitability of various materials for concrete was first determined through material tests. The design mix was prepared according to IS 10262: 2009 with appropriate water content to prevent bleeding. Slump tests were conducted to ensure workability, and the cubes were sun-dried after 7 days wet curing up to 28 days before testing.

(i) Mixed Design

The mix design of M20 concrete is is prepared according to guidelines such as IS 10262: 2009, ensuring proper mixing, compaction, and curing to prevent issues like bleeding and segregation.

(ii) Slump Test

The slump test, as outlined in IS 1199:1959, is used to assess the workability of fresh concrete. The slump test observation it presents in the Table 2.

(iii) Bonding Length Test

The bonding length test typically involves embedding a single fiber in a concrete specimen and subjecting it to tensile forces until failure occurs. The critical length at which the fiber can no longer sustain the load without slipping or breaking is identified as the bonding length.

(iv) Compressive Strength Test

This test involves casting concrete into cube molds, of dimensions 150mm x 150mm x 150mm, and curing them for specified periods, of 7 and 28 days. After curing, the cubes are placed in a compression testing machine, which applies a gradually increasing load until the specimen fails. The maximum load at failure is recorded, and the compressive strength is calculated by dividing this load by the cross-sectional area of the cube.

(v) Splitting Tensile Strength Test

The splitting tensile strength test of concrete is performed, as per Indian Standard IS 5816:1999. This test involves placing a cylindrical concrete specimen horizontally between the platens of a compression testing machine. A diametrically opposed compressive load is then applied along the length of the cylinder until it splits along the vertical diameter. The maximum load at failure is recorded, and the tensile strength is calculated using a specific formula provided in the standard.

(vi) Flexural Strength Test

The single point flexural test of concrete, as per the Indian Standard IS 516:1959, involves determining the flexural strength of concrete using a simple beam with a single point load applied at the center is adopted for flexural strength test. The test specimen, typically a beam of dimensions 150 mm x 150 mm x 700 mm, is placed on two supporting rollers spaced 600 mm apart. A load is then applied at the midpoint of the beam until failure occurs. The flexural strength is calculated using the formula

$$Flexural\ Strength = \frac{\mathrm{bd}^2}{PL},$$

where (P) is the maximum load applied, (L) is the span length, (b) is the width, and (d) is the depth of the specimen. This method provides valuable insights into the concrete's ability to withstand bending forces, which is critical for designing durable and resilient structures and adopted by researchers.

3. RESULTS AND DISCUSSION

(i) Mixed Design

The mix design of FRC incorporates fibers to enhance its mechanical properties, particularly tensile strength and crack resistance. A mix design was carried out according to IS 10262 –1982 to achieve a minimum target strength of 20 N/mm². This same mix design was applied to the FRC. The quantities of different ingredients per cubic meter of concrete mix are provided below.

Grade of concrete : M20
Types of cement : OPC
Cement Content : 400kg/m^3
Aggregate Content : 40% of 20mm (695 kg/m^3)
: 60% of 40mm (455 kg/m^3)
Sand Content : 700 kg/m^3
Water cement ratio : 0.45
Workability (Slump) : 95mm
Chemical Admixture : 2 kg/m^3

Table 1: Strength during Trial Mixes

Specimen	w/c ratio	Slump Value(mm)	Compressive strength(N/mm2)	
	0.45	**95**	**7 day**	**28 day**
1			27.08	34.07

Table 1 shows the compressive strength of concrete from the trial mix. The test results indicate good agreement with target compressive strength. Consequently, the same ingredient proportions in the mix design were used for further tests, now including coconut fiber.

(ii) Slump Test:

Table 2: Slump test observation

Coconut fiber %	Trial	Avg. w/c ratio	Slump Value(mm)	Avg. Slump Value(mm)	Remarks
1%	Cube	0.45	95	83.33	Sample prepared for Cube, Cylinder and Beam separately at different days
	Cylinder		80		
	Beam		75		
3%	Cube	0.45	90	78.33	
	Cylinder		75		
	Beam		70		
5%	Cube	0.45	85	73.33	
	Cylinder		70		
	Beam		65		

The slump test is performed as per IS 516. The test results shows that workability of concrete get compromised as the percentage of fiber content increases.

(iii) Bonding Length

Fibers act as bridges within the concrete matrix, enhancing its ability to resist crack propagation by increasing the energy required for a crack to grow. The effectiveness of this bond depends on several factors, including the type of fiber, its surface texture, and its chemical compatibility with the concrete. Ideally, fibers should slip out of the matrix rather than break, as this gradual pull-out mechanism helps dissipate energy and improve the concrete's overall durability. According to IS 456:2000, bond strength is evaluated through pull-out tests, where a fiber is embedded in a concrete specimen and subjected to tensile loading until it is pulled out. In the lab, coconut fibers of various lengths (1.0, 1.5, 2.0, and 2.5 cm) were embedded in the concrete. After 28 days, the fibers were pulled out using a spring balance to determine their non-sleeve length. Table 3 indicates the gripping length of fibers, while Figures 1 and 2 show the preparation of development length and cutting length. (Fig. 1, Fig. 2)

Table 3: Gripping Length observation

Sample	Gripping Length (cm)	Remark
1	1.0	Non-Sleeve
2	1.5	Non-Sleeve
3	2.0	Non-Sleeve
4	2.5	Non-Sleeve

For the preparation of fiber-reinforced concrete, a development length of 1.5 cm was selected, and consequently, a cutting length of 3 cm was used for the laboratory test.

