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Composite Cement Reinforced Coconut Fiber: Physical and Mechanical Properties and Fracture Behavior

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Abstract: This research paper reports the effect of natural fiber content on the physical and mechanical properties as well as fracture behavior of composite cement reinforced with coconut fiber. The mix design was based on 1:1 for cement:sand ratio and 0.55 was fixed for amount of water per cement ratio. Coconut fiber was added as reinforcement and replacing the composition of sand. Composites were developed based on 3 wt. %, 6 wt. %, 9 wt. %, 12 wt. % and 15 wt. % of coconut fiber by mixing and curing process. Composites were cured in water for 7, 14, and 28 days. It was observed that the composite reinforced with 9 wt. % of coconut fiber demonstrated the highest strength of modulus of rupture and compressive strength. Results of density, water absorption and moisture content are also presented.

Key words: composites, coconut fiber, construction materials, fibers, portland cement.

INTRODUCTION

Malaysia has plenty of agricultural waste products such as coconut fiber, rice husk and oil palm frond fiber. Among the advantages of these fibers are: renewable, nonabrasive, cheaper, abundance and show less health and safety concern during handling and processing (Zulkifli, 2009). There is a research activity in the utilization of agricultural waste products as low cost construction materials especially in developing countries (Asasutjarit, 2009). Most recently, there have been considerable efforts to develop natural fiber-reinforced cementations composites for affordable infrastructure (Asasutjarit, 2009; Penamora, 1997; Asasutjarit, 2007). Among those agricultural wastes, coconut fiber or coir fiber has the potential to be used as reinforcement in the development of cement fiber composites. From previous investigations, there is limited application of the coconut fiber except some product based on polymer composite (Woolley, 1997; Savastano, 1999). Coconut fiber is the most interesting fiber as it has the lowest thermal conductivity and bulk density. Some researchers have reported that the addition of coconut fiber reduced the thermal conductivity of the composite samples (Asasutjarit, 2009; Asasutjarit, 2007; Khedari, 2005). Asasutjarit and co-workers (Asasutjarit, 2009) investigated the effect of chemical composition modification and surface modification of coconut fibers as reinforcement to the mechanical properties of cement composites. They reported that the mechanical properties of composites; modulus of rupture and internal bond, increased as a result of chemical composition modification and surface modification. Asasutjarit and co-workers (Asasutjarit, 2007) also researched the effect of fiber length, fiber pre-treatment and mixture ratio that affect the physical, mechanical and thermal properties of cement composites after 28 days of hydration. They observed that the boiled and washed fiber improved mechanical properties. In addition, the optimum fiber length was 1 to 6cm fraction and the optimum (cement:fibre:water) mixture ratio by weight was 2:1:2. Thermal property of composites revealed that coconut fiber-based lightweight cement board has lower thermal conductivity. Khedari and co-workers (Khedari, 2005) investigated on the development of a new type of soil–cement block using coconut fiber. Various compositions were tested. In their investigation, the use of coconut fiber as an admixture can reduce the block thermal conductivity and weight. The composition ratio of soil:cement:sand to produce good properties is 5.75: 1.25: 2. The compressive strength and thermal conductivity decreased when the quantity of fiber increased. From the previous studies, most of the works have been focused on the influence of fiber to the mechanical properties of cement composites. This paper reports on the development of coconut fiber based-green composites by conventional method of mixing and curing process. This research work was aimed to investigate the potential use of coconut fiber in substituting the portion of sand in production of cement

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composite. The influence of coconut fiber addition to the physical and mechanical properties was investigated. Correlation between modulus of rupture and fracture behavior is also presented.

2. Experimental:

2.1 Materials and Samples Preparation:

The Ordinary Portland Cement (Blue Lion trademark), coconut fiber, sand as fine aggregate and water were used in this work. All raw materials were supplied locally. The size of sand used is less than 2.0 mm. All raw materials were weighed before the mixing process. The ratio of cement to sand was fixed at 1:1 and the amount for water per cement ratio also was fixed at 0.55. Coconut fiber was weighed according to the percentage ratio of cement weight. The details of the proportion are shown in Table 1.

Table 1: Proportion of cement composites.

Sample	Cement : Sand	water/ cement	Coconut fiber (wt. %)
0	1 : 1	0.55	0
3	1 : 0.97	0.55	3
6	1 : 0.94	0.55	6
9	1 : 0.91	0.55	9
12	1 : 0.87	0.55	12
15	1 : 0.84	0.55	15

The work has focused on six different ratios of cement to sand, and then coconut fiber was added to the mixture replacing the portion of sand. The weight percent starts from the reference sample which was 0 wt. % of coconut fiber and then increased to 3 wt. %, 6 wt. %, 9 wt. %, 12 wt. % and 15 wt. %.

The mixing process was carried out in a mechanical mixer where all of raw materials were mixed together until homogenous mixture was formed. At first, cement was added to mechanical mixer. Water was added in proportion to the cement to form uniform slurry. Once uniform slurry was formed, coconut fiber was added in proportion as well as sand and water. Water was constantly added in proportion so as to avoid balling effect by the coconut fiber.

