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Ultimate Tensile and Compressive Strength of Concrete Containing Coir Fibers

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Abstract

This paper describes the results of the study to determine the feasibility of coir fibers as reinforcement to concrete, specifically to evaluate the ultimate tensile and compressive strength of concrete containing coir fibers. The average ultimate tensile and compressive strength of plain concrete and concrete containing various amounts and lengths of coir fibers were determined and their strengths compared. Generally, the addition of coir fibers has negative influence on the compressive and tensile strength of concrete, but the addition of fibers converts the sudden and brittle failure of plain concrete in tension into gradual and ductile failure.

Introduction

Natural fibers of vegetable origin such as straw, grass and reeds were used to reinforce mud bricks as early as 1400 B.C. Even today, straw and some naturally occurring fibers are still being used to reinforce

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mud bricks and other brittle matrix. Modern day use of fibers in concrete gained broad recognition when Romualdi and Batson published their pioneering research on steel fiber-reinforced concrete in 1963 (Abdel-Azim, 1995). The major improvement in using steel fibers in concrete occurred in the areas of ductility and fracture toughness, even though flexural strength increases were also reported. Adding steel fibers increases the local tensile strength of the concrete at almost all points, reducing or preventing the spread of cracks. The addition of steel fibers converts the sudden brittle failure of plain concrete in tension into a gradual and ductile failure. The fibers also evenly distribute drying shrinkage. Since then, considerable development and innovation has taken place with the use of steel fibers in concrete. However, steel fibers are susceptible to the problem of corrosion at cracks. Because of this, new fiber types and composites are continually being developed using stainless steel, carbon glass, plastic, polymeric and some naturally occurring fibers (Balaguru, 1992).

The recent exponential increase of cost of labor and materials, the devaluation of peso, and the need to reduce foreign reserve expenditures on importing steel, carbon and polymeric fibers, call for a renewal of interest in using naturally occurring fibers as alternative materials. Natural fibers such as coconut, bamboo, sugarcane bagasse and cellulose fibers are relatively inexpensive and abundant.

A possible problem with some of the naturally occurring fibers is their lack of durability in the alkaline environment of concrete, unless modifications are done either to the fiber surfaces or to the matrix composition (Balaguru, 1992).

In the Philippines, one of the naturally occurring fibers that is considered inexpensive, renewable and abundant is the coir fiber from ripe coconut husk. Coir fiber has many characteristics that make it suitable in enhancing Portland cement concrete in the construction of low cost housing. A unique aspect of this fiber is the low amount of energy required to extract this fiber.

Plain concrete is basically strong in compression but weak in tension and shear, has limited ductility and little resistance to cracking unless modifications are introduced to improve its ductility. Microcracks are inherently present in concrete and because of its low tensile strength the cracks magnify with the application of the load, leading to brittle fracture of concrete, thus making the presence of tensile reinforcement in concrete a necessary condition.(Siddique, 1997)

Objectives of the Study

This study is conducted:

1. to determine the ultimate tensile and compressive strength of concrete with untreated coir at specified fiber lengths of 3 cm, 6 cm, and 12 cm and specified fiber percentages of 0.25%, 0.5% and 1.0%;
2. to determine the ultimate tensile and compressive strength of concrete with treated fibers at specified fiber lengths of 3 cm, 6 cm and 12 cm and at specified fiber percentages of 0.25%, 0.50% and 1.0%;
3. to determine if the random dispersion of small and short coir fibers in concrete will significantly affect the tensile and compressive strength of concrete;
4. to determine if immersing the coir fibers in a cement solution of 100 grams of cement per 200 ml potable water for about 4 hours prepared at room temperature would affect the tensile and compressive strength of concrete;
5. to determine the extent of reinforcement provided by coir fibers to concrete; and
6. to determine the relationship between the compressive or tensile strength of the composite and fiber length or fiber percentages.

Review of Related Literature

Coir fiber-concrete development

The use of coconut fiber in concrete is still at its early stage of development. Studies on naturally occurring fibers such as sisal, coconut, bamboo, sugarcane bagasse and cellulose fibers were conducted in areas of thin-sheet products. Their primary application is for nonstructural elements such as wall partitions and roofing elements that can support small live loads. This development came as a result of the gradual phasing out of asbestos-reinforced products. Asbestos is a health hazard and efforts have been made to find a convenient substitute (Balaguru, 1992).

