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A study into flexural, compressive and tensile strength of coir-concrete as sustainable building material

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Abstract. Coir has been known as a potential natural fiber for many sustainable construction material developments due to its wide availability and sustainable resource of coconut tree. This research study aims to investigate the flexural, compressive and tensile properties of concrete incorporating coir fiber and to find the fiber content which gives optimum results. In this study, coir concrete specimens were cast and tested with variations of fiber content of 0%, 0.25%, 0.5%, 0.75%, and 1% by weight of aggregates. Flexural test was conducted based on SNI 4431:2011, compressive test was conducted based on SNI 1974:2011 and tensile test was conducted based on SNI 2491:2014. Slump tests and unit weight showed reduced values when fiber content was increased. Flexural, compressive and tensile strengths of coir-concrete at a 28-day curing were optimum for the variation with 0.25% fiber content. Compressive strength of control concrete at 28 days was approximately 23 MPa while BS-0.25 was 27.5 MPa. Flexural strength of control concrete was 5 MPa while BS-0.25 was 6 MPa. Tensile strength of control concrete was 3 MPa while BS-0.25 was 2.5 MPa. Results from the study showed that the presence of 0.25% fiber (by total weight of aggregate) in the concrete gives approximately 19% improvement in 28 days compressive strength and flexural strength.

1 Introduction

Coir fibers or coconut fibers are extracted from the husk of coconut fruit. Coconut is a versatile plant, which grows mostly in tropical areas. According to 2015 data from Indonesian Directorate General of Estate Crops [1], the total area of coconut plantation in Indonesia is 3.585.599 Ha, with smallholder plantations having the biggest percentage (98.98%) while the rest is shared between government and private plantations. Major products of coconut from Indonesia are copra, coconut oil, desiccated coconut, fresh coconut, coconut shell charcoal, raw coconut fibers and processed coconut fibers [1]. Production of raw coconut fibers or raw coir was 15,814,069 kg and processed coir was 19.857.460 kg [1]. Furthermore, the 2010-2014 statistics data from the Asian and Pacific Coconut Community (APCC) showed that the area of coconut plantation in Indonesia was 3,610,000 Ha, which is the largest in the APCC list, followed closely by The Philippines and India [2]. Therefore, effective utilisation of products from coconut trees will promote sustainable development.

The production of coir justifies the sustainable choice of material for development. As a natural material, locally resourced, continuous supply and lower price, the benefits of developing coir containing materials offer sustainable options in many areas including construction industry. Usage of coir in concrete is meant firstly is to substitute the concrete material with a more sustainable material, secondly to achieve competitive mechanical properties and thirdly to minimise production cost by reducing the material and the usage of local product.

When coir is incorporated into concrete, it offers the potentiality of economical and lightweight products that can be used for examples as concrete blocks, shear walls, structural or architectural walls.

For coir-concrete to be used as sustainable building material, research into the mechanical performance is important to ensure that it meets the design criteria, economical and environmentally viable. Therefore, in this study, the flexural, compressive and tensile strength of coir-concrete are investigated.

Different studies have reported the benefits of increased strength and durability, and the use of coir as potential reinforcement and additive materials in concrete and cementitious materials. Yan et al. (2016), reported the compressive strength and flexural strength of concrete containing untreated and 5% alkali-treated coir [3]. From their test results they found that there were increases in compressive strength and flexural

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strength of concrete with 1% fiber fraction (from mass of cement) compared to the control concrete specimen. Similarly, Andiç-Çakir et al (2014) reported increases in compressive strength and flexural strength of mortar specimens containing untreated and 5% alkali-treated coir fiber [4]. They observed 0.4%, 0.6% and 0.75% fiber fraction (from wt. of total mortar mixture). Sathiparan et al. 2017, studied the mechanical and durability properties of mortar containing 24 mm coir fibers [5]. Their results show that an increase in fiber fraction in mortar specimens has resulted in lower density, increased water absorption rate, porosity and sorptivity.