The uniform wet mix was transferred to an empty mould according to the mould's size to make composite. The size of mould is depending on the test that will be carried out for that composite. After setting (hardening), the composites were kept in the mould for 24 hours before curing. After 24 hours, the composites were de-molded and cured in water for 7, 14 and 28 days before mechanical testing.

2.2 Testing Procedures:

Morphological analysis of the raw materials was studied by a JEOL JSM-6460LA scanning electron microscope (SEM) with EDS analysis. The test samples were taken with care to avoid any damage and contamination that would affect the result. Density test of the samples was carried out by measuring its mass and volume for different days of curing. The sample size for density test was 100mm x 100mm x 40mm according to the BS 5669: Part 1. The sample size for water absorption tests was 100mm x 100mm x 40mm according to the BS 5669: Part 1. Samples were immersed in water for 24 hours and the difference in weight before and after immersion were measured.

For moisture content tests, sample size of 100mm x 100mm x 40mm (BS 5669: Part 1) was placed in oven at 100ºC for 24 hours. The difference in weight before and after test was calculated. Modulus of rupture (MOR) test was carried out on the samples size of 400mm x 100mm x 16mm according to the British Standard (BS) standard BS 5669 part 1. The tests were conducted at a cross-head speed of 5 mm/min and the loading span was 384 mm. Compression test was done to determine the compressive strength of the samples under crushing loads. The sample size for compression test was 100mm x 40mm x 40mm (BS 5669: Part 1). The samples were compressed in vertical position by using the Universal Testing Machine (Gotech). Finally, fracture surface of the composites after modulus of rupture test was investigated under Stereo microscope model SZ2-STU1. This observation was performed in order to study the fracture behavior of the composites. Figure 1 shows the flowchart of the development and characterization of composite cement reinforced with coconut fiber.

RESULTS AND DISCUSSION

3.1 Morphology:

Micrograph from scanning electron microscope (SEM) indicates the morphology of coconut fiber (Figure

2). It can be observed that the fiber surface is covered with protrusions which indicated by oval shape. Some small voids, long cracks and rough fiber surface can be seen in the coconut fiber. EDS analysis that performed at a micro region of the fiber surface indicating the presence of carbon, oxygen and calcium in the fiber (Figure 3).

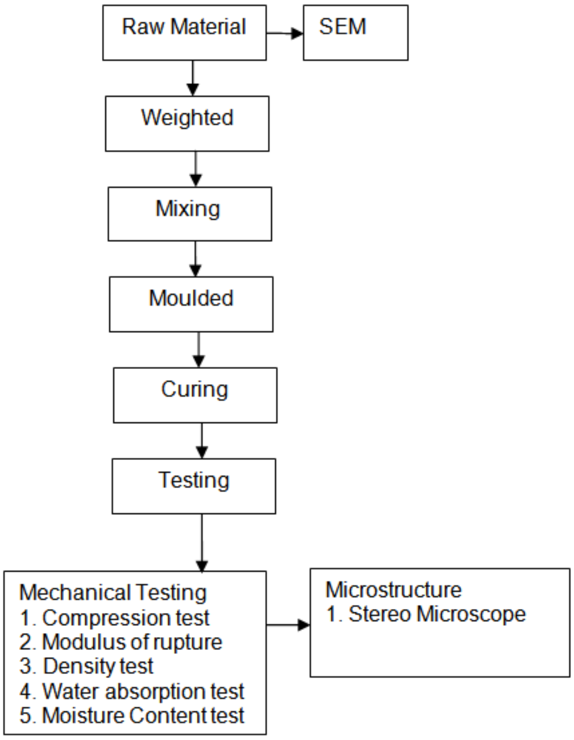

Fig. 1: Flow chart of the development and characterization of the composites.

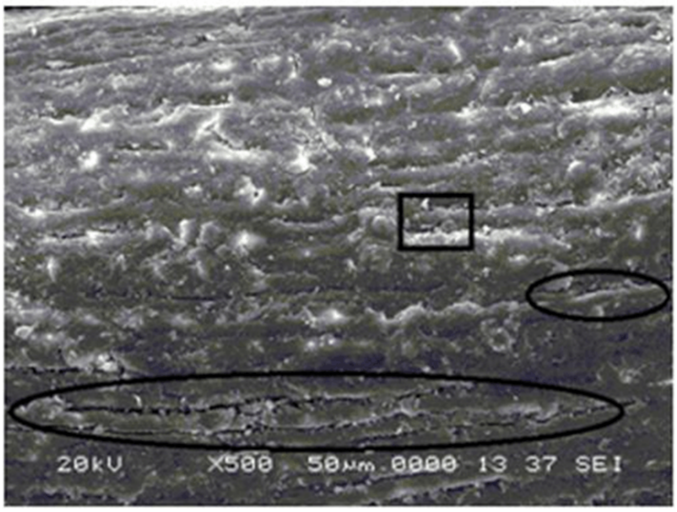

Fig. 2: SEM image of a coconut fiber at 500x magnification.

The coconut fiber used in this research was from brown fiber type. The brown coconut fiber was obtained from matured coconuts and has a higher content of lignin (Rowell, R.M., 2008). Lignin in this fiber can be used as binders, surface-active agents and dispersant. The principal use of lignin based product in concrete manufacture is as chemical admixtures (Nadif, 2002).

