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Characterization of Impact, Bending and Water Absorption Properties of Coir Fiber-Reinforced Concrete (CFRC) Fiberboard

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Highlights

- CFRC have outstanding physical and mechanical properties.
- Better alternative material in construction and engineering.

Abstract

Coir Fiber is a valuable material in the production of composite material like concrete fiberboards to serve as alternative materials in construction and other industrial applications. The engineering application of natural fibers is presently considered an environmentally correct alternative to replace more expensive, non-recyclable and energy-intensive synthetic fibers. Economic and environmental reasons sustain a promising future trend for natural fiber composites. With the current environment situation of our planet, natural fibers are regarded as “green” environmentally friendly materials. They are abundant, renewable, biodegradable, and recyclable, and above all, neutral with respect to carbon dioxide emission.

This research paper reports the effect of natural fibers on the density, water absorption, thickness swelling, modulus of rupture, modulus of elasticity, and impact strength of composite cement reinforced with coconut ‘coir’ fibers. The CFRC fiberboard was fabricated based on the mix designs with 0%, 30%, 40% and 50% fiber volume in a 2:1 sand-cement ratio and 0.57 water-cement ratio. The composites were cured for 28 days before testing its physical and mechanical properties. It was observed that the CFRC with 30% fiber volume has the best performance in terms of water absorption, flexural strength, and stiffness compared to the other composites with fiber reinforcements. The CFRC with 50% fiber volume has the best performance in terms of its density with a mean value of 1255.9 kg/m^3, thickness swelling of 0.37% and impact strength equal to 65.25 J/m. And finally, the CFRC with 40% fiber volume was found to be the most elastic compared to the other mix designs having a modulus of elasticity equal to 1.36 GPa.

Key Words: coconut fiber, green engineering , composites, cement, fiberboards

1. Introduction

Coir fibers is one of the by-products of coconut that is a great potential reinforcement material of cement composites. Natural fibers like coir, abaca, jute, sisal, wood, palm, etc. has drawn much interest to be a better alternative to synthetic fibers as a reinforcement material to composites because of its numerous advantages, the most important being renewable and environmentally friendly material.

Coir fibers are found between the hard, internal shell and the outer coat of a coconut. It is thick, strong and has high abrasion resistance. It is also relatively waterproof, and is one of the few natural fibers resistant to damage by saltwater (Ray, 2005). Moreover, coir fiber is corrosion resistant, lightweight, and has high strength to weight ratio. Due to these characteristics, coir fibers is a favorable reinforcement to cement composites, especially in the development of fiberboards for indoor and outdoor applications. The use of coconut fibers as a substitute reinforcement will not only improve long-term durability in concrete but will also bring down the cost of construction (Noor, Md, et.al, 2012).

Studies have been conducted using coconut fibers as a reinforcement to concrete for low-cost roofing material (Cook, 1978), low-cost housing (Paramasivam, 1984) as well as the manufacture of tiles, bricks and hollow blocks. Investigation on the mechanical and physical properties of coir-fiber reinforced cement composites have been conducted using different parameters. The mechanical properties of cement paste composites for different lengths and volume fractions of coconut fibers were studied (Aziz, 1981; Das Gupta, 1979). It concluded that the tensile strength and modulus of rupture of cement paste increased when fibers up to 38mm fiber length and 4% volume fraction were used. The physical properties such as density, water absorption, and thickness swelling were also studied using cement-fiber-water ratio of 2:1:2 (Asasatjant, 2007). A study on the mechanical properties of fiber-reinforced cement sand mortar with cement-sand ratios 1:2.75 and 1: 4 with 0.54 water-cement ratio mixed with 0.08, 0.16, 0.32% by total weight of cement, sand and water. The researcher observed a decrease in strength of the mortar as the fiber content is increased (Slate, 1976). Also, a researcher investigated the flexural strength, fracture toughness and fracture energy of epoxy polymer concrete reinforced with natural fibers such as coconut, sugarcane, bagasse, and banana fibers. The tests showed that using coconut fibers yielded the highest fracture toughness and energy compared to the other reinforcements (Reis, 2006).

Most of the studies conducted about the static properties of coir fiber cement composites were done mostly using a fiber length of 4 cm (Baruah, 2007). With regards to dynamic properties of CFRC, a few studies have been reported. Dynamic tests had been performed only for concrete reinforced by other fibers, e.g. polyolefin fibers or rubber scrap. In order to apply CFRC in cheap housing in tropical earthquake regions, the knowledge of static and dynamic properties of CFRC is necessary. From the above literature, most studies were using coir-fiber proportions less than 15% fiber volume. Hence, a study was conducted to examine further the physical and mechanical properties of Coir Fiber-Reinforced Concrete Fiberboard using 30%, 40%, and 50% fiber volume. The study used coir, sand, cement and water to fabricate the fiberboards before evaluating its density, water absorption, thickness swelling, modulus of rupture, and impact strength using ASTM Methods.