Coir-cement

Coir fiber reinforcement has been studied in Brazil by Savastrano Jr. Using mat fibers processing residues, cement and sand, he produced less brittle material suitable for producing partitions (Swamy,1988).

An investigation on coir-cement composite was conducted by Dantas using concrete with low cement content (175 kg/m^3) and a high percentage of mortar (60%), reinforced with fibers with a constant length of 50 mm, and where the fiber volume fraction varied from 1 to 6%. The results showed that the compressive strength was reduced with the increase of fiber content and the best tensile strength in bending tests (1.25 MPa) was obtained with about 4% fiber volume (Swamy, 1988).

A research was conducted by CEPED to determine the effects of fiber lengths and volume, matrix composition, manufacturing method and workability on roofing tiles using cement-sand mortar in the proportion of 1:3 by volume. Tiles with a length of 1 m, 1% fiber content and water-cement ratio of 0.85 were tested in flexure. Results of the study show that tiles with 4-cm long fibers presented 83% more strength than the unreinforced tiles (Swamy, 1988).

A study using coir fibers as reinforcement in cement-sand matrix shows that water-soluble constituent in the fiber caused retardation in setting and strength development of the composite. Coir is found to resist deterioration when subjected to alternate cycles of wetting in saturated lime solution and decinormal solution of sodium hydroxide and drying. While coir fibers, due to its low modulus and high elongation characteristics, do not contribute towards strength improvement, they are capable of absorbing large strain energy and thus impart a greater degree of toughness and resistance to impact and explosion as compared to high-modulus rigid fibers. The fiber-concrete bond depends upon the keying action between matrix and the individual filaments in the fiber. The length of the fiber has to be sufficient in order to mobilize the interfacial bond force (Krishnamoorthy and Ramaswany, 1982).

Coir

Coir fiber is the fiber from the husk (mesocarp) of coconut. It is one of the structurally hard fibers. Compared with other vegetable fibers, coir is highly lignified and correspondingly contains less cellulose. The largest fibers have a length of up to 350 mm and are from 0.30 mm to 1 mm in diameter, being thickest in the middle of their length. The fibers are made up of elementary fiber cells varying in length of around 0.7 mm and 12 to 20 mm thick. The fiber is extracted from the retted coconut husks by the mechanical defibering process(Woodroof, 1970).

Coir is light, elastic, tough, water-resistant, heat insulating, and resistant to mechanical wear. In this respect, it has advantages for rope and cable making. Coir yarn can stretch beyond its elastic limit without breaking and can take up a permanent stretch when so loaded. The ability of coir yarn and ropes to withstand the prolonged action of seawater makes them especially suitable for use on boats and ships. However, it is disadvantageous in terms of its lop-sided surface roughness. Its chief competitors are hard fibers such as abaca, agave, sisal and hanequen fibers. Price is the chief factor in maintaining coir's competitiveness (Woodroof, 1970).

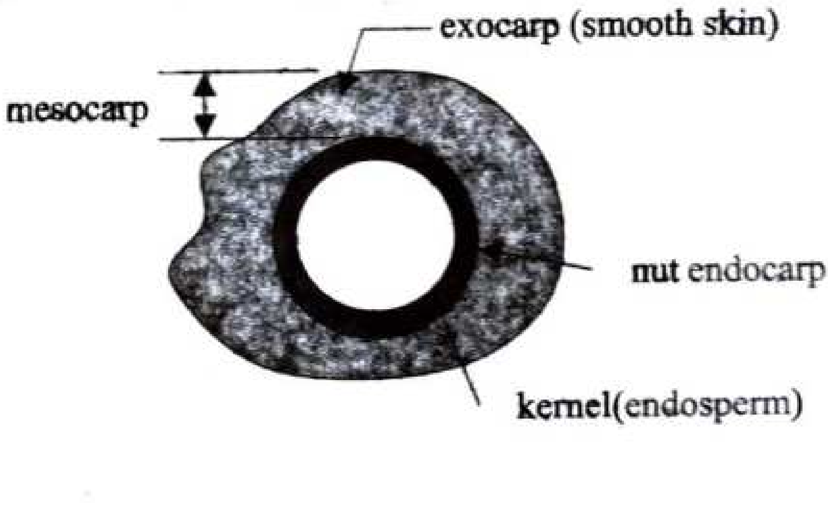

Figure 1. Cross section of ripe coconut fruit

Chemical composition of coir

Coir belongs to the group of natural cellulosic fiber and contains, apart from cellulose, lignins and other substances which serve as building materials for a cell structure. The chemical composition of fiber of different origin is given in Table 1 (Ohler,1984).

