

Experimental Investigation of the Effect of Coconut Coir Fibre Content on the Mechanical Properties of M20-Grade Concrete

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Abstract - Concrete is the most widely used construction material in the world because of its versatile property. However, its relatively low tensile strength limits its performance under tensile and flexural loading. Coconut coir fibre (CCF), an abundant and low-cost agricultural by-product, is a promising material for improving the mechanical properties behaviour of concrete. This study investigates the effect of CCF on the compressive, split tensile and flexural strength of M20 grade concrete. Coconut coir fibre was added at 0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of cement. Cube, cylinder and beam specimens were cast, demoulded after 24 hours, and water-cured for 7, 14 and 28 days before testing. The results show that adding CCF improved the mechanical performance of concrete. The optimum fibre content was 2.0%, beyond which the strength decreased. At 28 days, the maximum compressive, split tensile and flexural strengths were 33.37 MPa, 3.51 MPa and 5.01 MPa respectively, which are 12.2%, 17.3% and 13.4% higher than those of the control mix. These findings show that coconut coir fibre can be used as a sustainable reinforcing material in concrete.

Keywords - coconut coir fibre, M20 concrete, compressive strength, split tensile strength, flexural strength, natural fibre.

I. INTRODUCTION

A. General

Concrete is versatile, easily moulded, and the most widely used construction material in the world, with cement as one of its important ingredients. Despite its extensive use in construction, cement production and use are increasingly associated with air pollution, greenhouse gas emissions, water contamination, and the generation of landfill waste [1]. One of those costs is the substantial production of cement, which has been reported to be about 8% of global emissions [5]. The researchers have been steered towards concretes that utilize renewable or waste materials [1, 2]. Composed of natural materials, conventional unreinforced concrete has inherent disadvantages such as low tensile strength, poor flexural properties and high brittleness, and cracks occur and spread with little warning [2]. These tensile shortcomings can be mitigated by reinforcing it with discrete fibres, which are distributed throughout the matrix to spread crack-toughness enhancing forces over the crack [2]. Structural designs are traditionally based on steel or synthetic fibre reinforcement. Steel and synthetic reinforcement have serious environmental and financial costs, such as high embodied carbon emissions, corrosion, quick depletion of resources and high energy consumption in production. As a result, many researchers pushed for the research of natural

fibers like jute, hemp, banana, flax, sisal, bamboo, sugarcane bagasse, kenaf and coir [1].

B. Coconut Coir Fibre as a Structural Reinforcement

Amongst all the natural fibres exist in nature, it is found that coconut coir fibre shows more ductile behaviour compared to the other natural fibres [2]. It consists primarily of lignin and cellulose, with content of 45.84% and 43.44% respectively in the fibre grains [3] and it was reported to be relatively unaffected after a year of concrete exposure. If coir fibres are randomly distributed in the concrete, they form a three-dimensional mechanical network. The main mechanism is by crack-bridging, which redistributes tensile stresses across the micro-cracks when they are under load, and thus avoids catastrophic brittle failure. Despite the production of approximately 280,000 tonnes of coir fibre in last decade, [1] huge amount of husk is dumped in landfills or burned, leading to pollution [2], [4], [5]. It is therefore expected that the use of the fibre in concrete can provide a solution to a waste problem, which can be recovered and used as a construction material. The advantages of coir fibres are recognized, but organic fibres should be used in the concrete with proper optimization of the mix. Low levels of fibre give little reinforcement and high levels make the mix too difficult to work and cause the fibres to aggregate and increase in internal porosity of the matrix. This is experimental study to study the hardened property behaviour of concrete reinforced with coconut coir fibre in a controlled percentage range of 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% as per the weight of cement. The main goals of this research are to assess the mechanical characteristics of concrete of different percentage of CCF.

II. LITERATURE REVIEW

Studies in which the fibre is added to the concrete mix are the most directly comparable with the present work. Usman et al. [2] prepared M20 concrete with water-cement ratio of 0.5 with coconut fibre in the range of 0 to 5% by mass, and prepared 150 mm cubes. The 28-day compressive strength peaked at 20.44 N/mm² at 1% fibre, against 19.87 N/mm² for the control, and fell to 14.00 N/mm² at 5%. They attributed the decrease to fiber collection in large masses which decreased bonding. Ahmad et al. [5] have used fibre (oil coated) at 1%, 2% and 3% of the cement in C25 concrete. Their 28-day strength was 24.8 N/mm² for the control, 22.61 and 21.91 N/mm² at 1% and 2%, and 25.7 N/mm² at 3%, so the response was not a simple rise and fall. Guruswamy et al. [1] have tested concrete with fibre volume fractions of 4–12% and fibre lengths of 4–12 mm and they

found that the highest strength (34 N/mm²) occurred at 4% fibre and 10 mm fibre length; the strength decreased with increasing percentage of fibre. Mudiyo and Sudarno [9] used paving blocks and fibre content of 0.1-0.3% of the cement, with 0.1% being best, which yielded approximately 4% more strength than the control at 7 days, and 0.3% had a negative effect. Bamigboye et al. [8] reported that strength increased with up to 0.5% fibre and decreased beyond but that their fibre concrete retained greater strength than the plain concrete after being heated to 150 °C and 250 °C.