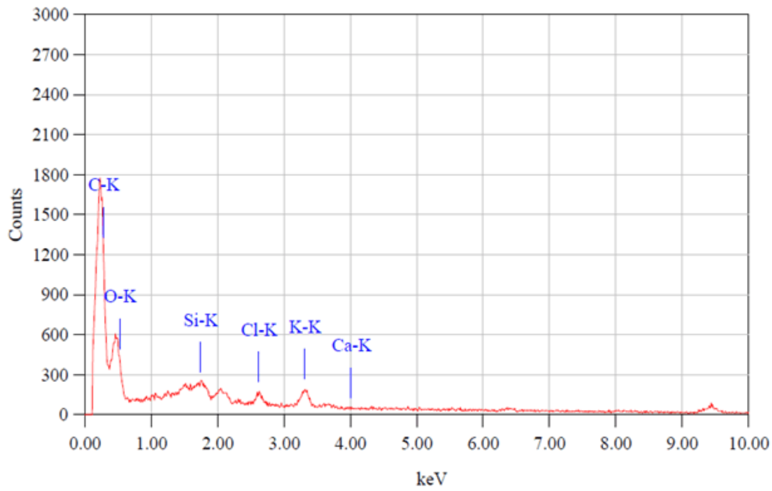

Fig. 3: EDS spectrum for coconut fiber.

3.2 Density:

Density values for composites after 7 days of curing are presented in Figure 4. From the graph, the value of density has decreased with increasing weight percent of coconut fiber. The composite cement reinforced with 9 wt. % of coconut fibre has the lowest value which is 2035 kg/m? whereas the reference sample indicated the highest value about 2242.5 kg/m?.

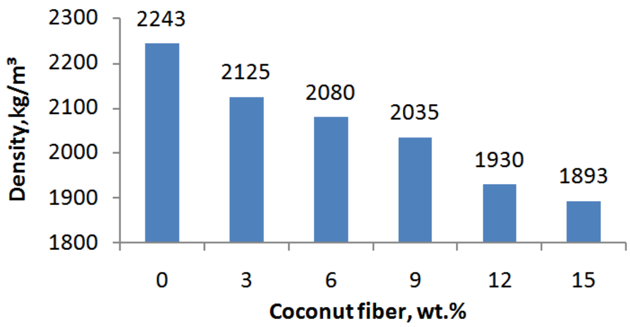

Fig. 4: Density of composites for 7 days curing.

Density values of the composites after 14 days of curing are depicted in Figure 5. From the graph, it was shown that the highest value is given by the reference sample without coconut fiber. The value is 2232.5 kg/m?, whereas the lowest value is given by the composite reinforced with 9 wt. % of coconut fiber which is about 2025 kg/m?.

Density values of the compostíes after 28 days of curing still indicating similar trend of result as shown after 7 and 14 days of curing. The decreasing values of density with the addition of coconut fiber is shown in Figure 6. The highest value of density (2192.5 kg/m?) is given by the reference sample without coconut fiber, and the composite contains highest amount of coconut fiber has the lowest value of density which is 1955 kg/m?.

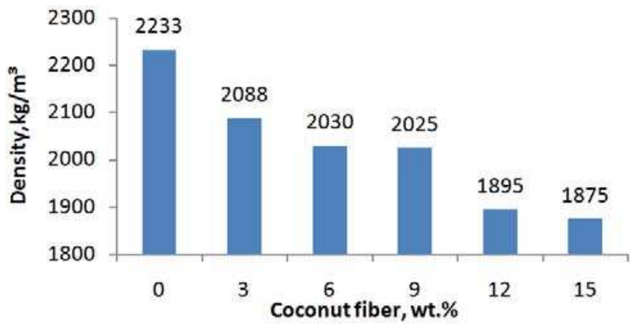

Fig. 5: Density of composites for 14 days curing.

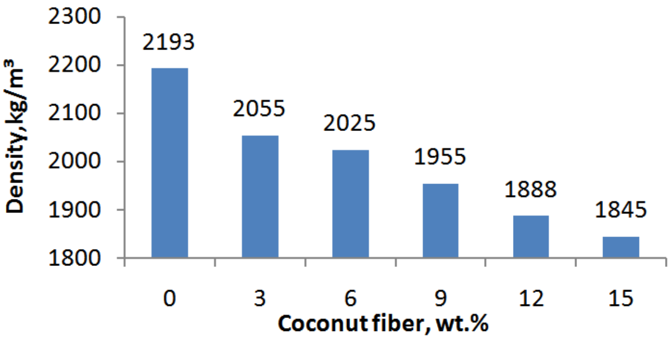

Fig. 6: Density of composites for 28 days curing.

The density results obtained in this work are similar to the previous works. Aggarwal in his study about baggasse-reinforced cement composite also reported that density values of cement composites decreased with increasing of bagasse content (Aggarwal, L.K., 1995). However, this result is contradict with the researcher who studied the effect of palm oil fiber content in concrete. The results showed that density of the concretes with 0.25 % and 0.50% of palm oil fiber higher than control sample without fiber (Subramani, M., 2007).

3.3 Moisture Content:

Figure 7 depicts the results of moisture content of the composites after 7 days of curing. From the graph, it was indicated that the composite cement reinforced with 3 wt. % of coconut fiber gives the highest moisture content which is 4.32% and the lowest moisture content of 3.58% is given by the composite cement reinforced with 9 wt. % of coconut fiber.