Table 1. Chemical composition of coir fiber (percent on dry basis)

Fiber and Source	Water soluble substances	Pectin and other soluble substances in boiling water	Hemi-cellulose	Lignin	Cellulose
Old nut	5.2	3.0	0.25	45.8	43.4
Young nut	16.0	2.7	0.15	40.5	32.9
Very young nut	15.5	4.0	0.25	41.0	36.1

Lignin is the main constituent responsible for the stiffness of the coir. It is also partly responsible for the natural color of the fiber. Husks that are exposed to the sun or allowed to dry become brittle and do not yield good fiber. Complete delignification will result in the breakdown of the fiber to the ultimate cells.

Interaction between coir and concrete

During the service life, the composite may remain uncracked. However, in most cases, the composite will crack. The fiber interaction with the uncracked concrete has limited importance in practical applications (Balaguru, 1992). When the load is applied to the composite, part of the load is transferred to the fiber along its surface. Because of the difference in stiffness between the fiber and concrete, shear stress develops along the surface of the fiber. Since the fiber modulus of coir is less than the concrete modulus, the deformation around the fiber will be higher (Figure 2). Elastic stress transfer exists in uncracked composite as long as the concrete and the fiber are within the elastic range. The stress-strain response of the composite could exhibit non-linearity and inelastic behavior prior to fracture.

Fiber-concrete bond behavior can be studied using either direct or indirect tests. This study uses the indirect test to determine the ultimate tensile and compressive strength of the composite. In this test, the composite is tested in tension or compression and the fiber contribution is evaluated. The results obtained in this process are highly dependent on the mathematical model used for the analysis.

