

Research Article

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Influence on compressive and tensile strength properties of fiber-reinforced concrete using polypropylene, jute, and coir fiber

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Abstract: This research work is related to the use of environment friendly materials like fibers of coir, polypropylene and jute in concrete. An economical reinforced concrete is produced by reducing the diameter of steel bar by using fiber ropes. We have examined the compressive and flexural strength of fiber-reinforced concrete. In this study, concrete mix is prepared by using coir fibers. Although instead of using only conventional steel bars, reinforced concrete behavior was investigated with the combination of polypropylene fiber and jute fiber ropes along with steel bars for a constant water binder ratio. These fiber ropes are wound around steel bar with the help of Zepoxy 300 for proper bonding of fiber ropes and steel bar. The results demonstrate that properties of concrete are enhanced by using fibers. Fiber ropes with steel bar in coir concrete increased the flexural strength and compressive strength by 6 and 7%, respectively. Furthermore, it is observed that the addition of fibers in concrete changes the cracking pattern of reinforced concrete beams.

Keywords: concrete, polypropylene fiber, jute fiber, coir fiber, reinforcement, compressive strength, flexural strength

1 Introduction

Reinforced concrete is commonly used in buildings, dams, highways and so on. The high cost of steel in reinforced

concrete is a major concern. The main goal of this research is to reduce the cost of steel by reducing the area of steel using jute and polypropylene fiber ropes. The purpose of this research is to investigate the possible use of jute and polypropylene fiber ropes in reinforced concrete because of their high tensile strength-to-weight ratio and relative cheap cost. Jute and polypropylene fiber ropes as steel replacement in concrete can avoid the steel rusting problem.

Jute fiber is a vegetable, soft, and shiny fiber. It is produced from the genus *Corchorus* of the plants, which classify with the family of Tiliaceae and Malvaceae. *Corchorus olitorius* is the primary source of jute fiber. Polypropylene fiber is a synthetic fiber. It was first introduced in 1970 in textile industry. It has good heat-insulating properties and has resistance against solvent, alkalis and acid attacks. Coir fiber is extracted from coconut shell fiber. A common advantage of coconut fiber is insect resistance. It provides excellent thermal insulation, fire resistance, moisture resistance and durability, and can restore its shape after continuous usage. Coir fiber is the most solid fiber among natural fibers [1].

The use of geosynthetic and natural fiber can improve the properties of soil and concrete. The use of natural fibers can improve the mechanical behavior of road sub-base course [2]. The use of coir fiber in concrete can change the failure crack pattern in reinforced concrete beams [3]. Therefore, deflection behavior of concrete needs to be carefully investigated [4].

Concrete is an inelastic material with high compressive strength and low tensile strength. It is therefore primarily used for bearing compressive load. Concrete under impact loading behaves in an even more brittle manner so that it fractures instantaneously once cracks occur. It is also a strain rate-sensitive material, and it has been observed in mode I (crack opening) fracture that both strength and fracture strain increase with the increasing strain rate [5]. The concrete mechanical properties can be improved by using the fibrous material [6]. The main advantage of the fiber reinforcement is transfer of

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additional absorbed energy and the conversion of brittle materials into a relative ductile material. Fibers are added to concrete to enhance postpeak load bearing. Fiber-reinforced concrete is more capable of withstanding impacts and other loads compared with conventional concrete. Fibers in cement or concrete result in slow crack growth and gradual failure of material [7]. The technique of using natural fibers to reinforced materials is not innovative. In ancient times, horse hair was also used as reinforcement. Straw was used in mud as reinforcement in the ancient Babylonian wall [8]. The Masonary wall in many countries is still made from unreinforced clay bricks. The brick properties can be enhanced by using fibers [9]. Researchers have also performed a detailed experimental evaluation of the physical properties of coir fiber-reinforced polymer composites [10]. Correlations have also been developed between properties of fiber-reinforced concrete [11]. Concrete is strong in compression but weaker in tension. To overcome this problem, steel reinforcement is provided. However, steel is prone to rusting, and once rusting starts, its use becomes almost ineffective to reduce the cracks. Steel rusting problem can be avoided by using natural fibers as reinforcement in concrete.

Natural fibers are biodegradable and nonabrasive. Natural filaments are cost effective, low density and easy to use [12]. Fibers are used in reinforced concrete to enhance its durability. In addition, the properties of natural fiber-reinforced concrete depend on fiber material geometries, distribution, placement and density. Researchers around the world have tried to improve the tensile properties by adding wood, iron and other material fiber in concrete [13]. Concrete with the addition of 0 and 0.5% fiber, by the volume, results in improvement in toughness, compressive, shear, split flexural strength and modulus of rupture. Using industrial byproducts like coir fiber and rice husk ash as a reinforcement in concrete can reduce the environmental impact by reducing consumption of cement [14].