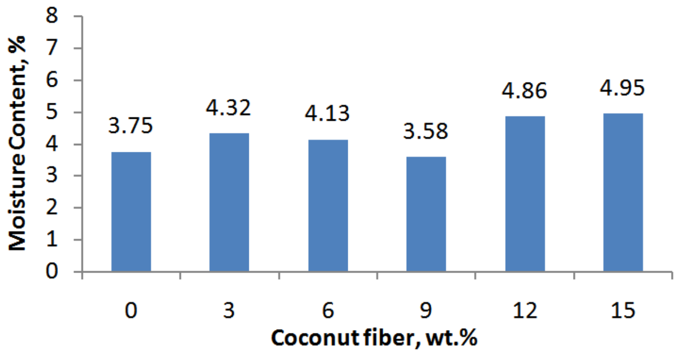

Fig. 7: Moisture content of composites for 7 days curing.

Figure 8 shows the results of moisture content of the composites after 14 days of curing. Similar trend was observed in which the composite reinforced with 9wt. % coconut fiber represents the lowest value of moisture content (4.28 %). The composite cement with highest content of coconut fiber (15wt. %) gives the highest value of moisture content (6.52 %).

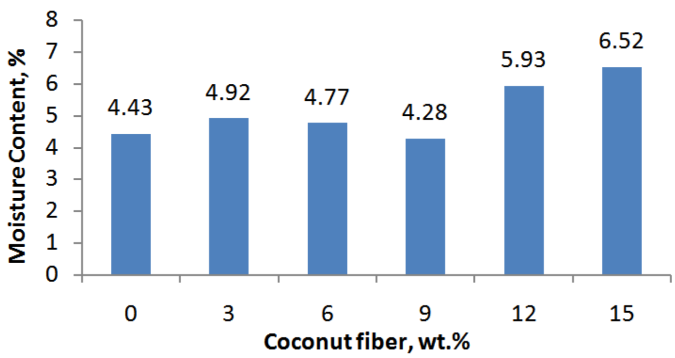

Fig. 8: Moisture content of composites for 14 days curing.

Figure 9 shows the results of moisture content of the composites after 28 days of curing. The composite cement reinforced with 15 wt. % of coconut fiber gives the highest value of moisture content whereas the reference sample and the composite cement reinforced with 6wt. % give almost same value of moisture content (3.81-3.86%).

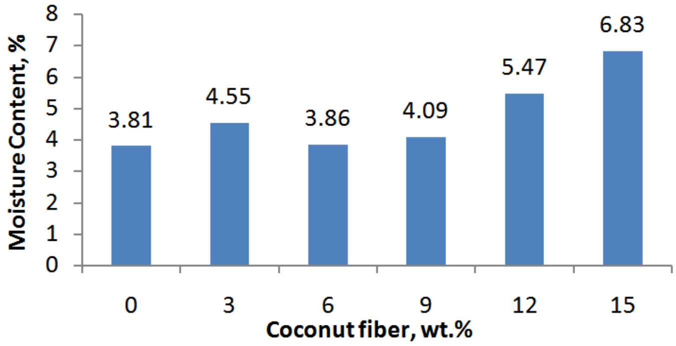

Fig. 9: Moisture content of composites for 28 days curing.

Generally, the moisture content results indicate similar trend of increasing moisture content when the cement reinforced with more than 9 wt. % of coconut fiber. However, when adding coconut fiber less than 9 wt. %, it does not give significant change on the moisture content. Based on moisture content results after 7 days, 14 days and 28 days of curing, we can conclude that the cement composite with 9 wt. % of coconut fiber gives the better results among all compositions in term of low moisture content. This is because higher moisture content will lead to the lower strength of composites.

3.4 Water Absorption:

Water absorption results for composites after 7 days of curing are presented in Figure 10. Water absorption increased with increasing weight percent of coconut fiber. The composite cement reinforced with 15 wt. % of coconut fiber has the highest value which is 4.79% whereas the reference sample indicated the lowest value about 1.34%.

Water absorption results for 14 days of curing are depicted in Figure 11. From the graph, it was indicated that the highest water absorption is given by the composite reinforced with 9 wt. % of coconut fiber. The value is 3.79 %, whereas the lowest water absorption is given by the reference sample which is about 1.16%.

Water absorption results for 28 days of curing indicated the same trend of increasing in water absorption with the addition of coconut fiber (Figure 12). The lowest value of water absorption (0.89 %) is given by the reference sample without coconut fiber, and the composite contains highest amount of coconut fiber has the highest value of water absorption which is 2.64 %.

From the overall result of water absorption after 7 days, 14 days and 28 days of curing, it was indicated that the water absorption increased with increasing weight percent of the coconut fiber. It was also observed that by increasing day of curing, the value of water absorption also decreased. The reference sample without coconut fiber showed the lowest percent of water absorption compared to the composite. In this research, both density and water absorption are inversely proportional to the increasing of coconut fiber content. Higher content of coconut fiber in composites resulted in low density, but high in water absorption and moisture content. It shows that less dense of composites have more void spaces than dense ones so that more water can be absorbed. The same observation was also reported in previous research on the development of coconut fiber based lightweight cement composite (Asasutjarit, 2009) which thickness of water absorption and moisture content are inversely proportional to the density.