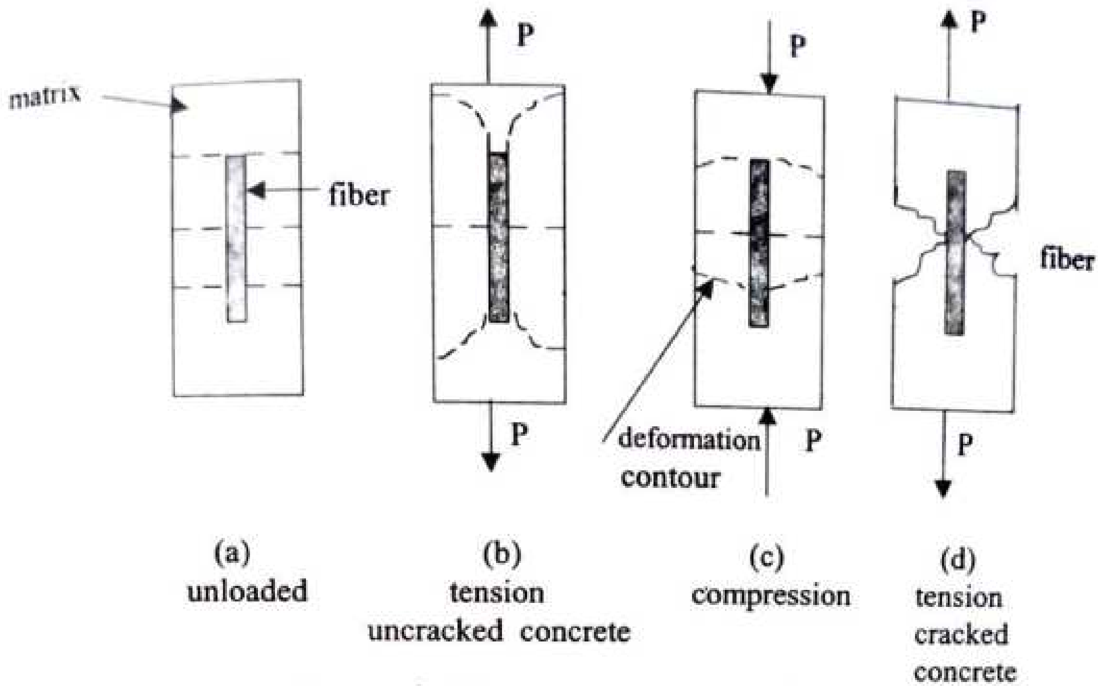

Figure 2. Fiber-concrete interaction

Methodology

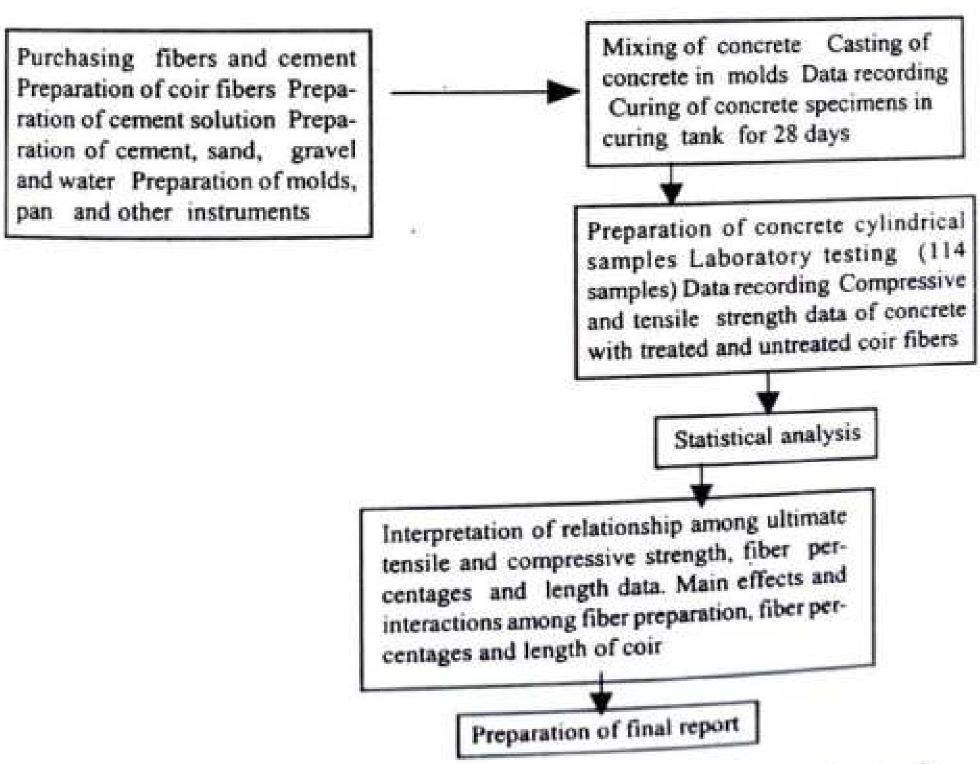

Figure 3. *Flowchart of the basic process of the study*

Preparation of coir fiber

Several long sections of coconut fibers with approximate lengths of 3 cm, 6 cm, and 12 cm are cut using scissors. Pith dusts that adhere to the surface of the fiber are manually removed. Absorbed water is removed by air drying the prepared samples for at least 48 hours at room temperature and the weights of the samples are measured using a weighing balance. Moisture in the sample can also be removed by allowing the samples to dry under the heat of the sun for at least 1 hour. The samples are then weighed dry. Three kinds of fiber samples in various proportions are prepared as follows: 0.25% (0.187 kg), 0.5% (0.374 kg) and 1% (0.75 kg).

Preparation of concrete test cylinders

To investigate the effect of treating coir on the compressive and tensile strength of concrete, two groups of composites are cast. The first group of composites receives untreated fibers and the second group of composites receives treated fibers. In the first group, sections of plain coconut fibers, previously prepared, are simply added to the mixture of cement, sand, gravel and water in a mixing pond. The resulting mixture is then cast in 6 cylindrical molds, demolded after 18 to 24 hours and cured in a curing tank for 28 days. In the second group, sections of coconut fibers previously immersed in cement solution are added to concrete mix prior to casting in cylindrical molds. The cylinders are removed after 18 to 24 hours and cured in a curing tank for 28 days at 23 °C. Ultimate tensile and compressive strength tests are then conducted on both composites to determine and evaluate the effects of treatment.