Based on results of recent published literature, it can be observed the addition of coir in concrete mix increased the mechanical strength when the suitable or optimum amount of coir is used. This study aims to investigate the flexural, compressive and tensile strength of coir-concrete and to find the fiber content which gives optimum results.

2 Materials and methods

2.1 Coir fiber

Coir (coconut fibers) used in this study was obtained from CV Puri Bitung Gemilang, North Sulawesi, Indonesia. Figure 1 shows a bale of coir, Figure 2 shows the prepared and cut coir fiber, while Figure 3 shows the morphology of coir under optical microscope. All experimental processes and testings were performed at the concrete laboratory, Manado State Polytechnic. Coir fibers were cut into 30 mm length, conditioned and prepared for different coir-concrete variations.

Variations of coir fibers percentage in coir-concrete mixture are 0%, 0.25%, 0.5%, 0.75%, and 1% of the total weight of aggregates. The variations are labelled as BS-0, BS-0.25, BS-0.5, BS-0.75 and BS-1, respectively.

2.2 Fiber treatment

To evaluate the effect of alkali treatment to coir fibers in concrete, separate groups of fibers were treated with 5% NaOH. Firstly, the 30 mm length fibers were washed to remove impurities. Next, they were dried for 24 hours at room temperature 24 ^{0}C. In a container, 5% NaOH with water was prepared. The fibers were immersed in the solution for 180 minutes. After that, the fibers were rinsed several times and then dried at 30 ^{0}C for 24 hours. The treated dry fibers were put in closed plastic containers.

Fig. 1. Bale of coir fiber.

Fig. 2. Prepared coir fibers.

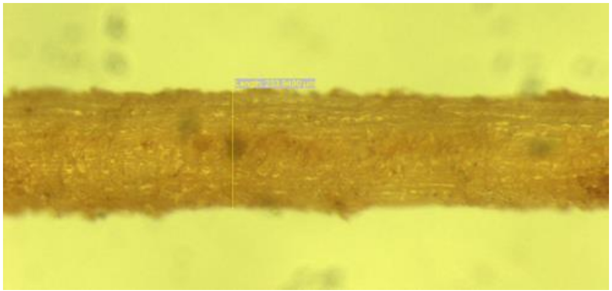

Fig. 3. Coir fiber under optical microscope.

2.3 Concrete mix

Coir-concrete mixes were prepared using Portland Composite Cement (PCC), gravel and sand. The aggregates, gravel and sand, were locally available. Density of gravel was 1339 kg/m^3 and density of sand was 1149 kg/m^3. Design of concrete mix was based on the Indonesian Standard for Concrete Mix Design, SNI 03-2834-2000 [6]. Variation of coir-concrete is presented in Table 1.

Table 1. Composition of coir-concrete mixtures variation (kg/m^3)

Mix	Cement	Fine Aggregate	Coarse Aggregate	Water	Coir Fiber
BS-0	420.1	736.8	789.2	205	0
BS-0.25	420.1	736.8	789.2	205	3.8
BS-0.5	420.1	736.8	789.2	205	7.6
BS-0.75	420.1	736.8	789.2	205	11.5
BS-1	420.1	736.8	789.2	205	15.3

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To ensure a good and homogenous distribution of coir fibers when mixing, the fibers were added by hand. A concrete mixer with a capacity of one hundred litres was used. Every concrete batch was mixed for approximately 10 minutes in the mixer. Before casting the concrete into steel moulds, the consistency and workability of each batch were evaluated by slump tests using Abrams cone.

Figure 4 shows the cast concrete specimens for flexural test and Figure 5 shows those for compressive and split tensile tests. All samples were taken out of the moulds 24 hours after casting. Afterwards, they were weighed and then immersed in water until one day before the scheduled testing dates.

2.4 Flexural strength

Flexural test was set-up for a three-point bending test with distance between supports of 420 mm. Specimens for flexural test are 100x100x500 mm rectangular prisms. Three specimens are tested for each concrete mix variation.

Fig. 4. Cast concrete specimens for flexural test.

Fig. 5. Cast concrete specimens for compressive and split tensile tests.