Fibers can improve the ductility and durability of concrete. It also delays the crack propagation and changes the failure pattern of concrete. The production cost of steel used as a reinforcement in concrete increases with passage of time. To economize the reinforced concrete, the identification of alternate material to enhance the tensile characteristics of concrete is essential. The goal of this research is to investigate the compressive and flexural behaviors of fiber-reinforced concrete. The area of steel reinforcement is reduced with the area of jute and polypropylene fiber ropes.

2 Materials and methods

2.1 Materials

Cement, sand, aggregates, water and fibers are mixed to produce fiber-reinforced concrete. In the concrete mix, only coir fibers (Figure 1) are added. The coir fibers used are 0.6 and 50–70 mm in diameter and length, respectively. The chemical composition of ordinary Portland cement (OPC) is given in Table 1. Sand with 2.74 and 2.65 of fineness modulus [15] and specific gravity [16], respectively, is used. The water absorption of sand is 0.7%. The gradation curve is shown in Figure 2.

The characteristics of water used for concrete preparation are given in Table 2.

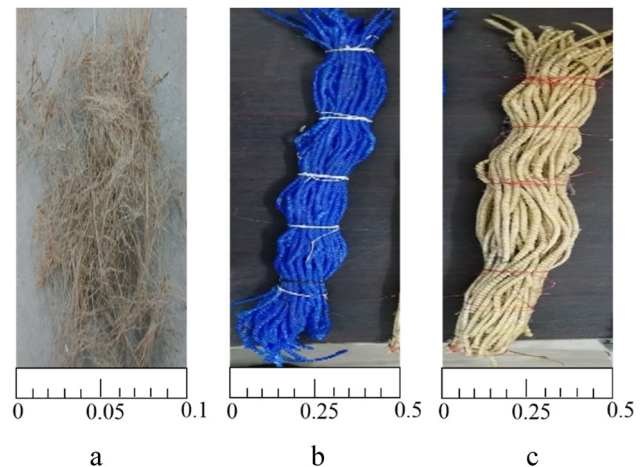


Figure 1: Fibers used: (a) coir fiber, (b) polypropylene fiber and (c) jute fiber (scale in meters).

Table 1: Chemical composition and properties of OPC

Chemical Composition		Properties	
Compound	Quantity (%)	Parameter	Value
SiO ₂	21.8	Specific surface area	320 m ² /kg
Al ₂ O ₃	5.49	Consistency	29%
Fe ₂ O ₃	3.49	Initial setup time	1 h, 42 min
CaO	6.26	Final setup time	3 h, 55 min
MgO	2.49	Specific gravity	3.14
SO ₃	2.89	Compressive strength (28 days)	40.68 MPa
Na ₂ O	0.2		
K ₂ O	1		
LOI	0.64		

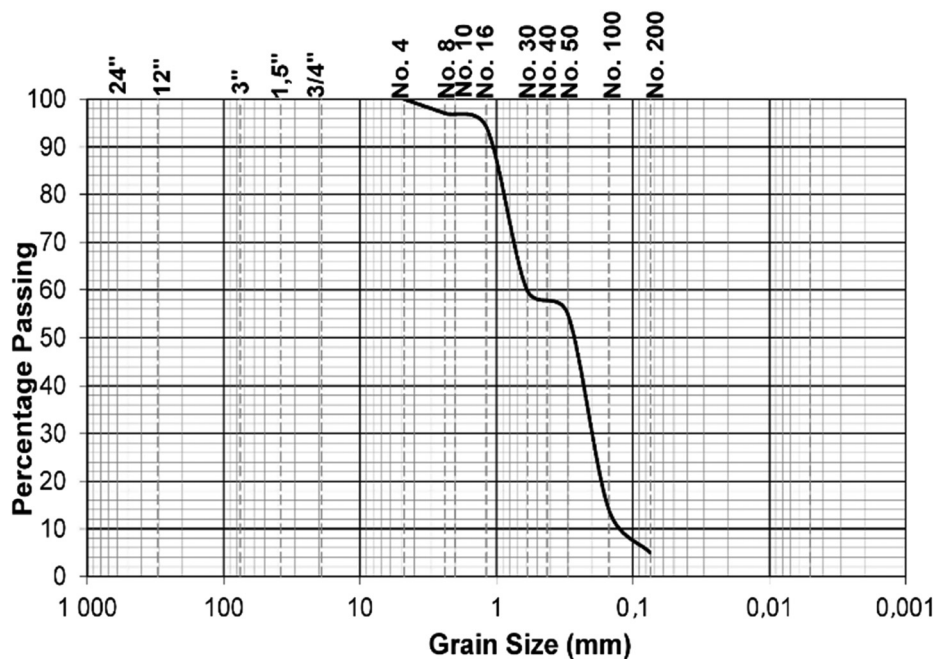


Figure 2: Sand gradation curve.