3.5 Compressive strength:

Figure 13 depicts the result of compressive strength of the composites after 7 days of curing. From the graph, it was indicated that the composite cement reinforced with 9 wt. % of coconut fiber gives the highest compressive stength which is 31.08 MPa and the lowest compressive strength is 22.47 MPa given by the composite cement reinforced with 15 wt. % of coconut fiber.

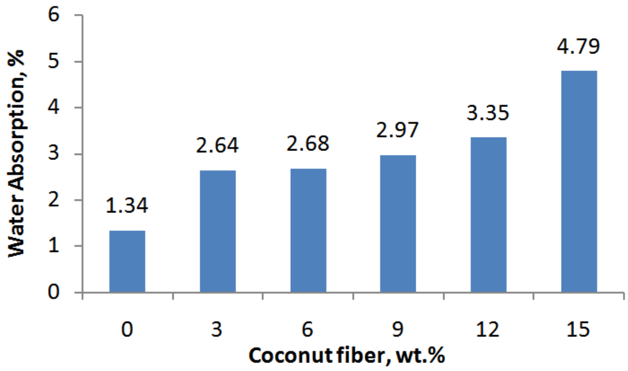

Fig. 10: Water absorption of composites for 7 days curing.

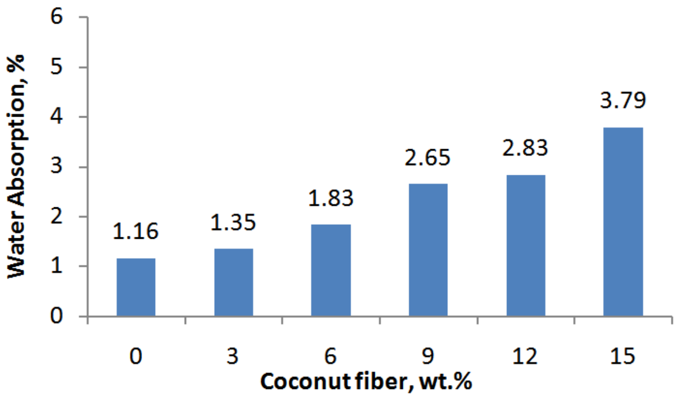

Fig. 11: Water absorption of composites for 14 days curing.

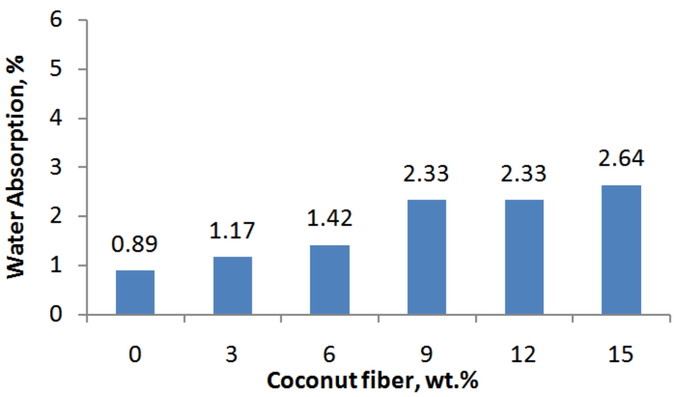

Fig. 12: Water absorption of composites for 28 days curing.

Figure 14 shows the result of compressive strength of the composites after 14 days of curing. Similar trend was observed in which the composite cement reinforced with 9 wt. % of coconut fiber represents the highest value of compressive strength (39.08 MPa). Again, composite cement with 15 wt. % content of coconut fiber gives lowest value of compressive strength (25.48 MPa).

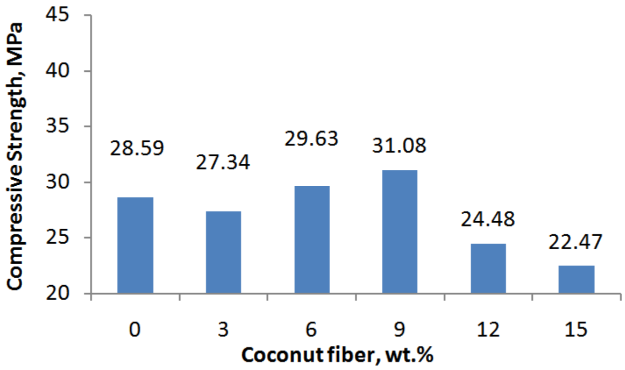

Fig. 13: Compressive strength of composites for 7 days curing.

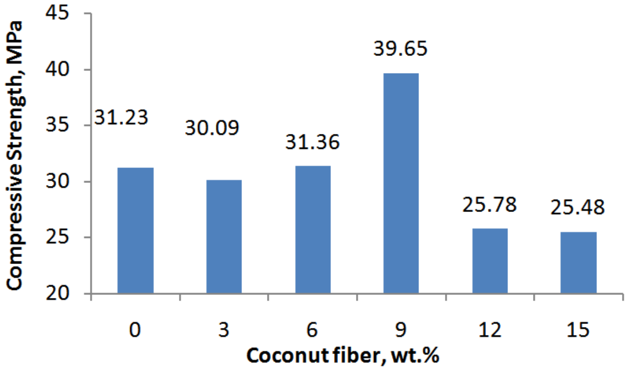

Fig. 14: Compressive strength of composites for 14 days curing.

