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MECHANICAL PROPERTIES OF COCONUT FIBER-REINFORCED CONCRETE

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The use of natural fibers in concrete has significantly increased in recent years as a result of the push for sustainable construction. Coconut fibers, also known as coir fibers, have been used as natural fibers in concrete, particularly in some parts of Asia. This paper presents an experimental study that investigates the use of coconut fibers in concrete. Two baseline concrete mix designs were selected based on design standards with a water-cement ratio of 0.4 and 0.5 respectively. For each baseline mix design, four 20 cm x 20 cm x 1 cm concrete plates were constructed by varying the percentage of coconut fibers by weight of cement. The fiber contents studied are 0%, 0.1%, 0.175%, and 0.25%. The concrete plates were then tested to determine the mechanical properties of the coconut fiber-reinforced concrete and comparisons were made with the mix designs with 0% coconut fiber content. The results show that adding coconut fibers increases the flexural strength of concrete plates. This is particularly beneficial for low scale construction applications such as those in concrete tile production. For both mix designs, adding 0.25% of coconut fibers increased the flexural strength of the concrete plates by 90% when compared to concrete with no coconut fibers.

Keywords: Coir fibers, Natural fibers, Concrete plates, Sustainable construction.

1 INTRODUCTION

The use of natural fibers has shown promise in improving the strength and durability of concrete as a construction material (Hardjasaputra *et al.* 2009, 2014). Natural fibers are particularly appealing from sustainability and cost-reduction viewpoints (Hasan *et al.* 2012). Some of the natural fibers investigated by researchers from overall the world include coconut, sisal, jute, bamboo, cellulose and eucalyptus. In general, the use of fibers has advantages in that they increase the mechanical properties of the cement matrix in concrete.

The focus of this paper is on coconut fibers also known as coir fibers. The production of coconut fibers starts from dehusking after the mature coconut crop is harvested. The fibers are then extracted from the husk surrounding the coconut. After dehusking, coconut fibers and coconut peat are produced (Ali and Urgessa 2012). Maintaining quality of coconut fiber is very important. These can be locally exploited on relative small-scale, and have the potential to produce a more constant quality of fibers. According to the Central Coir Institute, using a bio-technological approach such as adding specific microbial enzymes could reduce the retting time significantly to three to five days. In addition, it also maintains the quality of production of fibers. Another development has been done to enhance the properties of the fibers regarding to surface properties such as smoothness and porosity. By using the right microbial enzymes, the surface can be activated to react more easily with the dyes. The fibers are made of individual fiber cells of about 1 mm length and 5-8 µm in diameter. However, fiber extraction processes create varying sizes of fibers. Coconut fiber consists of fibers ranging in length from 10-30 cm (Kavitha 2015). In addition, long fibers that are at least 20 cm are called bristle fiber, while shorter fibers that are finer called mattress fiber.

Ramakrishna and Sandararajan (2005) performed experimental investigations for determining the resistance to impact loading on four cement-sand mortar slabs reinforced with natural fiber including coir. They showed that 2% coir fiber reinforced concrete with a fiber length of 40 mm showed excellent performance. Ali and Urgessa (2012) reviewed tabulated mechanical properties of different types of coir fiber concrete from thirteen researchers. The compiled tensile strengths varied significantly. The fibers were collected from different regions of the world and had different properties, such as density and diameter of coir. Such a variation makes it difficult to standardize coconut fibers as construction material. He suggested that guidelines should be developed for the acceptance of particular natural fiber for a particular purpose.

Agrawal *et al.* (2014) described the need for research on finding alternate materials that could improve the strength of concrete with less cost, such as the use of coconut fibers in reducing the cost of concrete as a conventional construction material and their role in decreasing the amount of cement used in construction. It was highlighted that more than 12 million coconut trees worldwide eventually produce a lot of waste, which can be used in concrete to improve the tensile strength of concrete as well as reduce the cost of concrete production. It was pointed that while coconut fibers are beneficial, they can only be used to reinforce non-structural components at the moment.

Nadgouda (2014) investigated natural fibers that have certain physical and mechanical characteristics to improve the weakness in concrete strength. Coconut fibers are waste materials in most countries and they are available in large quantity with low price. Experiments were conducted with 0%, 3%, 5%, and 7% coconut fiber added by weight of cement in the concrete mix. By adding 3% fibers in the concrete mix, the flexural strength of concrete increased and made the concrete to work more efficiently. The performance of the concrete mix with 5% fiber content turned out to be slightly less than regular concrete mix. This unexpected behavior was also observed in concrete mix with 7% fibers in which the performance of the concrete was significantly less than regular concrete. Possible causes included improper mixing of concrete due to high fiber content and water content.