Not all studies show that there is an advantage. Bediako et al. [4] found that when approximately 1% coir (50 mm long) was added to a C32/40 mix with a water-cement ratio of 0.356, it was weaker than the control at all ages tested, 35.5 N/mm² at 28 days against 38.2 N/mm² for the control. They related these to the amount of water taken up by the fibre and the interstices it created, and found that synthetic fibre gave better results.

In the second set of studies, a portion of the cement or sand is being substituted with fibre. Osuji and Ukeme [6] replaced 5–35% of the cement by volume in three mixes (1:2:4, 1:1.5:3 and 1:3:6) and found strength falling steadily; in the 1:2:4 mix the 28-day strength dropped from 28.97 to 17.11 N/mm² at 35%. Prayag and Shete [10] replaced 1.5–3.5% of the cement in M30 concrete, with 28-day strength of 31.14 N/mm² for the control, 32.29 at 1.5% and 29.95 at 3.5%. Kala et al [3] replaced 1-7% of fine aggregate in M25 grade concrete and obtained optimum result with 5% replacement of fine aggregate as its 28-day strength is 32.87 N/mm² as compared to 32.12 for control concrete. Yuvaraj et al. [7] added 1-4% coir with 30% replacement of cement by GGBS, and the 1% mix produced 46 N/mm², which is lower for higher addition rates and 45.33 N/mm² without the addition of fibre making up the mix.

There are fewer studies that measure tensile behaviour. At 1% coir the 28-day split tensile strength was 6.05 MPa (an increase of 88%) while the flexural strength was 5.56 MPa (an increase of 32%) and at 3% and 4% fibre both properties declined but remained above the control. The largest effect was at 1% coir where the 28-day split tensile strength was 1.85 MPa (an increase of 54%) and the flexural strength was 5.56 MPa (an increase of 32%). The effect of 1% and 5% fibre contents on split tensile strength and flexural strength was found to be smaller and less regular by Kala et al. [3] as the split tensile strength were 2.43 N/mm² and 2.54 N/mm² respectively and flexural strength increased only by 4.52 N/mm² and 4.67 N/mm² respectively. Bediako et al. [4] found the flexural strength of coir concrete to be 5.4 MPa which is approximately 12% higher than that of the control, but the flexural strength obtained for the control was 8.0 MPa when polypropylene fibre was added. These studies indicate that the coir fibre has a greater effect on tensile and flexural strength compared to compressive strength, but the number of studies is limited.

III. MATERIALS & METHODOLOGY

The experimental programme was carried out to study the effect of coconut fibre on the compressive and tensile strength of concrete. The materials used were commercially fly ash-based Portland pozzolana cement, kiul river sand as fine aggregate, crushed stone of 20 mm nominal size as coarse aggregate, natural coconut coir fibre as the reinforcing

material, and potable water. The fine and coarse aggregates were sieved 4.75 mm and 20 mm IS sieve before use, and their properties, namely specific gravity, fineness modulus and water absorption, were determined and shown in Table I, Table II and Table III. All ingredients were weighed on a digital weighing scale according to the mix design.

TABLE I. TEST RESULTS OF CEMENT

S. No.	Test / Property	Test result	IS code (test method)
1	Specific gravity	3.11	IS 4031 (Part 11):1988
2	Fineness (residue on 90 μ sieve)	3.5%	IS 4031 (Part 1):1996
3	Initial setting time	39 minutes	IS 4031 (Part 5):1988
4	Final setting time	800 minutes	IS 4031 (Part 5):1988
5	Standard consistency	35%	IS 4031 (Part 4):1988

TABLE II. TEST RESULTS OF FINE AGGREGATE

S. No.	Test / Property	Test result	IS code (test method)
1	Specific gravity	2.65	IS 2386 (Part 3):1963
2	Bulk density	1660 kg/m ³	IS 2386 (Part 3):1963
3	Fineness modulus	2.36	IS 2386 (Part 1):1963; IS 383:2016