2.5 Compressive strength

Compressive tests to the samples were performed on 100/200 mm cylinder specimens. Compressive strength data were subsequently recorded. Three specimens are tested for each concrete mix variation.

2.6 Tensile strength

Tensile strength of concrete sample is measured by split tensile test which is an indirect tensile testing. Tensile specimens are 100/200 mm cylinders. Three specimens are tested for each concrete mix variation.

3 Results and discussions

3.1 Workability and unit weight of coir-concrete

Figure 6 shows the slump tests result of coir-concrete. The concrete mix without coir fiber shows a slump value of 80 mm, which indicates the required workability index according to SNI 03-2834-2000. By observing the figure, it can be clearly noticed that the addition of untreated coir fiber has significantly reduced the workability of the concrete mix. The addition of 0.25% coir fiber (by total weight of aggregate) resulted in lowered slump value to 50 mm. The slumps of the subsequent variations show gradually decreased values with increased amount of coir fiber. This tendency can be attributed to the surface morphology and physical properties of coir fibers. As reported by Yan et al. [3], coir fibers have hydrophilic surface morphology and therefore resist water.

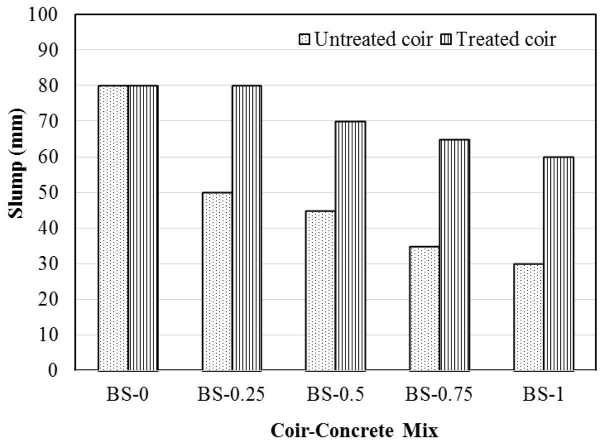

Fig. 6. Slump tests result of coir-concrete.

Interesting tendency can be seen for concrete mix with alkali-treated coir fiber. As shown in the figure, the slump values only started to decrease at the addition of 0.5% coir. Furthermore, the values are not considerably decreased as in the case of concrete with untreated fiber. For BS-0.25, the slump is 80 mm and then reduced to 70 mm for BS-0.5. Overall, for concrete with both untreated and treated coir fibers, the slump is reduced in contrast to the increased amount of fiber. This infers that coir fiber reduced the workability of concrete mix and indicates that the treatment has increased the workability for the same amount of fiber. Similar findings are also reported in Ozerkan et al. [7] and Ali & Chouw [8]. Considerable lower slumps of concrete with coir were also reported by Yan et al. (2016) although according to their observation, the workability of the coir fiber reinforced concrete was reasonable [3].

The unit weights of coir-concrete at 28 days are presented in Figure 7. Overall, the unit weight of concrete with untreated coir is between 2080–2250 kg/m^3, while the unit weight of concrete with alkali-treated coir is between 2030–2230 kg/m^3. In contrast, the average unit weight of the control specimens is 2271 kg/m^3. This shows that for both variations (untreated and treated), the addition of coir fiber influenced the unit weight of concrete. By being a lightweight material itself, coir in concrete has reduced the unit weight. It is found in this study that the more the amount of coir in the concrete, the lesser the unit weight. It is also observed that the unit weights of concrete with treated coir are lesser than that of with untreated coir. Yan et al. (2016) reported a reduction of 1.7% of the density of concrete with untreated coir, and 1.3% of concrete with treated coir [3]. The reduction in density was inferred as because of 'possible enhancement of porosity' due to the incorporation of the fiber and also because coir is a type of fiber that has low density [3].