The longitudinal steel reinforcement area is reduced by polypropylene and jute fiber ropes (3 mm diameter) wrapped around the steel bar (Figures 3 and 4). Zepoxy 300 is used for bonding of fiber [17]. It is a high-strength, mild-to-moderate chemical resistance epoxy coating/adhesive useful for materials such as wood, concrete, ceramic, textile, metal, leather and glass. Zepoxy 300 consists of two parts, epoxy resins and hardeners, which upon mixing results in a suitable for glue applications. The bond is prepared by using one part of epoxy resin and 0.5 part of hardener. The fiber is left for drying for 7 days after applying resin.

2.2 Methods

A concrete mix of 1:1.7:2.8 ratio was used. The experiment is conducted on both plain-reinforced and fiber-reinforced concrete. Cylinders of 150 mm × 300 mm and beams

specimens of 100 mm × 100 mm × 500 mm are casted. The length of coir fibers used is 5 cm, and the fiber content is 0.5% by the volume of concrete (Figure 5). The water-to-binder ratio (W/B) is kept constant at 0.508.

80% steel and 20% polypropylene/jute fibers ropes diameter is used for longitudinal reinforcement. Jute and polypropylene fiber ropes (3 mm diameter) are wrapped on steel (10 mm diameter). Three samples of each combination are casted and cured. The specimens are tested at 7, 14 and 28 days. In total, 18 cylindrical and 36 beam specimens are casted. The cylindrical and beam specimen distribution details with the fiber content are given in Tables 3 and 4, respectively.

Table 2: Characteristics of water used

Parameters	Value
pH	7
Hardness (mg/L)	300
Chloride (mg/L)	240
Sulfate (ppm)	45

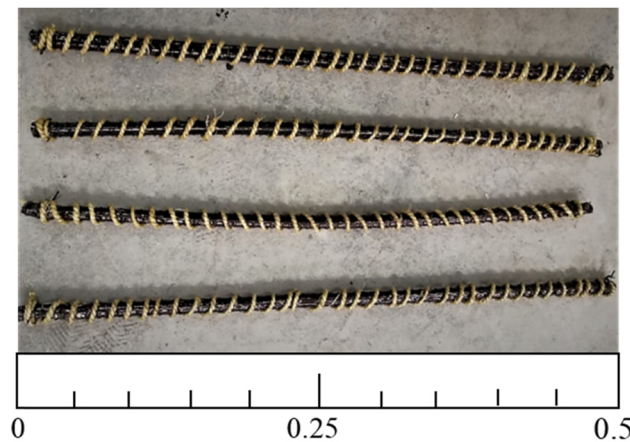


Figure 3: Jute fiber wrapped around steel bar (scale in meters).

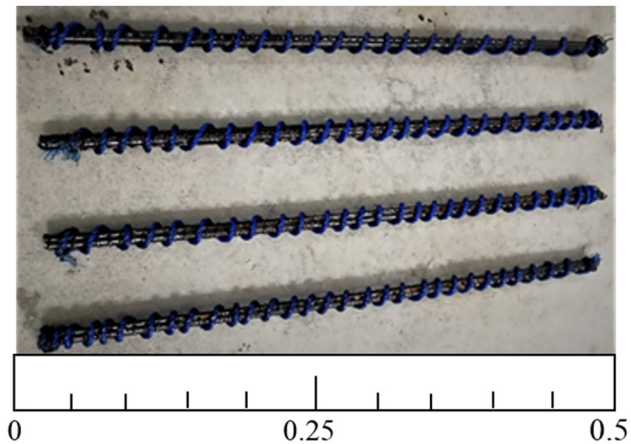


Figure 4: Polypropylene fiber wrapped around steel bar (scale in meters).



Figure 5: Mixing (coir fiber 0.5% of the total volume of concrete).

The cost analysis of control and fiber-reinforced concrete is given in Table 5.

Compression and flexural test are performed on fiber-reinforced concrete. The uniaxial compression test is performed as per the ASTM standard. The three-point bending test is performed on the beam specimens.