Dhandhinia and Sawant (2014) conducted research on the use of coir fibers using nine experiments with 6-inch concrete cubes. Three cubes of regular concrete were cast and then compared with three concrete cubes with 0.25% coconut fiber and other three concrete cubes with 1% coconut fiber. It was observed that the concrete mix with 0.25% fibers was the best mix based on crushing load test when compared to the 1% coconut fiber mix and regular concrete mix. In addition, it was reported that coir fibers may reduce the temperature up to 30% and reduce the overall weight of concrete. Furthermore, the addition of coconut fibers was shown to reduce the production cost of concrete.

2 EXPERIMENTAL WORK

This paper presents an experimental study that investigates the use of coconut fibers. Two baseline concrete mix designs, Mix Design #1 and #2, were selected based on design standards with a water-cement ratio of 0.4 and 0.5 respectively. For each baseline mix design, four 20 cm x 20 cm x 1 cm concrete plates were constructed by varying the percentage of coconut fibers by weight of cement. The fiber contents are 0%, 0.1%, 0.175%, and 0.25%.

2.1 Mix Designs

Table 1 shows the constituents of the concrete used here. Superplasticizers were used to reduce the water cement ratio of the mix without compromising workability. Reducing the water cement ratio resulted in a higher paste quality, which in turn improved compressive and flexural strength of concrete (Ali and Urgessa 2012). In addition, it reduced shrinkage cracking tendencies, decreased volume change by temperature, and improved the bond of concrete and reinforcement (Kosmatka and Panarese 1988). Silica fume, a byproduct of producing silicon metal or ferrosilicon alloys, was used because it is a proven additive in improving the durability and strength of concrete.

Table 1. Constituents of the concrete mix.

Item	Comments
Cement	Ordinary Portland cement type 1
Aggregate	Fine sand with particle size less than 2 mm (sieve #10)
Water	Regular tap water
Superplasticizer	Sika Viscocrete 10
Additive	Silica fume
Natural Fibers	Coconut fibers as shown in Figure 1 (with varying percentage)

Two mix designs, shown in Table 2, were considered based on the DOE method. In both mix designs, 4% silica fume and 0.45% of superplasticizers (by weight of the Portland cement) were used. The physical properties of the coconut fibers are shown in Table 3 based on Ali (2012).

Table 2. Mix proportions.

Material	Mix Design #1 (w/c = 0.4)	Mix Design #2 (w/c = 0.5)
Cement	512.5 kg/m^3	410 kg/m^3
Aggregate	1,549.7 kg/m^3	1,656.7 kg/m^3
Water	205 kg/m^3	205 kg/m^3
Superplasticizer	2.3 kg/m^3	16.4 kg/m^3
Silica fume	20.5 kg/m^3	1.845 kg/m^3

Figure 1. Coconut fiber used.

Table 3. Calculated maximum moment of concrete plates with varying coconut fiber content.

Property	Value	Property	Value
Length	15-20	Diameter (mm)	0.1-1
Density	670-1370	Modulus of rigidity (dyne/cm^2)	1.892
Tenacity	10	Swelling in water (%)	5%
Breaking elongation (%)	10%-40%	Moisture at 65% RH	10.5%

2.2 Small Plate Experiments

Eight 20 cm x 20 cm x 1 cm plates were constructed with varying percentages of coconut fibers using two baseline mix designs. Figure 2 shows a representative example of the plates before test. Table 4 shows the fibers included by weight for each mix design. The coconut fibers used in the mix passed the extraction process and treatment ensuring cleanliness and dryness. In addition, the fibers were cut into smaller piece (around 10 mm) before they were mixed with the concrete paste.

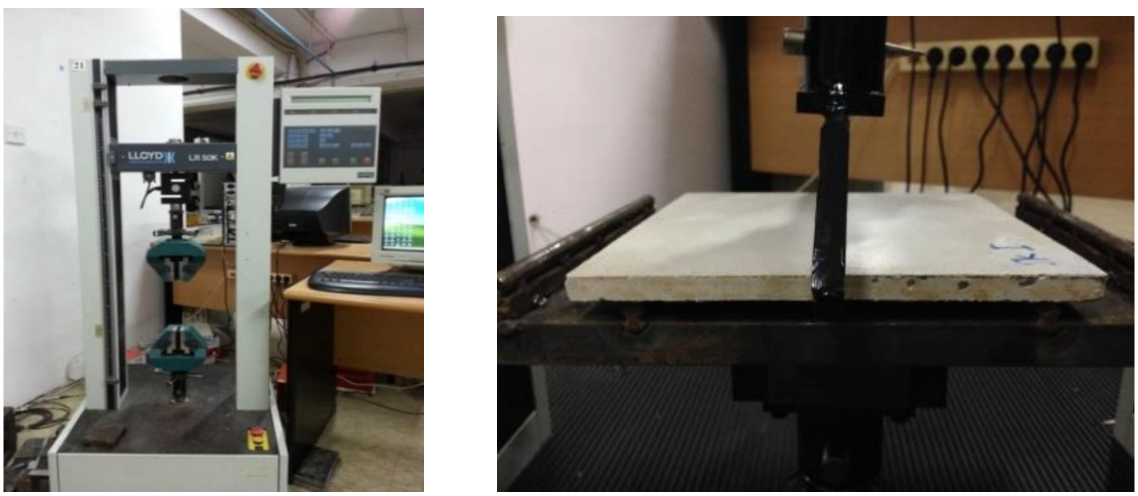

Figure 2. Experimental setup: (a) test machine (b) small concrete plate.