TABLE III. TEST RESULTS OF COARSE AGGREGATE

S. No.	Test / Property	Test result	IS code (test method)
1	Specific gravity	2.63	IS 2386 (Part 3):1963
2	Bulk density	1620.87 kg/m ³	IS 2386 (Part 3):1963
3	Water absorption	2.0%	IS 2386 (Part 3):1963
4	Aggregate impact value	16.63%	IS 2386 (Part 4):1963; IS 383:2016
5	Aggregate crushing value	17.03%	IS 2386 (Part 4):1963; IS 383:2016

The designing of a concrete mix of M20 grade was done by taking the ratio of (1: 1.5: 3) (cement: fine aggregate: coarse aggregate) and the water-cement ratio as 0.5. The proportions of coconut fibre added to the cement are (0%, 0.5%, 1.0%, 1.5% and 2.0%) by weight of cement with the mix containing 0% coconut fibre as the control. To ascertain the compressive strength, the cube specimens of 150 x 150 x 150 mm were cast for every curing age; for split tensile strength test, the cylindrical specimens of 150 x 300 mm were cast for every curing age and for flexural strength test, cube specimens of 150 x 150 x 700 mm were cast for each curing age. The dry mixing of weighed cement, fine aggregate and coarse aggregate was done on a clean non-absorbent platform. The coconut fibre was finally slowly added to the dry mixture and mixed uniformly using trowels. The quantity of water calculated was then added and mixing was continued until a uniform and workable mix was obtained. The fresh concrete was poured in the moulds. The moulds were filled and left to stand at room temperature for 24 hours. The specimens were then carefully extracted from the moulds after this time and identified by the percentage of fibre and date of casting. The demoulded specimens were completely placed in a clean water tank and cured for 7, 14

and 28 days at 27 ± 2 °C. The specimens were removed from the curing chambers and surface dried at the end of each curing period and tested for compressive strength, split

tensile strength and flexural strength. The materials used and the methodology used in this study are explained in the Fig.1.



Fig. 1. Flowchart of the experimental procedure and the materials used for testing

IV. RESULTS AND DISCUSSION

The coconut coir fibre (CCF) reinforced concrete was tested at curing ages of 7, 14 and 28 days to examine the effect of incorporation of CCF on its mechanical properties. The results were compared with the control mix which was made without any fibres. The outcomes show that the properties of compressive strength, split tensile strength and flexural strength of concrete were affected with the addition of CCF.

A. Compressive Strength

Compressive strength of concrete increased with fibre content up to 2.0% at every age as shown in Fig. 2. At 2.0% CCF it was 8.4%, 10.2% and 12.2% higher than the control at 7, 14 and 28 days. The 0.5% mix was near the control (+0.2%, -0.9% and +3.4%), as a small quantity of fibres means they were not able to prevent micro-cracking. The fibres fill in micro-cracks and prevent them extending at a concentration of 1.0–2.0%. As the curing time went on, strength improved in all mixes and the control mix showed approximately 72% strength increase between 7 days and 28 days. A study carried out on M25 concrete indicated that the strengths of concrete increased up to an optimum value of 1% of coconut fibre [11]. Several other studies have reported reduction in the compressive strength performance with the incorporation of coir fibre [12, 13] which depends on the mix grade, fibre length and dosage.

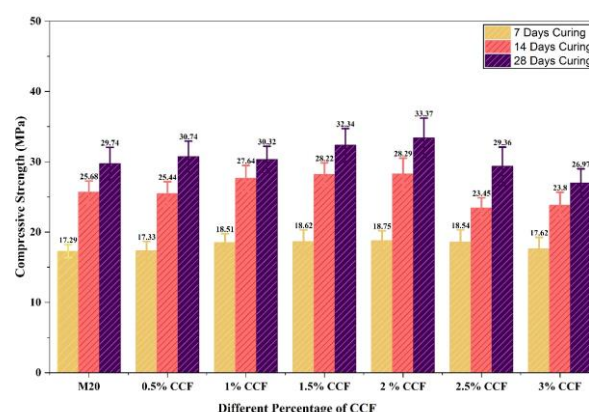


Fig. 2. Variation of compressive strength of concrete with varying percentage of CCF

After 2.0% the strength has dropped. At 28 days it was 29.36 MPa at 2.5% and 26.97 MPa at 3.0%, which is 1.3% and 9.3% below the control. The fibers clump together, bind air, decrease workability and decreases fiber–matrix bond at high fiber content. Other researchers [14, 55] also have reported the decreasing workability with increasing coconut fiber content. This creates voids and weak areas which cancel out the crack bridging. So, the optimum content is 2.0% by weight of cement.