3 Test results and discussion

3.1 Compression test

The uniaxial compression test is performed on cylindrical specimens of normal concrete- and coir fiber-reinforced concrete samples (Figure 6). The test is performed according to ASTM standards. The testing is performed on the

Table 3: Cylindrical specimen details for each day of compression testing

Sample designation	Coir fiber content (%) by total volume of concrete	Length of fiber (mm)
C-1	—	
C-2	—	
C-3	—	
C-4	0.5	50
C-5	0.5	50
C-6	0.5	50

universal testing machine having a capacity of 1,000 kN. Compressive strength values according to the mix of coir fiber at 7, 14 and 28 days are presented in Table 6 and shown in Figure 7. The difference in the rate of gain of strength for coir fiber-reinforced concrete and control specimen is very less. The rate of gain of compressive strength with the addition of coir fiber is higher at 28 days curing period compared with 14 days because of the possibility of its strain-hardening ductile failure characteristics [18].

The results show that the concrete with the coir fiber has greater compressive strength compared with control concrete for 28 days. The compressive strength of coir fiber-reinforced concrete increases up to 7%.

3.2 Flexural test

The flexural test is performed on steel-reinforced concrete beams and also on fiber-reinforced beams (Figure 8). The

Table 4: Beam specimen details for flexural testing

Sample designation	Coir fiber content (%) by volume of concrete	Jute fiber rope diameter (mm)	Polypropylene fiber rope diameter (mm)
F-1	—	—	—
F-2	—	—	—
F-3	—	—	—
F-4	0.5	—	—
F-5	0.5	—	—
F-6	0.5	—	—
F-7	0.5	3	—
F-8	0.5	3	—
F-9	0.5	3	—
F-10	0.5	—	3
F-11	0.5	—	3
F-12	0.5	—	3

Table 5: Cost analysis

Specimen	Approximate cost/0.005 m ³ (USD*)
Steel-reinforced concrete	1.67
Steel-reinforced concrete with 0.5% coir fiber	1.70
Steel-reinforced coir fiber concrete + Jute fiber rope	1.39
Steel-reinforced coir fiber concrete + polypropylene fiber rope	1.41

*1 USD = 150 PKR.

control reinforced steel specimen is produced with concrete having no coir fiber. Fiber-reinforced specimens consist of coir fiber steel-reinforced beams with jute or polypropylene fiber ropes wound around steel bar. Flexural strength values for control and fiber-reinforced beams at 7, 14, and 28 day are presented in Table 7 and shown in Figure 9.

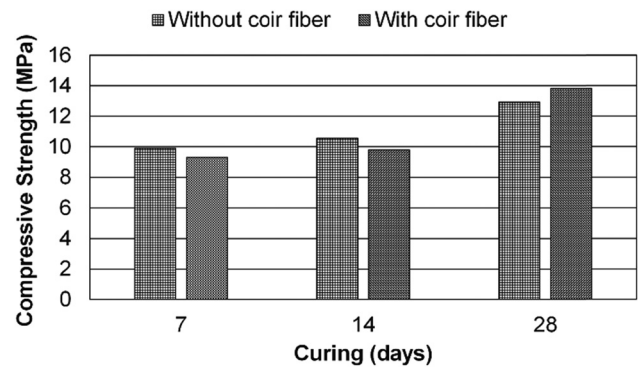
The result shows that the variation in flexural strength of control and coir beams is very less. The flexural strength of coir-jute beam and coir-polypropylene reinforced concrete beams increases to 4 and 6%, respectively, compared with control beam.

4 Conclusion

Compression tests are performed on coir fiber-reinforced concrete. Flexural tests are performed on coir fiber steel reinforced concrete beams with jute and polypropylene

Table 6: Compression test on cylindrical specimens

Specimen condition	Compressive strength (MPa)		
	7 days	14 days	28 days
Control specimen	9.88	10.54	12.91
With 5% coir fiber	9.29	9.79	13.82

**Figure 7:** Compressive strength variation with curing time.**Figure 6:** Failure pattern: (a) concrete without coir fiber and (b) concrete with 0.5% coir fiber.