Tests performed on concrete

Compression test

The ASTM C 39-86 Standard Method for Compressive Strength of Cylindrical Concrete Specimens for plain concrete is applied to concrete containing coir fibers. In this method a concentric compression force was applied to the ends of 150 mm diameter, D, concrete cylinder with a height, L_H, of 300 mm at a constant rate of 5 kN/sec until failure occurred at a load P. The compressive strength f 'c in N/mm² (MPa) is calculated by:

$$f'c = \frac{4P}{3.14\ D2} \qquad (1)$$

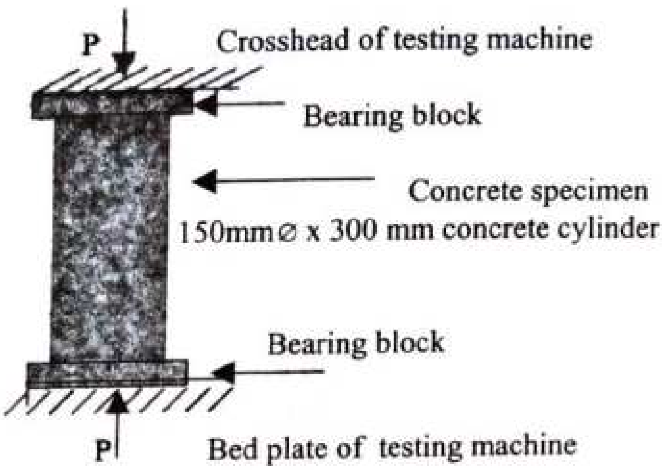

Figure 3. *Compression test on concrete test cylinder*

Split cylinder test

The ASTM C 496-90 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens for plain concrete is applied to concrete containing coir fibers. This test was used to measure the tensile strength of concrete. The test was chosen because of the suitability of the test arrangements and the difficulty of using the direct tension test on FRC specimens. In this test, a concrete cylinder 150 mm in diameter, D and 300 mm in length, L_H, was placed with its axis horizontal between the plates of the testing machine. An applied load was increased at a rate of 5 kN/sec until failure occurred at a load P. The failure was characterized by splitting of the concrete cylinder along the vertical plane connecting the two contact lines with the machine heads. The ultimate tensile strength, based on a linear elastic assumption, was calculated as follows:

$$f_{st} = \frac{2P}{3.14 \times D \times LH} \qquad (2)$$

where: L_H = the length of concrete cylinder.
D = the diameter of concrete cylinder
P = the applied load

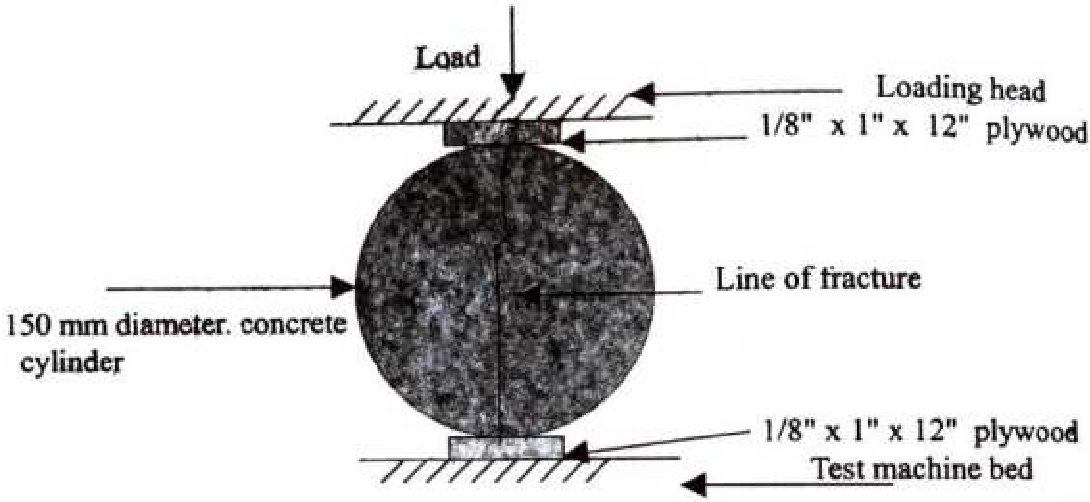

Figure 4. *Method of loading concrete specimen for splitting tensile test*

Slump test

The slump test is performed in accordance with ASTM C 143, Slump of Portland Cement Concrete. This test is used as a gage to determine the workability of the mixture. Slump value was maintained below 100 mm.