2. Materials and Methods

2.1 Materials

Ordinary Portland cement was used in this research. It conformed to PNS 07:2005 and ASTM C 150-02a (PNS, 2005; ASTM. 2003). Sand was sourced from a local supplier and was passed through a No. 50 sieve. It conformed to PNS ASTM C 33:2013 – Standard specification for concrete aggregates (PNS ASTM, 2013). The coconut husks was sourced from local coconut traders. The coir fibers was extracted, washed and air-dried before it is cut. Water from the Mechanical Engineering Laboratory at Silliman University, Philippines was used for this research.

2.2 Methods

Fiberboards measuring 12 x 12 x 0.5 in (305 mm x 305 mm x 12 mm) with different sand-cement-fiber proportions was fabricated for characterization.

2.2.1 Preparation of Coir Fibers

Coir Fibers was extracted from husks of seasoned or matured coconut fruit (brown) from a local variety. The extraction was done by feeding the husks into the decorticating machine. After the fibers are separated from the pith, the extracted fibers was soaked and washed in water to remove the remnants of pith and impurities still adhering to the fibers. The fibers was air dried at ambient temperature.

2.2.2 Mix Design of Coir Fiber Reinforced Cement Fiberboard

This research focused on four CFRC mix designs with different ratios of coir fibers to sand-cement. All the four mix designs have 2:1 sand-cement ratio and 57% water to cement ratio. Table 1 shows the proportions of cement composites for the four mix designs (0%, 30%, 40%, 50% volume of coir fibers to sand-cement).

Table 1. Proportion of Cement Composite.

Mix Design	**Samples**	**Sand : Cement**	**% volume of Coir Fibers (to sand-cement)**	**Water/ cement**
1	*1-5*	*2:1*	*0*	*0.57*
2	*6-10*	*2:1*	*30*	*0.57*
3	*11-15*	*2:1*	*40*	*0.57*
4	*16-20*	*2:1*	*50*	*0.57*

2.2.3 Fabrication of Coir-Fiber Reinforced Cement Fiberboard

The constituents (coir fibers, sand, cement and water) will pass through several steps in the fabrication process. The fabrication process is illustrated in Figure 1.

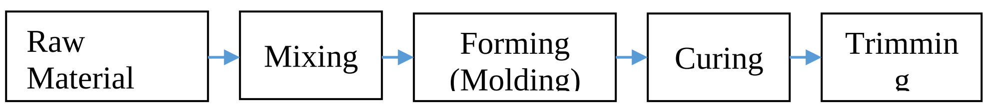

Figure 1. Fiberboard Fabrication Process.

The raw materials were prepared according to the given proportions. To ensure consistency in the fiber distribution, the mixing was carried out by adding water to the cement until a uniform slurry was formed. Then fibers and sand was slowly added and mixed to form a homogeneous mixture before the randomly distributed fiber mixture was molded to the desired sizes and cured at atmospheric conditions for 28 days. The following tests and specimen specifications are based on American Society for Testing and Materials (ASTM D 1037-99) Methods. All tests were conducted at the Mechanical Engineering Laboratory at Silliman University, Dumaguete City, Philippines. The tests are as follows:

2.2.4 Density Test, Water Absorption Test, and Thickness Swelling Test

Twenty samples for the four mix designs, measuring 12 x 12 x 0.5 in. was used for testing. Each test sample was weighed. The width, length and thickness of the test specimen was also measured. The volume and density of the specimen was calculated from these measurements. The twenty samples were then submerged in water in a single continuous 24-h submersion period. The thickness and weight of each sample was taken before and after submersion. The amount of water absorbed was calculated from the increase in weight of the specimen during the submersion. The water absorption is expressed as the percentage of the weight of the water absorbed by the dry weight of the composite before submersion while the thickness swelling is expressed as the percentage of the thickness after immersion by the original thickness (ASTM D 1037, 1999).

2.2.6 Static Bending Test: Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

Five samples measuring 3 by 12 by 0.5 in. (76 by 305 by 12 mm) for each mix design was used for testing. Figure 2 shows the configuration of the static bending test using a Universal Testing Machine. The test specimen was loaded at the center of the span with the load applied at a uniform rate of motion. The speed of testing is at a uniform crosshead speed of 0.24 in/min (6 mm/min) for fiberboard thickness of 0.5 inches (12 mm). The Modulus of Rupture (MOR) and the Modulus of Elasticity for each specimen were then calculated.

2.2.7 Impact Strength Test

The Impact Test was carried out in accordance with ASTM D 5942 (ASTM 6110-04, ASTM E23).
Five samples of each mix design was used for testing (Abdullah, 2011; Dhandhania, 2014) in the Charpy Impact Tester as shown in Figure 3.