The concrete paste was placed into mold and vibration was applied to it to flatten the paste until it is completely distributed. After the molds were completely full, vibration was applied to the mold for the second time using a table vibrator in order to pull out the bubble in the paste for about 45 seconds. The separator bar was released before continuing to the curing process. The specimens were stripped from the molds six hours after casting and submerged in water (Ali and Urgessa 2014) for seven days.

Table 4. Percent fibers in the mix design.

Experiment	Coconut fibers (% weight of cement)
1	0%
2	0.1%
3	0.175%
4	0.25%

3 RESULTS

All plates were tested using LLYOD type LR press machine with a maximum capacity of 50 kN. This machine was equipped with transducer for measuring the load- deformation characteristics. Table 5 shows the load capacity results for both mix designs (Urgessa and Horton 2005). Table 6 shows the maximum moment capacity of the concrete plates with varying coconut fiber content based on results obtained from the three-point bending configuration.

Table 5. Maximum load capacity of concrete plates with varying coconut fiber content.

Experiment	Coconut fibers (% weight of cement)	P_{max} (N) for plates with mix design #1 (w/c = 0.4)	P_{max} (N) for plates with mix design #2 (w/c = 0.5)
1	0%	398	412
2	0.1%	488	436
3	0.175%	572	532
4	0.25%	762	772

Table 6. Calculated maximum moment of concrete plates with varying coconut fiber content.

Experiment	Coconut fibers (% weight of cement)	M_{max} (N·mm) for plates with mix design #1 (w/c = 0.4)	M_{max} (N·mm) for plates with mix design #2 (w/c = 0.5)
1	0%	1592	1648
2	0.1%	1952	1744
3	0.175%	2288	2128
4	0.25%	3048	3088

Figure 3 shows the modulus of rupture results. We observed that adding coconut fiber clearly increases the flexural strength of the concrete. In fact, adding 0.25% (by the weight of cement) of coconut fiber for a water-cement ratio of 0.4 increases the flexural strength by more than 90% when compared to regular concrete mix with no coconut fibers.

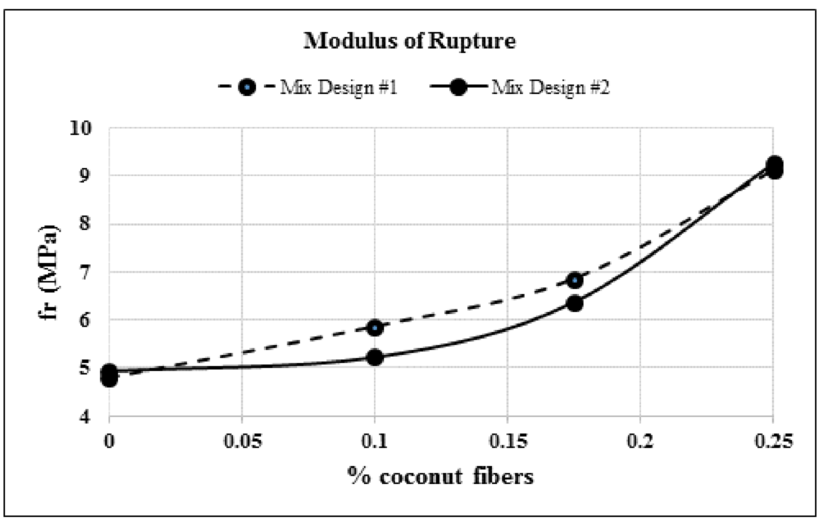

Figure 3. Modulus of rupture of concrete plates with coir fiber reinforcement.

4 CONCLUSION

Four 20 cm x 20 cm x 1 cm concrete plates were constructed with varying percentages of coconut fibers by weight of cement and varying water-to-cement ratio. The concrete plates were then tested to determine the mechanical properties of the coconut fiber-reinforced concrete and comparisons were made with the mix designs with 0% coconut fiber content. The results show that adding coconut fibers increases the flexural strength of concrete plates as high as 90%. This improved property is particularly beneficial for low scale construction applications such as those used in concrete tile production.

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