Proportioning of trial mix

The ACI Standard 211.1 computations for concrete trial mix were used to arrive with the following proportions

Table 2. Concrete mixture proportion

Constituents	Percent by weight
Coarse aggregates	48
Fine aggregates	26
Cement	17.6
Water	8.4

Table 3. Computed weights of water absorbed per corresponding batch weight of coir

Percent fiber	Weight of fiber, kg	Weight of absorbed water, kg
0.25	0.187	0.337
0.5	0.374	0.673
1.0	0.75	1.350

Table 4. Gradation and weight of coarse and fine aggregates per batch mix

US sieve (inch)	Recommended grading Requirements ¾ max. aggregate size (percent passing)	Adopted Percentage Passing	Percent retained on each sieve	Weight of aggregates Retained in the sieve,kg
¾	94-100	97	3	3.0
½	70-88	79	18	18.5
3/8	61-73	65	14	14.4
#4	48-56	48	17	5.0
#8	40-47	40	8	2.4
#16	32-40	32	8	2.4
#30	20-32	20	12	3.7
#50	10-20	10	10	3.0
#100	3-9	3	7	2.1
#200	0-2	0	3	0.9

Results and Discussion

Results of the slump tests are shown in tables 5 and 6. Values of slump indicate that the maximum slump of 100 mm is not exceeded. This means that the consistencies of the different mixes are within tolerable limits. Workability generally decreases as the amount of coir fiber is increased. To maintain workability and good fiber distribution, additional water is added to concrete mix per batch using the water absorption rate of coir of 180 %.

***Table 5.** Slump, compressive strength test results of concrete with untreated and treated coir fiber*

Mix no.	% fiber	Weight of fiber (kg)	Average length, of fiber (cm)	Slump un treated (mm)	Slump Treated (mm)	Ultimate compressive strength, untreated (MPa)			Ultimate compressive strength, treated (MPa)		
						C_1	C_2	C_3	C_4	C_5	C_6
1	Plain	concrete		50	50	27.22	22.35	25.15	27.22	22.35	25.15
2	0.25	0.187	3	12	42	11.63	13.75	18.50	26.48	18.56	26.37
3	0.25	0.187	6	100	20	16.61	21.16	21.28	23.03	28.46	27.39
4	0.25	0.187	12	50	24	12.84	11.97	13.84	27.39	23.88	26.40
5	0.5	0.374	3	25	10	9.39	8.66	11.32	18.81	23.11	22.29
6	0.5	0.374	6	20	30	20.94	20.54	19.52	21.76	23.23	20.96
7	0.5	0.374	12	25	40	9.68	13.69	9.96	18.22	27.67	23.34
8	1.0	0.75	3	19	25	8.37	13.5	12.59	18.61	16.81	16.95
9	1.0	0.75	6	10	30	12.73	14.46	12.76	17.99	17.26	17.12
10	1.0	0.75	12	10	30	14.99	15	15.05	17.29	17.85	18.05

***Table 6.** Slump, ultimate tensile strength test results of concrete with untreated and treated coir fibers*

Mix no.	% fiber	Weight of fiber, (kg)	Average length, of fiber (cm)	Slump Un-treated (mm)	Slump Treated (mm)	Ultimate tensile strength, untreated (MPa)			Ultimate tensile strength, treated (MPa)		
						T_1	T_2	T_3	T_4	T_5	T_6
1	Plain	Concrete		50	50	2.129	2.369	2.384	2.129	2.369	2.384
2	0.25	0.187	3	12	42	1.80	1.86	1.82	1.938	2.178	2.051
3	0.25	0.187	6	100	20	2.04	1.85	1.87	2.094	1.931	2.164
4	0.25	0.187	12	50	24	1.30	1.25	1.41	2.157	2.235	1.994
5	0.5	0.374	3	25	10	1.19	1.22	1.17	2.242	2.256	2.214
6	0.5	0.374	6	20	30	2.04	1.96	2.0	1.881	1.832	1.860
7	0.5	0.374	12	25	40	1.54	1.47	1.63	1.91	1.896	1.966
8	1.0	0.75	3	19	25	1.43	1.43	1.38	1.266	1.542	1.485
9	1.0	0.75	6	10	30	1.63	1.51	1.68	1.436	1.556	1.485
10	1.0	0.75	12	10	30	1.79	1.63	1.66	1.62	1.599	1.485