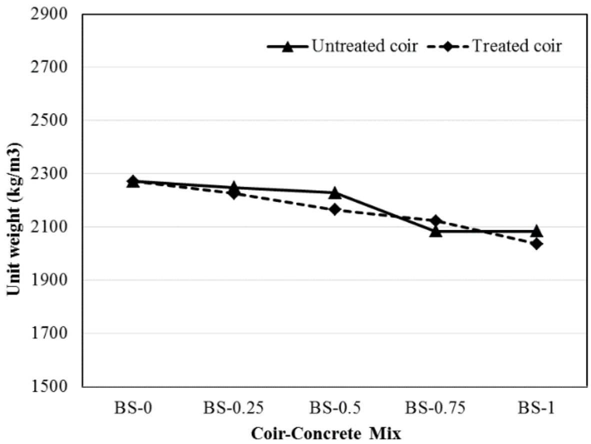

Fig. 7. Unit weight of coir-concrete.

3.2 Compressive strength

Results from compressive test of coir-concrete specimens can be observed from Figure 8. The figure presents the compressive strength of concrete specimens measured at 28 days. Overall, the trend of compressive strength values of coir-concrete for both untreated and treated coir variations in comparison to the compressive strength of plain concrete, is similar. When 0.25% (by total weight of aggregate) of untreated coir was incorporated into concrete mix, the compressive strength increased approximately 19%. However, when more untreated coir was added, the compressive strength dropped progressively. Coir percentage of 0.5% resulted in approximately 16.5% decreased strength, 0.75% resulted in approximately 23% decreased strength and 1.0% coir resulted in approximately 41% decreased strength.

Alkali treatment to coir resulted in lower compressive strength of the specimens. Slight increase of approximately 2.4% is shown by specimen with 0.25% treated coir. Similar to the trend of specimens with untreated coir, increasing the amount of fiber has resulted in lower compressive strength. An addition of 1.0% of treated coir resulted in reduced value to half the strength of plain concrete.

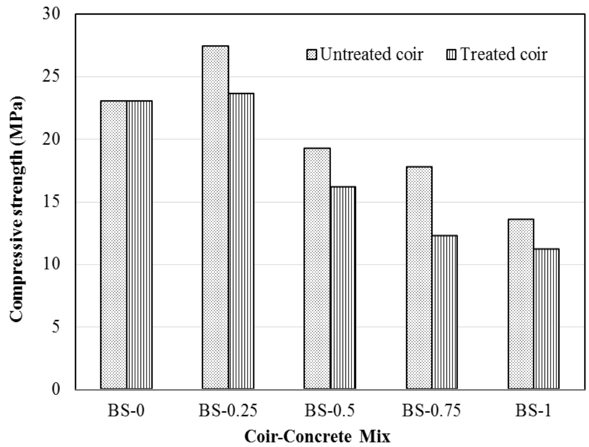

Fig. 8. Compressive strength of coir-concrete at 28 days.

The failure patterns of coir-concrete after compression are shown in Figure 9. Large damage area can be observed from the figure of BS-0, as expected from plain concrete. Although the compressive strength results show decreasing values after BS-0.25, the failure patterns show that the damage area is reducing linearly. As shown in the figure, the damage area of BS-1 is the least. This shows that the fibers assisted in reducing the damaged area by acting as cracks consolidating agents which slowed down the cracks propagations. Similar findings were reported by Yan et al. [3]. As can be observed from a close-up picture in Figure 9, the failure modes in coir-concrete are fiber pull-out and fiber breakage.

3.3 Flexural strength

Flexural strengths of coir-concrete at 28 days of curing are shown in Figure 10. Again, it can be clearly observed that the strength is optimum for specimens with 0.25% coir.

Fig. 9. Failure mode of coir-concrete after compression tests.

More than 0.25% fibers have resulted in declining flexural strengths. Significant difference can be observed for concrete specimens with untreated coir. Control specimen achieved 5.11 MPa, then peaked at 6.09 MPa for BS-0.25. The flexural strengths decreased to 5.62 MPa for BS-0.5 then drastically lower to 2.89 MPa for BS-0.75 and 2.55 MPa for BS-1. This shows that more fibers have created weakened parts in concrete. Flexural strengths of coir-concrete specimens with treated coir are generally lower in comparison to specimens with untreated coir, except for BS-0.75.

