PROPRIETĂȚILE MECANICE ŞI COMPORTAMENTUL LA RUPERE AL UNOR COMPOZITE CU CONȚINUT DE FIBRE DE COCOS
MECHANICAL PROPERTIES AND FRACTURE BEHAVIOUR OF COCONUT FIBRE-BASED GREEN COMPOSITES

ALIDA ABDULLAH*[1], SHAMSUL BAHARIN JAMALUDIN[1], MAZLEE MOHD NOOR[2], KAMARUDIN HUSSIN[2]
[1]*School of Materials Engineering, University Malaysia Perlis*
[2]*Kompleks Pusat Pengajian Jejawi 2, 02600 Arau, Perlis, Malaysia*

This paper presents the influence of natural fibre content on the mechanical properties of coconut fibre based-green composites. The mixture ratio of cement:sand by weight was fixed at 1:1. Coconut fibre was used as reinforcement and added to cement matrix to replace the sand composition. Cement matrix was reinforced with 3wt. %, 6wt. % and 9wt. % of coconut fibre by mixing and curing process. Composites were cured in water for 7, 14, and 28 days. It was observed that the composite reinforced with 9wt. % of coconut fibre demonstrated the highest strength of modulus of rupture and compressive strength.

Lucrarea prezintă influența conținutului de fibre naturale asupra proprietăților mecanice în crud ale unor compozite pe bază de fibre de cocos. Raportul masic al amestecului de ciment : nisip a fost fixat la 1:1. Fibrele de cocos au fost utilizate pentru înlocuirea nisipului din compoziție şi armarea matricii de ciment. Au fost utilizate adaosuri de 3%, 6% şi respectiv 9% fibre de cocos raportat la conținutul de ciment, amestecurile fiind omogenizate şi apoi păstrate în apă pentru 7, 14 şi 28 zile. S-a demonstrat că cele mai mari rezistențe la compresiune şi încovoiere sunt dezvoltate în cazul probelor cu un conținut de 9% fibre de cocos.

Keywords: *coconut fibre, construction, fibres, composites, portland cement*

1.Introduction

A huge amount of agricultural wastes is abundantly available in Malaysia. These wastes are needed to be disposed properly especially for environmental sustainability. They are mostly disposed of by incineration or used as fuel, although their calorific value is much lower than that of coal. Utilisation of these agro-wastes, apart from solving the problem of their disposal would improve the agricultural economy considerably [1]. There is a research activity in the utilisation of natural fibre as low cost construction materials especially in developing countries [2]. In recent years, there have been considerable efforts to develop natural fibre-reinforced cementitious composites for affordable infrastructure [3]. Among those agricultural wastes, coconut fibre or coir fibre has the potential to be used as reinforcement in the development of cement fibre composites. From the literature reviews and commercial product information, there is limited application of the coconut fibre except some product based on polymer composite [4,5].

Coconut fibre is the most interesting fibre as it has the lowest thermal conductivity and bulk density. Some researchers have reported that the addition of coconut fibre reduced the thermal conductivity of the composite samples [2,6,7]. Asasutjarit and co-workers [2] studied the effect of chemical composition modification and surface modification of coconut fibres as reinforcement to the mechanical properties of cement composites. They observed that the mechanical properties of composites: modulus of rupture and internal bond, increased as a result of chemical composition and surface modification. Asasutjarit and co-workers [6] also investigated the effect of fibre length, fibre pre-treatment and mixture ratio that affect the physical, mechanical and thermal properties of cement composites after 28 days of hydration. Their results indicated that the boiled and washed fibre improved mechanical properties. In addition, the optimum fibre 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 fibre-based lightweight cement board has lower thermal conductivity. A study from Khedari and co-workers [7] reported on the development of a new type of soil–cement block using coconut fibre. Various mixture ratios were considered. They concluded that the use of coconut fibre as an admixture can reduce the block thermal conductivity and weight. The optimum volume ratio of soil:cement:sand to produce good properties is 5.75:1.25:2. The ratio of coconut fibre is 20% of cement corresponding to 0.8 kg/block. The compressive strength and thermal conductivity decreased when the quantity of fibre increased. It can be seen that, from the previous investigation, major works have been focused on the effect of fibre to the mechanical properties of cement composites. However, this paper presents the de-

* Autor corespondent/Corresponding author,
Tel. +60199346986, e-mail: alida6986@gmail.com

velopment of coconut fibre based-green composites by conventional method of mixing and curing process. In this work, coconut fibre is added to substitute the portion of sand in the ratio of cement to sand. This proposed design mixture was aimed to reduce the use of sand in cement composite. The effect of weight % of coconut fibre to the modulus of rupture and compressive strength was investigated and correlation between modulus of rupture and fracture behaviour is also presented.