Basically, the effect of adding the coir fibers to the concrete mix is to increase the local tensile strength of concrete at large number of points in different directions, depending on the amount of added fibers and on the random directions of these fibers. This is clearly shown in the photo of split concrete cylinders and the photo of compressed concrete cylinders of Figures 5 and 6. The fibers "trap" cracks and stop or delay their spread.

Considering the compressive and tensile test results summarized in Table 5 and Table 6, the addition of fibers generally had negative effect on the compressive and tensile strength of concrete compared to similar strength of plain concrete.

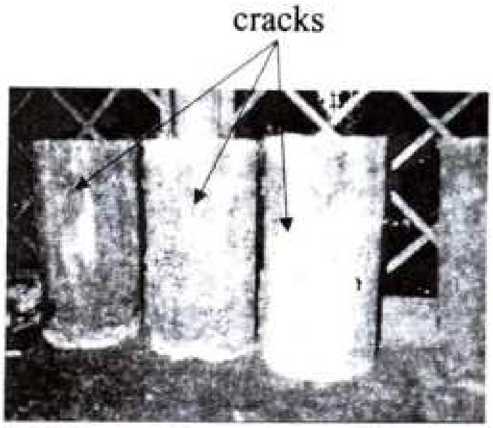

Figure 5. *Concrete test cylinders containing coir fibers after compressive strength test*

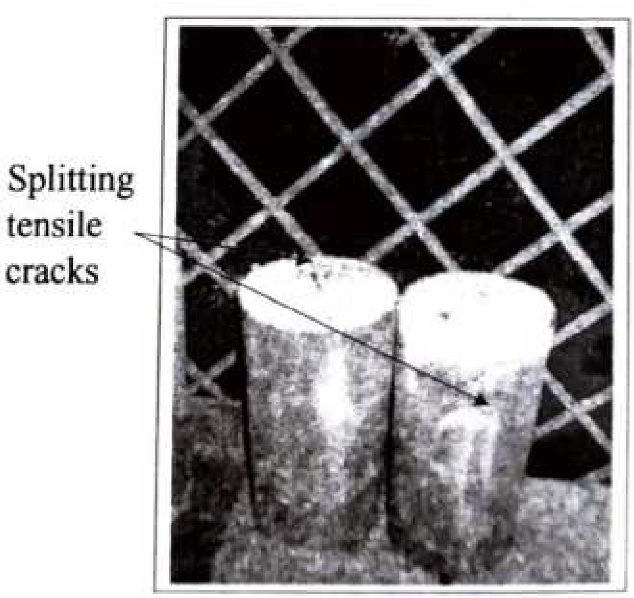

Figure 6. *Concrete test cylinders containing coir fibers after splitting tensile test*

The drop in compressive and tensile strength and the effect of treatment may be attributed to the following:

a) As the fiber's percentage and length are increased, the probability of these fibers nesting together and leaving large voids in the concrete is greater. This explains the very low value of compressive strength obtained for mixes that had a fiber percentage of 1 percent and a fiber length of 12 cm (Table 5 and Table 6). Tensile strength data for untreated specimen also exhibit lower strength values as fiber percentages and lengths are increased.
b) In many cases, concrete around the fibers are not completely hardened. In some cases the ingredients, particularly cement, were found in powder form. After mixing, the fibers had absorbed too much water, denying the cement around them enough water for hydration.
c) The problem was resolved by immersing the coir in cement solution for 4 hours before mixing them with concrete. The result of this action can be seen by comparing the averages of compressive and tensile strength in Table 7 which shows that the compressive and ultimate tensile strength significantly increased. This is because the treated fibers, when incorporated into the concrete mix, no longer absorb water since it has previously absorbed water and the ions of cement.
d) Generally, compressive and tensile strengths decrease as the weight of coir is increased regardless of length. This downward trend indicates that higher strengths are attained at low percent fiber. The interaction of length and percent fiber shows that the best combination which gives relatively high value of compressive and tensile strength is 0.25 percent fiber and at a fiber length of 6 cm.