Fig.1: Grip Length

Fig.2: Coconut Fiber Cutting Length

(iv) Compressive Strength Test of Cubes

Fig.3: Photo Compressive Strength Test

Coconut fiber was added to concrete in varying amounts (1%, 3%, and 5% by weight of cement) at a water-cement ratio of 0.45 for compressive strength testing (Fig. 3). It was observed that traditional concrete (without fiber) has comparatively lower compressive strength than fiber-reinforced concrete. As the percentage of fiber increases, the compressive strength decreases. However, the maximum compressive strength was found at 3% coconut fiber content, which aligns well with previous studies (Ahmad et al., 2022; Naamandadin et al., 2020). Overall, the inclusion of 1% to 5% coconut fiber increases compressive strength compared to normal concrete.

Table 4: CFRC Cubes- Compressive Strength Values

Specimen	% of coconut fiber added	Compressive strength (N/mm2)	
		7 day	28 day
1	0%	27.08	34.07
2	1%	27.81	36.7
3	3%	29.14	38.5
4	5%	28.9	37.01

(v) Split Tensile Strength Test

Fig.4: Photo Split Tensile Strength Test

Concrete cylinders (diameter: 15 cm, height: 30 cm) were used for split tensile strength testing (Fig. 4). These concrete samples, reinforced with coconut fibers, were cast with varying fiber percentages (1%, 3%, and 5%). Each sample was subjected to a compression testing machine at 7 and 28 days to gather strength data. Table 5 presents the results of the split tensile strength test of CFRC.

Table 5: Split tensile strength for processed CFRC cylinders

Specimen	Percentage of coconut fiber added	Splitting Tensile strength(N/mm2)	
		7 day	28 day
1	1%	3.32	3.98
2	3%	3.55	4.03
3	5%	2.94	3.45

The test indicates that the strength of the reinforced structure increased with the addition of fibers. Notably, the 3% fiber content exhibited slightly higher strength than the 1% and 5% fiber contents, likely due to the optimal amount of coconut fiber and mixing quality. Above the optimal quantity of coconut fiber proper mixing of the concrete could not achieved though strength decrease. These findings are consistent with previous research by Ahmad et al. (2022), Naamandadin et al. (2020), Otunyo and Nyechieo (2017), Zaman and Awang (2009), and Yadav and Singh (2019).

(vi) Flexural Strength Test

Fig.5: Photo Flexural Strength Test

Flexural strength tests were conducted on beams measuring 15 cm x 15 cm x 70 cm (Fig. 7 & 8). Three samples of concrete reinforced with coconut fiber were prepared with varying fiber contents (1%, 3%, and 5%). For CFRC, the strength values at 7 and 28 days were determined using flexural strength test equipment. The results of these tests, with 1%, 3%, and 5% fiber additions, are presented in Table 6.

Table 6: Flexural strength for processed CFRC Beams

Specimen	Percentage of coconut fiber added	Flexural strength (N/mm2)	
		7 days	28 days
1	1%	3.09	3.72
2	3%	3.33	3.85
3	5%	2.94	3.55

Table 6 shows that an increase in fiber content leads to an increase in flexural strength, with the optimal strength observed at 3% fiber content due to the proper ratio and mixing quality. Above the optimal quantity of coconut fiber proper mixing of the concrete could not achieved though strength decrease. This test has been recommended by Sarangi, S., & Sinha, A. (2016) and Ranjitham et al. (2019, July) for evaluating the strength properties of CFRC.

4. CONCLUSION

As an organic waste material, coconut fiber offers potential as a concrete reinforcement material, aligning well with sustainability principles. This study investigates the strength of coconut fiber-reinforced concrete using fibers of predefined lengths. A mix design was performed to determine the ratios of ingredients (cement, sand, aggregate, water, and additional admixtures). It was found that the inclusion of coconut fiber reduced workability, as indicated by moderate slump values for cubes, cylinders, and beams. Testing various gripping lengths of coconut fibers (1 cm, 1.5 cm, 2.0 cm, and 2.5 cm) on 5 cm cubes revealed that while a 1 cm gripping length could suffice, a 1.5 cm length was chosen for safe bonding. The experiments showed that a maximum of 3% coconut fiber content in concrete provided adequate compressive strength. Although there was no significant difference in split tensile strength between 1% and 3% fiber content, the 3% fiber content produced slightly higher split tensile strength. The flexural strength values also confirmed similar results. Thus, this study finds that 3% processed coconut fiber by weight of cement is the optimal content to enhance both compressive and flexural strength of concrete, while 1% and 5% fiber content also improve the strength of concrete compared to normal concrete.

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