2. Experimental

2.1 Materials

Raw materials used in this research were cement, coconut fibre, sand as fine aggregate and water. The Ordinary Portland Cement (OPC) ASTM C150 Type 1 and coconut fibre were supplied locally. This type of cement is suitable for all purposes and widely used in construction project such as buildings, bridges, floors and other precast concrete product. It complies with MS522 (Malaysia Standard) as well as BSEN (British Standard European Norm). The grain size of sand used is 2.0 ± 0.1 mm.

2.2 Sample Preparation

All raw materials were weighed before the mixing process. The ratio of cement to sand was fixed at 1:1. This ratio was referred from researcher in Thailand which studied to the coconut coir cement board [8]. The amount for water per cement ratio also was fixed at 0.55. Coconut fibre was weighed according to the percentage ratio of cement weight. The details of the proportion are shown in Table 1.

Table 1

Compoziția probelor/ *Sample composition*

Proba *Sample*	Raport ciment: nisip / *Cement : sand*	Raport apă: ciment / *Water: cement*	Fibre de cocos (%m) / *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

As for the ratio shown in Table 1, the work has focused on four different ratios of cement to sand, and then coconut fibre was added to the mixture replacing the portion of sand. The weight percent starts from the reference sample which was 0 wt. % of coconut fibre and then increased to 3 wt. %, 6 wt. %, and 9 wt. % depending to the sand content.

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 fibre 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 fibre.

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-moulded and cured in water for 7, 14 and 28 days before mechanical testing.

2.3 Testing procedures

Morphological Analysis

Morphological analysis of the raw materials was carried out using 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.

Modulus of rupture (MOR)

The sample size for MOR tests was 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.

Thermogravimetric analysis (TGA)

Thermogravimetric analysis was carried out on coconut fibre to determine changes in the weight of coconut fibre that correlated to the phase reaction with increasing temperature. Samples were analysed in the form of small pieces by using Pyris diamond TG/DTA machine.

Compressive strength

A compression test was carried out to determine the compressive strength of the samples under crushing loads. The sample size for compression test was 100mm x 40mm x 40mm by referring to the BS 5669: Part 1. The samples were compressed in vertical position by the Universal Testing Machine (Gotech). There are five numbers of samples for each ratio has been tested and the average was recorded.

Fracture behaviour

Stereo microscopy is widely used to study microstructure of concrete instead of using scanning electron microscope. In this work, 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 behaviour of the composites. Figure 1 shows the flowchart of the development and characterisation of coconut fibre based-green composites.

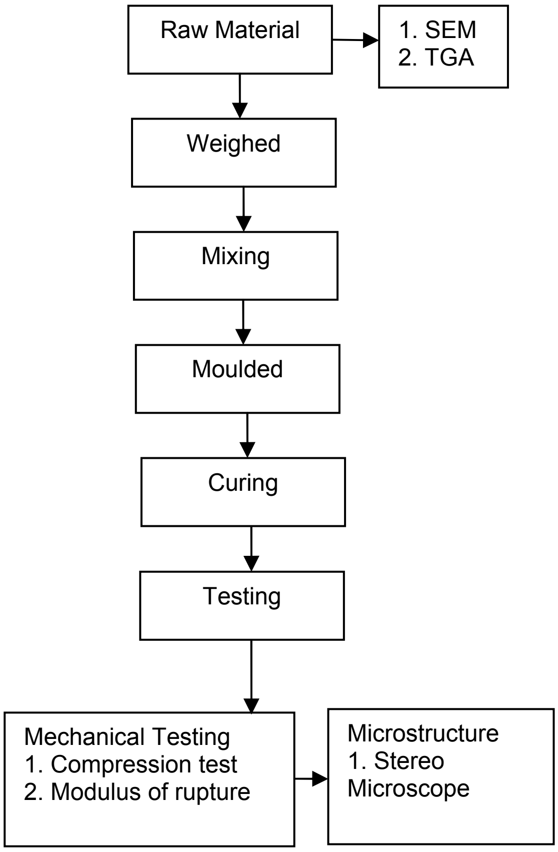

Fig. 1 - Flow chart of the development and characterisation of coconut fibre based-green composites / *Succesiunea etapelor de obținere şi caracterizare a compozitelor cu conținut de fibre de cocos.*