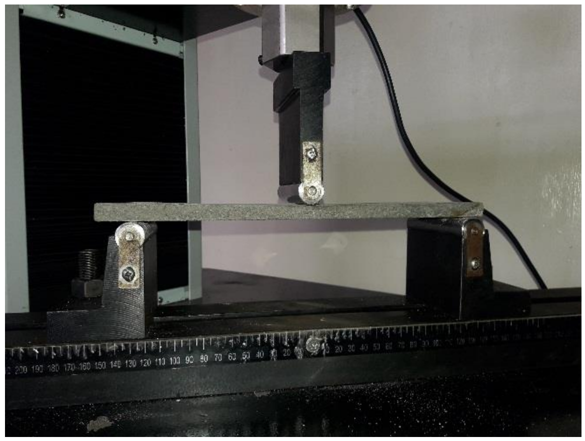

Figure 2 Center Loading Static Bending Test Assembly (ASTM)

Figure 3 Charpy Impact Test Assembly

3. Results and discussion

The physical and mechanical properties of coir-fiber reinforced concrete composite with different fiber content is indicated in Table 2. The addition of fibers into the concrete composites significantly reduces its density by 25-32% as indicated in the decrease in density of mix designs 2, 3 and 4, from a reference value of 1873.6 kg/m^3. This is equivalent to 475-617 kg weight reduction per cubic meter of composite material. The composite with 50% fiber volume is the lightest with a density equal to 1255.9 kg/m^3. From Figure 4, the trend shows a decreasing pattern of density values as the fiber volume of the composite is increased. The decrease in density values is attributed to the lower inherent density of coir fiber constituent than that of the sand-cement mixture. The density results obtained in this work is consistent with the results of a previous research conducted where density values of the composite decreases with increasing coir-fiber weight percentages (Abdullah, 2011).

It is also indicated in Table 2 that water absorption increased by 9-12.6 percentage points from the reference value of 7.27% for mix designs 2, 3 and 4. The composite with 30% fiber volume has the lowest water absorption of 16.27% compared to the other fiber reinforced mix designs. It is indicated in Figure 5

Table 2. Physical and Mechanical Properties of Coir-Fiber Reinforced

	Mix Design			
	1	2	3	4
Fiber Volume, %	0	30	40	50
Density, kg/m^3	1873.6	1398.2	1281.7	1255.9
Water Absorption, %	7.27	16.27	17.68	19.93
Thickness Swelling, %	1.94	0.7	0.45	0.37
Modulus of Rupture (MOR), MPa	3.28	2.2	1.16	1.09
Modulus of Elasticity (MOE), GPa	5.08	2.76	1.36	1.86
Impact Strength, J/m	18.46	57.07	58.93	65.25

that water absorption is increased with increasing coir fiber content of the composite. The reason may be due to the coir fibers containing more polar hydroxide groups, which result in a high moisture absorption level (Das, G., 2012). This result is similarto the previous work conducted where the water absorption

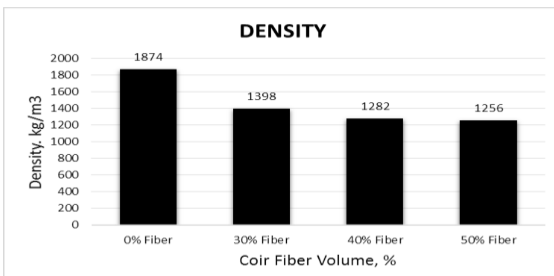

Figure 4. Effects of Fiber Volume on the Density

values increases with increasing coir-fiber and rubber content of the composite (Mahzan, 2010).
It is also observed in this study that the density and water absorption of the composite are inversely

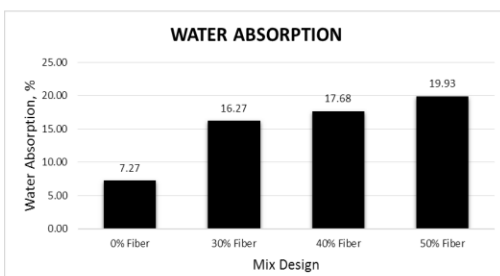

Figure 5. Effects of Fiber Vol. on the WA

proportional to the increasing coir-fiber content of the composite. Higher coir-fiber content in the composites resulted in low density values, but high in water absorption. On the other hand, the thickness swelling of the composites with fiber content decreased by 63-80% from the reference value. This is an indication of good dimensional stability when this material is exposed to extreme indoor and outdoor conditions. The composite with 50% fiber content has the best performance in terms of thickness swelling with a value of 0.37%. It can also be observed from Figure 6 that the thickness swelling decreases with increasing fiber content. This is consistent with the study conducted by Morales where the thickness

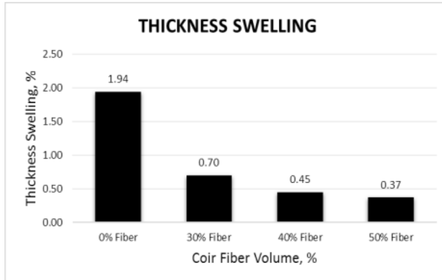

Figure 6. Effects of Fiber Volume on the TS

swelling values has a decreasing trend for fiberboards with fiber content of more than 25% (Morales, 2017).