Table 7. Average ultimate compressive and tensile strength of concrete with untreated and treated coir fiber

Mix no.	Percent Fiber	Weight of fiber, (kg)	Average length of fiber (cm)	Average ultimate compressive strength of concrete (MPa)			Average ultimate tensile strength of concrete (MPa)		
				Untreated	Treated	Difference	Untreated	Treated	Difference
1	Plain	Concrete		24.91	24.91	0	2.294	2.294	0
2	0.25	0.187	3	14.63	23.80	9.17	1.82	2.06	0.24
3	0.25	0.187	6	19.68	26.29	6.61	1.92	2.06	0.14
4	0.25	0.187	12	12.88	25.89	13.01	1.32	2.13	0.81
5	0.5	0.374	3	9.79	21.41	11.62	1.20	2.24	1.04
6	0.5	0.374	6	20.33	21.98	1.65	2.00	1.86	-0.14
7	0.5	0.374	12	11.11	23.08	11.97	1.55	1.92	0.37
8	1.0	0.75	3	11.49	17.46	5.97	1.42	1.43	0.01
9	1.0	0.75	6	13.32	17.46	4.14	1.61	1.49	-0.12
10	1.0	0.75	12	15.40	17.73	2.33	1.69	1.57	-0.12

Conclusions

The compressive and tensile strength of concrete containing coir fibers are significantly affected by fiber preparation, percentage of fiber and length of fiber. Basing on the results of the experiment, the following conclusions are drawn:

1. The compressive and tensile strength of concrete are negatively influenced by the addition of coconut fibers for all levels of fiber preparation, length and percent fiber.
2. The compressive and tensile strength of concrete decrease as the percentage of fibers is increased.
3. Higher compressive and tensile strength can be obtained by immersing the fibers in a cement solution for 4 hours before mixing them with concrete. Fiber preparation significantly affects the compressive and tensile strength of concrete.
4. There is a significant relationship among the three factors of the study. A linear regression model is appropriate to describe the relationship. In this model, factor length is not significant.
5. It can be fairly certain that a fiber length of 6 cm and fiber percentage of 0.25% of the weight of plain concrete will produce a fiber reinforced

concrete with the most desirable result. The best mean tensile strength for this combination is 1.85 MPa.

6. Coir fibers can be used as reinforcement to non-structural concrete components subject to tensile load.
7. The presence of coir fibers in concrete delays the setting time of concrete
8. The presence of coir fibers in concrete prevents or delays cracking and transforms the brittle failure of plain concrete into gradual and ductile failure. This slight ductility behavior can be very advantageous in solving many civil engineering problems in concrete construction where crack formation is to be minimized or eliminated.

Recommendations

The presence of coir fibers in concrete negatively influenced its compressive and tensile strength. However, the presence of coir fibers prevents or delays the growth of cracks. For more satisfying results, the following recommendations are made:

1. Use a fiber length of 6 cm and a fiber percentage of 0.25% of the weight of plain concrete to produce concrete with optimum performance in tension.
2. Increase the curing time of test cylinders in the curing tank and determine the strength of cured cylinders and the moisture condition of the fibers. Treatment of coir fibers using cement solution consisting of 100 g of cement per 200 ml of potable water is recommended.
3. Treatment of coir fibers using cement solution consisting of 100 g of cement per 200 ml of potable water is recommended.
4. Coir fibers used in this study are classified as bristle fibers. It will be interesting if a similar study is conducted using coir fibers classified as mattress fibers.
5. Researchers should ensure that cement to be used in the experiment has the ability to develop the designed compressive strength and to ensure that the strength of concrete is not influenced by poor cement product.
6. In constructing low-cost housing, concrete floor slabs placed on grade are usually not reinforced with steel reinforcement. It is observed that

such slabs usually crack. A study to determine if coir fibers will be effective as reinforcement is necessary.

7. Coir fibers present a promise in cost reduction Further studies are required to establish the possibilities of its use in actual practice.
8. Research programs aimed at large-scale production of composites reinforced with coir fibers and other naturally occurring vegetable fibers are encouraged.

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