3. Results and Discussion

3.1 Morphology

The morphology of coconut fibre observed under SEM is shown in Figure 2 (200x magnification) and Figure 3 (500x magnification). It was noticed that the fibre surface is covered with some small voids and long crack (Figure 3). EDS analysis performed at a micro region of the fibre surface indicated the presence of oxygen, silicon, chlorine, potassium and calcium in the fibre (Figure 4). Table 2 shows the composition of element in the coconut fibre.

Table 2

Composition of element in coconut fibre.
Componența element din fibre de nucă de cocos

Element	Mass, %
O	19.14
Si	6.44
Cl	22.8
K	45.22
Ca	6.39

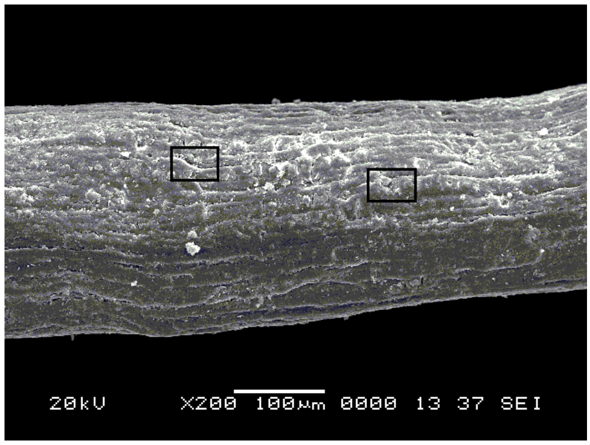

Fig. 2 - SEM image of a coconut fibre at 200x magnification. *Imagine SEM a unei fibre de cocos la o mărire de 200x.*

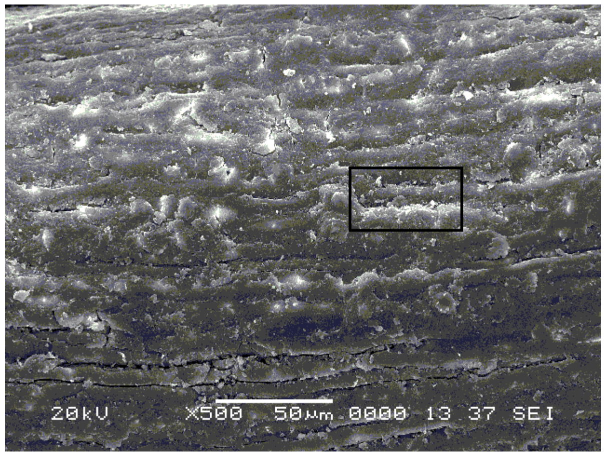

Fig. 3 - SEM image of a coconut fibre at 500x magnification. *Imagine SEM a unei fibre de cocos la o mărire de 500x.*

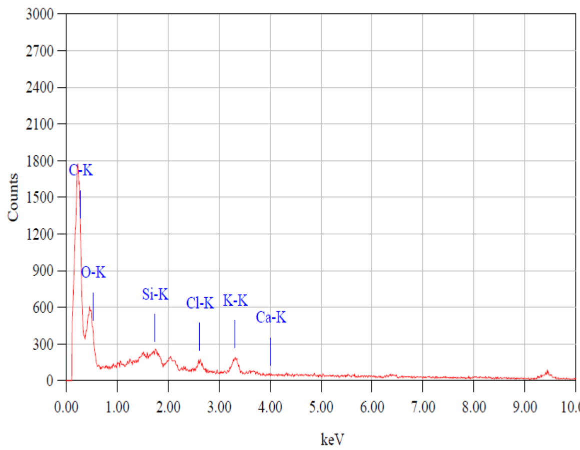

Fig. 4 - EDS spectrum for coconut fibre / *Spectrul EDS realizat pentru fibrele de cocos.*

The coconut fibre used in this research was of brown fibre type. The brown coconut fibre was obtained from matured coconuts and has a higher content of lignin [9]. Lignin in this fibre can be used as binders, surface-active agents and dispersant. The principal use of lignin based product in concrete manufacture is as chemical admixtures [10].