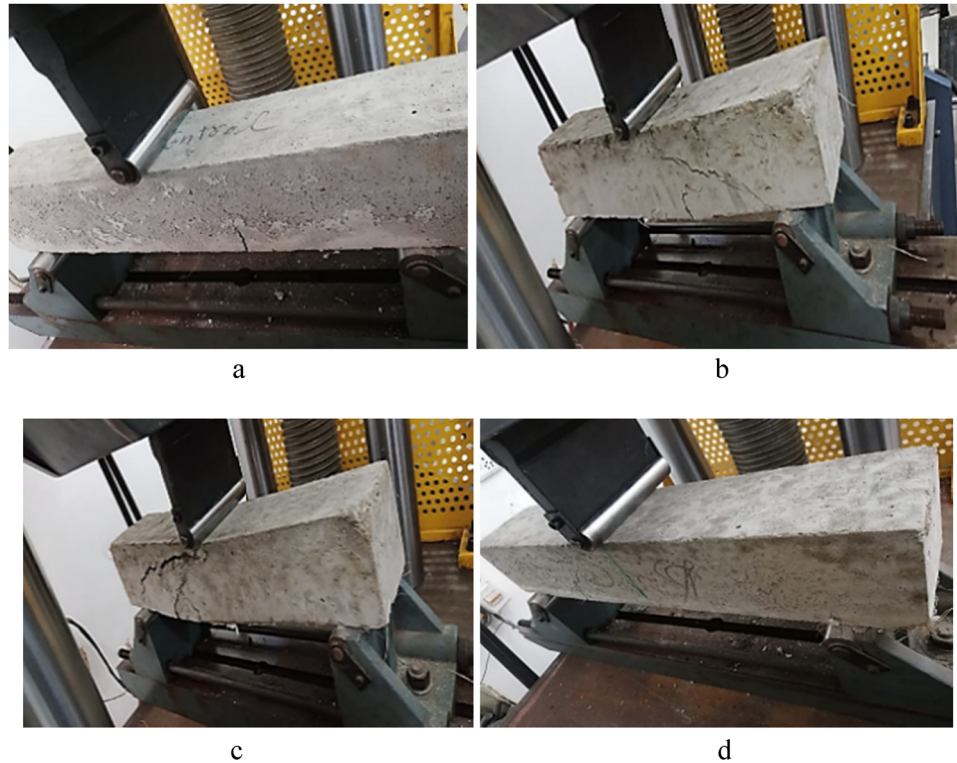


Figure 8: Failure pattern: (a) reinforced concrete without coir fiber; (b) reinforced concrete with 0.5% coir fiber; (c) reinforced concrete with 0.5% coir fiber + jute rope; (d) reinforced concrete with 0.5% coir fiber + polypropylene rope.

Table 7: Flexural test on beam specimens

Specimen conditions	Flexural strength (MPa)		
	7 days	14 days	28 days
Reinforced concrete	12.39	14.50	19.58
Reinforced concrete + 5% coir fiber	12.89	14.91	19.80
Reinforced concrete + 5% coir fiber + jute rope	13.50	15.52	20.21
Reinforced concrete + 5% coir fiber + polypropylene rope	13.83	15.73	20.44

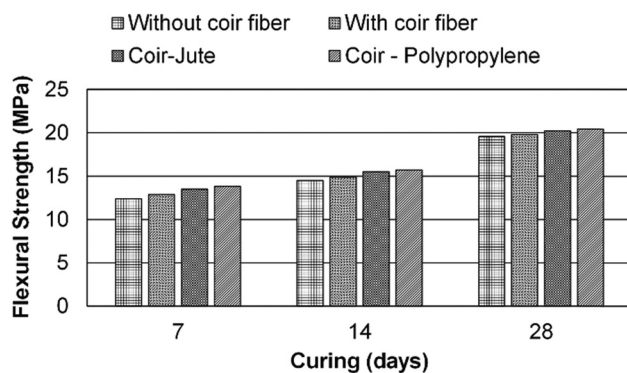


Figure 9: Flexural strength variation with curing time.

ropes wound around steel bars. Based on the test results, following conclusions can be drawn:

1. The rough surface of coir fiber gives good interfacial bond between coir fiber and cement matrix.
2. Compressive strength and flexural strength of fiber-reinforced concrete beam are higher compared with control concrete specimens.
3. Compressive strength of coir concrete is achieved as 13.82 MPa compared to control concrete of 12.92 MPa. The coir concrete compressive strength is about 6% higher compared to control concrete.
4. Flexural strength of coir polypropylene beam is 20.44 MPa compared to control beam, which is 19.57 MPa. The flexural strength of coir polypropylene beam is increased to about 6% compared with control beam.
5. The cracking pattern of fiber-reinforced steel concrete beams is changed from end supports to mid span compared with control samples.
6. The cost analysis shows that we can reduce the cost of concrete steel-reinforced beam by using jute and polypropylene fiber ropes wounding on steel bars. The reduction in cost compared to conventional reinforced concrete is about 15%.

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Conflict of interest: None.

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