The addition of fibers into the composites reduces its flexural strength by 32-66% from the reference value of 3.28 MPa as indicated in the MOR values in Table 2. The composite with 30% fiber volume, with MOR equal to 2.2 MPa, outperforms the other mix designs with fiber reinforcements. The decrease

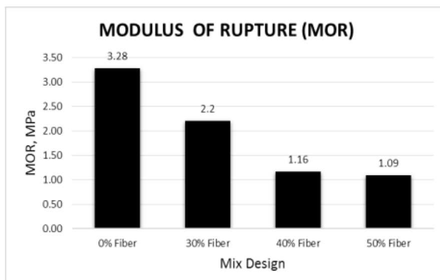

Figure 7 Effects of Fiber Volume on the MOR

could be attributed to the corresponding decrease in density value with increasing fiber content. A denser composite generally provides higher flexural strength due to fewer number of voids and porosity. Workability is also a factor at higher volume of fiber in the composite. It can also be observed that MOR values decreases with increasing fiber content as shown in Figure 7. This result is similar to the findings of the study conducted where the composites attained a decreasing MOR values with increasing fiber content above 9% fiber weight (Abdullah, 2011). Also, its modulus of elasticity decreases with increasing fiber content up to 40% fiber volume from a reference value of 5.08 GPa. This indicates that the composites with fiber content are more elastic than the reference samples. The composite with 30% fiber volume is the stiffest while the composite with 40% fiber volume is the most flexible among the mix designs with fiber reinforcements.

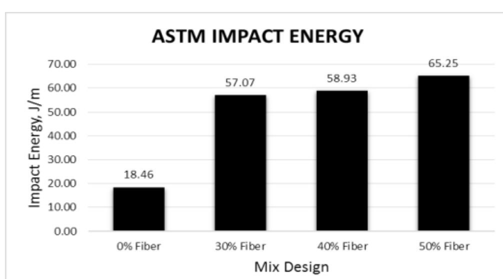

Figure 9 Effects of Fiber Volume on the Impact

The impact strength of the composites with fiber reinforcements significantly increased by 310-353% compared to the reference sample without fibers. From Table 2, there is an increase in impact strength from 18.46 J/m for the reference samples to 57.07 J/m, 58.93 J/m, and 65.25 J/m for composites with 30%, 40%, and 50% fiber volume, respectively. This means that reinforcing the concrete composite with coir-fibers will significantly improve its impact strength. An indication of improved toughness and durability. The composite with 50% fiber volume outperforms the other mix designs in terms of impact strength with a value equal to 65.25 J/m. However, all mix designs with fiber reinforcements have outstanding performance in impact strength. This may be due to the higher ductility of coir fibers as well as the interlocking of fibers in the cement matrix (Ramakhrisna, et.al, 2005). It is also shown in Figure 9 that the impact strength increases with increasing fiber content in the composites. From the graph, it can be clearly observed that the composites with fiber content all have significantly large impact strength value which means that CFRC significantly outperforms the concrete composite in terms of impact toughness.

4. Conclusions

It was found out that the introduction of fibers into the composite plays an important role in the performance of the composites. Based on the testing, the following conclusions were drawn: (a) the CFRC with 30% fiber volume has the best performance in terms of water absorption with a mean value of 16.27%, flexural strength of 2.2 Mpa, and stiffness of 2.76 GPa, (b) the CFRC with 50% fiber volume has the best performance in terms of its density with a mean value of 1255.9 kg/m^3, thickness swelling of 0.37% and impact strength of 65.25 J/m and (c) the CFRC with 40% fiber volume was found to be the most elastic compared to the other mix designs with MOE equal to 1.36 Gpa. All mix designs with fiber reinforcements generally have outstanding performance in terms of density, water absorption and thickness swelling, flexural strength, stiffness and elasticity, and impact toughness. These composites will be a better alternative material in construction and engineering due to these characteristics. Also, being an environmentally friendly material, it will become one of the most favored material to use to reduce pollution rate while achieving physical and mechanical properties desired for many applications such as roofing, wall sidings, wall paneling system, underlayment for floors and countertops to name a few.

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