Figure 15 shows the result of compressive strength of the composites after 28 days of curing. The composite cement reinforced with 9 wt. % of coconut fiber still gives the highest value of compressive stength which is 43.84 MPa and the lowest value is 26.04 MPa given by the composite reinforced with 15 wt. % of coconut fiber.

From all the compressive strength results after 7 days, 14 days and 28 days of curing, it can be concluded that the compressive strength increased with increasing amount of coconut fiber. The highest compressive strength (43.84 MPa) recorded is for the composite cement reinforced with 9 wt. % of coconut fiber after 28 days of curing. The lowest compressive strength (27.34 MPa) is given by the composite reinforced with 3 wt. % of coconut fiber after 7 days of curing. Day of curing also influences the compressive strength of the samples. In this work, when the amount of coconut fiber is fixed at 3 weight percent, workability and uniformity of the mixture is difficult to achieve at 0.55 of water per cement ratio. Excessive bleeding was found during the production process. It means that the mixing ratio is not workable and contributed to lowest compressive strength. The concept found here is almost similar in concrete. The increasing of water cement ratio beyond the minimum required for workability for some mix design will decrease the compressive strength of the concrete (Askeland, 2006).

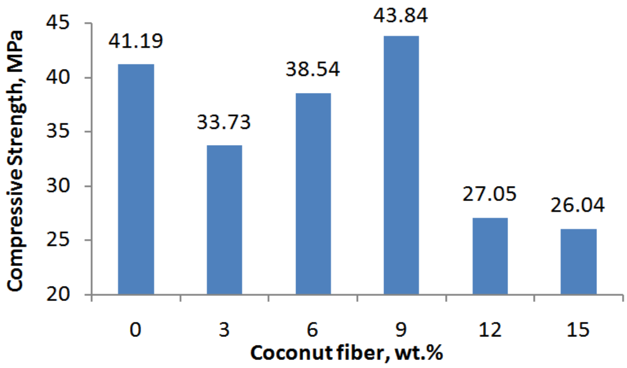

Fig. 15: Compressive strength of composites for 28 days curing.

However, when the fiber content is increased until its optimum value, the mixing process becomes more compatible and workable. In this work, the optimum content of coconut fiber is 9 wt. %. However, further increased in the content of coconut fiber more than 9 wt. %, it shows the decreased in compressive strength. This due to the lack of water for composites with both mixing ratio (12 wt. % and 15 wt. %) causes the mixing is not workable and difficult to mix homogenously. In actual fact, if the fiber is stiff because of less water in mixture, then the packing of the fiber becomes difficult at high fiber content and voids are introduced into the product.

The compressive strength result obtained in this work is in contrast to some other previous findings that documented compressive strength decreased with increasing of fiber content (Asasutjarit, 2009; Khedari, 2001). This might be due to the different of mix design where the fiber was added as an additive to cement paste and it is not as a part of the mortar's composition in their work, whereas in this work composition of coconut fiber was added to replace some amount of sand.

3.6 Modulus of Rupture (MOR):

Modulus of rupture (MOR) for composites after 7 days of curing is presented in Figure 16. MOR increases with increasing weight percent of coconut fiber. The composite cement reinforced with 9 wt. % of coconut fiber has the highest value which is 14.45 MPa whereas the composite with 15 wt. % of coconut fiber indicated the lowest value about 11.85 MPa.

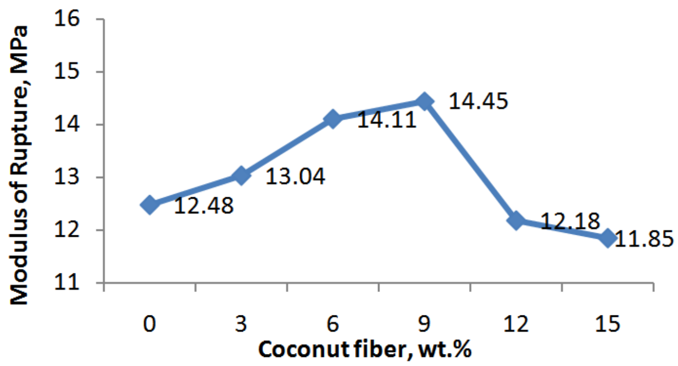

Fig. 16: Modulus of rupture of composites for 7 days curing.

Modulus of rupture for 14 days curing of composites is depicted in Figure 17. From the graph, it can be observed that the lowest value is given by the sample with 15 wt. % of coconut fiber. The value is 13.13 MPa, whrereas the highest value is given by the composite reinforced with 9 wt. % of coconut fiber which is about 14.78 MPa.

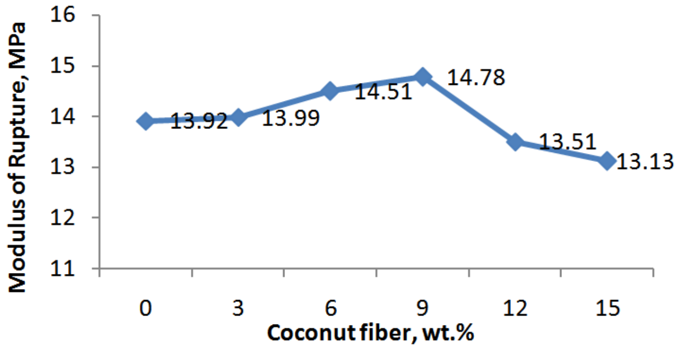

Fig. 17: Modulus of rupture of composites for 14 days curing.