B. Split Tensile Strength

The split tensile strength increased greater than the compressive strength. At 2.0% CCF the gains over the control were 13.7%, 12.7% and 17.3% at 7, 14 and 28 days, and the 28-day maximum was 3.51 MPa as shown in Fig. 3. When under tension, fibers will span a crack and bring load

across the crack and postpone the sudden splitting failure of plain concrete. This is why the tensile strength has more of an advantage over the compressive strength. Earlier researches have also reported the increase of tensile strength of coconut fiber [12, 14, 15].

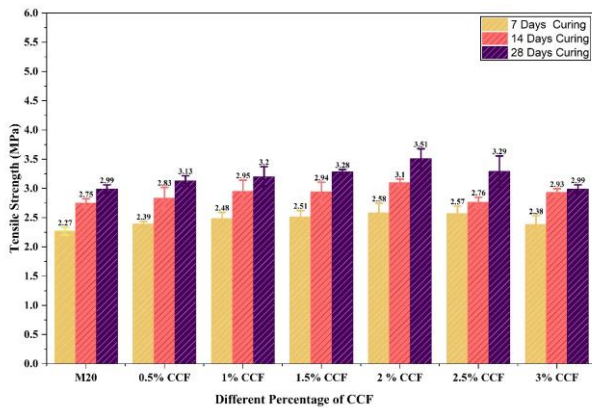


Fig. 3. Variation of split tensile strength of concrete with varying percentage of CCF

Similarly, 2.0% CCF produced the highest values when compared with other CCF concentrations, like compressive strength. The 28-day value was 10.0% higher than the control value at 2.5%, but less at 2.0%. The 28-day value dropped to the control value (2.99 MPa) after 3.0%, meaning that when excess fiber is added the benefit is lost. The 28-day strengths were ranging between 0.98 and 1.08 times the strength obtained by IS based estimate of $0.56\sqrt{f_c}$, which falls within the expected range (IS 5816 [16] covers the split tensile test).

C. Flexural Strength

Flexural strength is evaluated on beams of size 150 mm x 150 mm x 700 mm. The variation of test results with CCF are shown in Fig. 4. The 2.0% CCF mix gave the highest values, with gains of 15.4%, 11.3% and 13.4% over the control at 7, 14 and 28 days, and a 28-day maximum of 5.01 MPa. In a beam, the fibers prevent cracking opening in the tension zone and they add energy to the failure. At 0.5–1.0% CCF the 28-day improvement was small (−0.2% to +1.5%), and a useful gain began at 1.5%. Gains of similar flexural were reported at fiber content of 0.4–1.0% with maintaining uniform workability in concrete using superplasticizer [15] and at approximately 1% fiber content in M25 concrete [11].

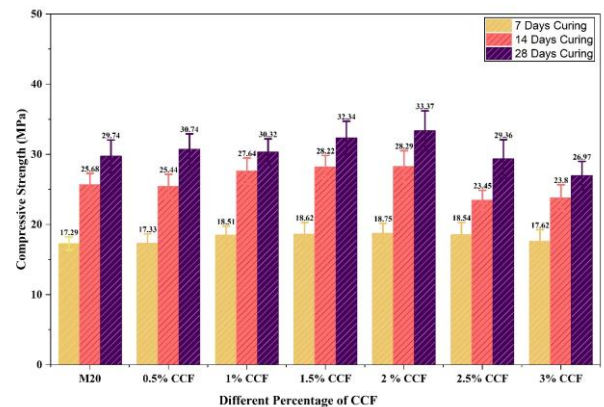


Fig. 4. Variation of flexural strength of concrete with varying percentage of CCF

Above 2.0% flexural strength declined. At 3.0% CCF the 28-day value of 4.24 MPa was 4.0% below the control, for the same reasons given for compressive strength. All flexural values were 1.10–1.24 times the IS 456 estimate of $0.7\sqrt{f_{ck}}$ [18], so they meet the code requirement.

V. CONCLUSIONS

The following conclusions were drawn from the experimental results obtained in this study.

- 1) Addition of coconut coir fibre improved the compressive, split tensile and flexural strength of M20 concrete up to an optimum content of 2.0% by weight of cement.
- 2) At 28 days, the 2.0% CCF mix reached a compressive strength of 33.37 MPa, a split tensile strength of 3.51 MPa and a flexural strength of 5.01 MPa. These are 12.2%, 17.3% and 13.4% higher than the control mix.
- 3) Tensile and flexural strengths improved more than compressive strength, which confirms the crack-bridging role of the fibers.
- 4) Beyond 2.0% CCF the strength decreased, because fiber clumping, lower workability and poorer bonding offset the benefit. At 3.0% the 28-day compressive and flexural strengths fell below the control.

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