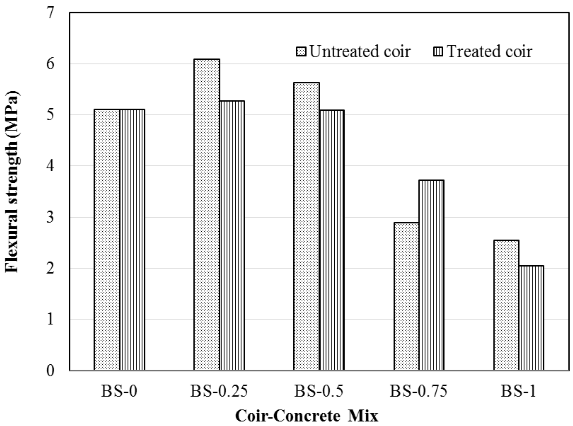

Fig. 10. Flexural strength of coir-concrete at 28 days.

From Figure 11, the failure modes of representative flexural specimens can be observed. It is obvious that the presence of coir fibers in concrete have assisted in reducing the cracks opening. This means that the fibers have provided tensile properties in certain extent. As can be observed from the figures, the normal concrete cracked and separated at approximately the centre where the load was applied. Pictures of BS-0.25, BS-0.5, BS-0.75 and BS-1 display visible cracks at the centre point, however the cracks have less than 3 mm opening and the tested specimens were holding together, i.e. did not separate. BS-1 has the lowest flexural strength but the cracks that happened can be observed as hair-line cracks. This can be attributed to the fact that coir fibers are resilient and provides excellent toughness. Similar findings are also reported by Yan et al. [3]. In their study, Yan et al. (2016) reported that the failure modes of their specimens are fiber breakage and pull-out, and fiber debonding between matrix and fiber.

3.4 Split tensile strength

Concrete has low tensile strength compared to its compressive strength. However, for design purposes, the tensile strength is also an important input. Split tensile test is the method used to obtain the tensile properties.

Figure 12 shows the results of split tensile strength of coir-concrete. The overall tensile strengths vary between 1.5 MPa to 3.1 MPa. The picture shows that more fibers have created weakened parts in concrete. Overall, for concrete with both untreated and treated coir fibers, the tensile strength is reduced to the increased amount of fiber. Tensile strengths of coir-concrete specimens with treated coir are generally lower in comparison to specimens with untreated coir, except for BS-0.25.

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Fig. 11. Failure mode of coir-concrete after flexural tests.

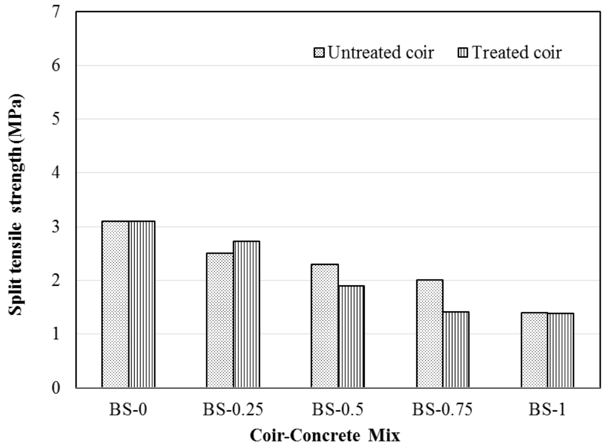

Fig. 12. Split tensile strength of coir-concrete.

4 Conclusions

As a natural resources material with large amount of annual production in Indonesia and many other countries, coir fiber offers potentiality for many applications including as reinforcement to concrete mixture. In this study, the compressive, flexural and split tensile strength of coir-concrete were obtained and evaluated. Variations of coir amount were 0%, 0.25%, 0.5%, 0.75% and 1% by weight of aggregates. Results from this study showed that the optimum amount of coir fiber in concrete is 0.25%, which gives approximately 19% improvement in 28-days compressive strength and flexural strength. It is found in this study that the more the amount of coir in the concrete, the lesser the tensile strength. It was also found that the presence of fiber in the concrete has resulted in lower workability.

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