Modulus of rupture for 28 days curing of composites indicated the same trend of increasing MOR with the addition of coconut fiber (Figure 18). The lowest value of modulus of rupture (14.07 MPa) is given by the composite with 15 wt. % of coconut fiber, and the composite contains 9 wt. % of coconut fiber has the highest value of MOR which is 15.23 MPa.

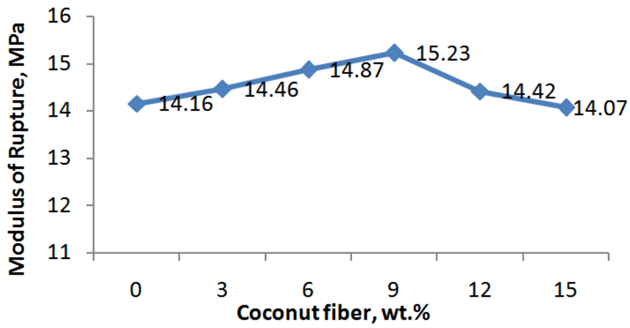

Fig. 18: Modulus of rupture of composites for 28 days curing.

From the overall result of MOR after 7 days, 14 days and 28 days of curing, it is indicated that the MOR increased with increasing weight percent of the coconut fiber. However, there is sharp decrease in modulus of rupture when the coconut fiber content in the mixture exceeds 9 wt. %. The same reason as discussed in compressive strength is also relevant to the result found in MOR test. Composites with more than 9 wt. % did not have good workability and lack of water since the water per cement ratio was fixed to 0.55 for the entire compositions.

From the curve, it was also observed that by increasing day of curing, the value of MOR is also increased. The reference sample without coconut fiber showed the low value of MOR compared to the composites. The lowest strength is due to the only internal bond of cement in cement mixture that contributed as an adhesive bonding to control the strength (Asasutjarit, 2005).

Coconut fiber reinforcement was found to increase the strength of cement matrix until its optimum weight percentage. In this work, the optimum content of coconut fiber is 9 wt. %. Jennifer *et al.*, also observed that MOR of cement composite increased with the addition of kraft fiber (Pehanich, 2004). Ramakrishna and Sundararajan reported the same, in which the addition of natural fibers has increased the impact resistance by 3–18 times than that of the reference sample (plain mortar slab). They found that coconut fiber gave the best performance compared to sisal, jute and hibiscus cannebinus (Ramakrishna, 2005).

In the composite cement reinforced coconut fiber, the mechanical properties depend on the bond between fiber and cement which may be chemical, physical, or a combination of the two. Thus, fiber–cement materials are probably bonded together by several complex physical and chemical mechanisms. The mechanical interlocking is an important mechanism contributing to the strength. The fluid cement flows into cracks and on the rough fiber surface (Figure 2) and then crystallizes to form cement plugs, which interlock the cement and fiber (Asasutjarit, 2007).

3.7 Fracture Behavior:

Fracture surfaces of the MOR samples were examined using stereo microscope. Figure 19 is a stereo microscope image showing large voids for reference sample. The formation of voids might come from the air bubbles during processing. These voids will reduce the strength of the reference sample.

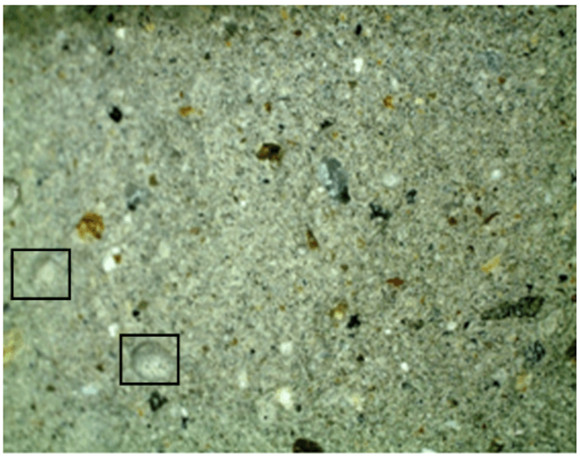

Fig. 19: Fracture surface of the reference sample. Large void is indicated by rectangular zone.

Figure 20 shows the fracture surface for cement composite with lowest content of coconut fiber (3 wt. %) indicating some delamination of coconut fiber (indicated by oval shape) and some voids (represented by rectangular shape).

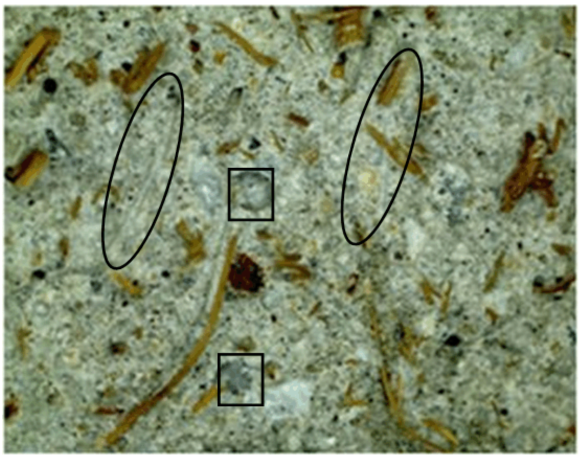

Fig. 20: Sample with lowest content of coconut fiber (3 wt. %).

Figure 21 shows the fracture surface of composite cement with 9 wt. % of coconut fiber. From the image, there are many small holes and cracks (represented by rectangular) were observed on the fracture surface of composite cement.

Figures 22 and 23 represent the fracture surfaces for the sample reinforced with 9 wt. % of coconut fiber, which has highest compressive strength and modulus of rupture. Figure 22 reveals some fiber pull out (indicated by circle) and some delamination (indicated by rectangle). Figure 23 shows fiber push out (indicated by rectangular zone) and there are also some holes due to fiber pull out.

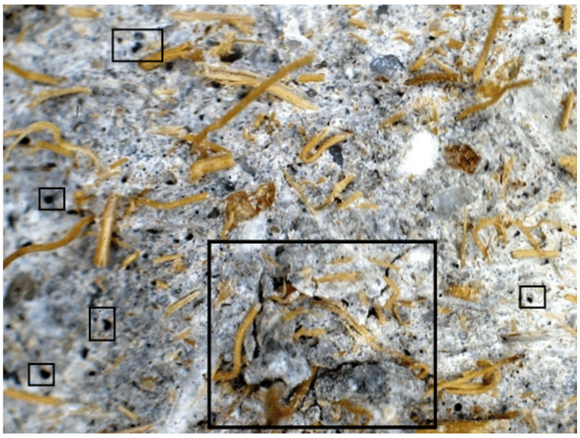

Fig. 21: Small holes on the fracture surface of composite cement with 9 wt. % of coconut fiber.

Figure 24 shows the fracture surface the composite cement reinforced with 9 wt. % of coconut fiber. The fracture surface reveals crack bridging that strengthen the composite and small holes due to fiber pull out. From the image, it can be seen that there is a big crack at the edge of the sample but this crack does not propagates because of fiber still hold the sample. It was also observed that no cracks propagate across the centre of the composite. Fracture behavior is almost similar with fracture behavior found in concrete. Several authors have reported (Wang, 2000; Grzybowski, 1990; Keyvani, 1997) that in fracture process of fiber-reinforced concrete, crack bridging effects induced by fibers can improve resistance to crack propagation and crack opening.

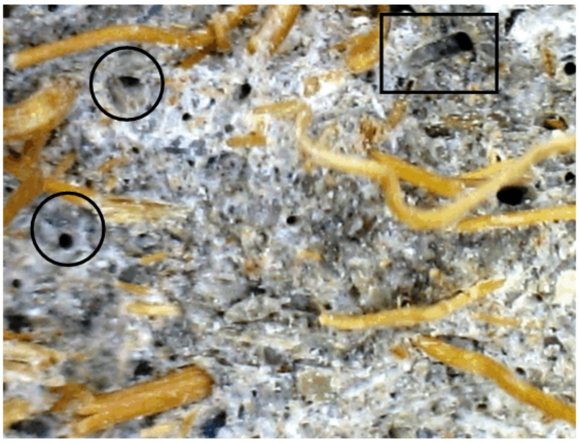

Fig. 22: Fibers pull out and delamination,

Fig. 23: Fibers push out.

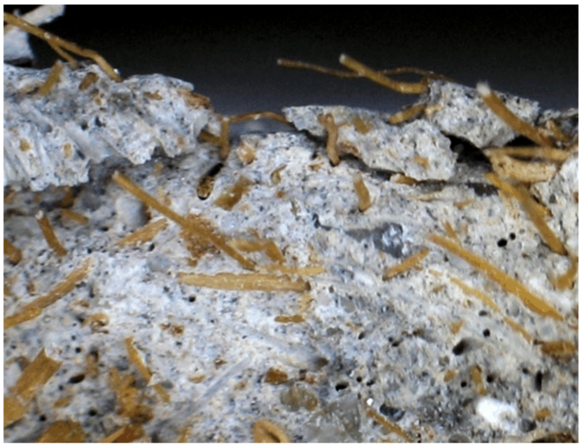

Fig. 24: Crack bridging and small holes observed in the fracture surface of composite cement reinforced with 9 wt. % of coconut fiber.

4. Conclusions:

From the research that has been carried out, we can conclude that coconut fiber can be used as reinforcement and to substitute sand in the development of composite cement reinforced coconut fiber. Increasing content of coconut fiber will increase the modulus of rupture and compressive strength of the composites up to a certain optimum composition. In this work, the optimum content of coconut fiber is 9 wt. %. Further increase in coconut fiber content will decrease the mechanical properties due less workability. Increasing in fiber content also increased the percentage of water absorption and moisture content. However, density has decreased with the addition of fiber content. The fracture behavior of high strength composite consists of crack bridging and fiber push out that responsible to resist crack propagation and improve the strength of the composite. Fracture behavior likes small holes due to the fiber pull out and fiber delamination is also observed in this study.

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