3.2 Modulus of rupture (MOR)

Modulus of rupture for composites after 7 days of curing is presented in Figure 5. From the graph, it can be seen that MOR has increased with increasing weight percent of coconut fibre. The composite cement reinforced with 9 wt. % of coconut fibre has the highest value, which is 14.45 MPa, whereas the reference sample indicated the lowest value about 12.48 MPa.

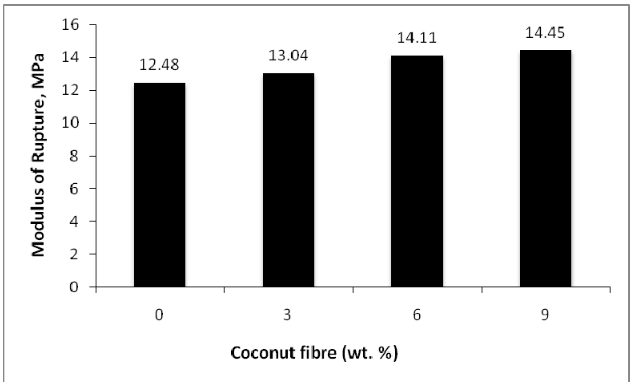

Fig. 5 - Modulus of rupture of composites for 7 days curing . *Rezistența la rupere a compozitelor după 7 zile de întărire.*

Modulus of rupture for 14 days curing of composites is depicted in Figure 6. From the graph, it shows that the lowest value is given by the reference sample without coconut fiber. The value is 13.92 MPa, whreреas the highest value is given by the composite reinforced with 9 wt. % of coconut fibre which is about 14.78 MPa.

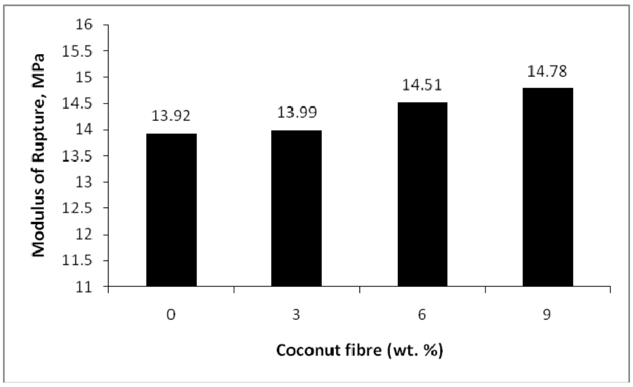

Fig. 6 - Modulus of rupture of composites for 14 days curing. *Rezistența la rupere a compozitelor după 14 zile de întărire.*

Modulus of rupture for 28 days curing of composites indicated the same trend of increasing MOR with the addition of coconut fibre (Figure 7). The lowest value of modulus of rupture (14.16 MPa) is given by the reference sample without coconut fibre, and the composite containing the highest amount of coconut fibre has the highest value of MOR which is 15.23 MPa.

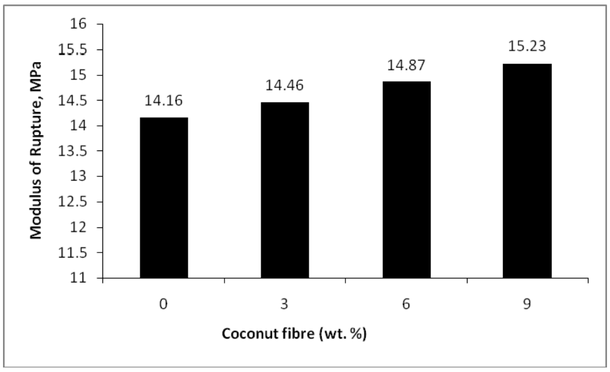

Fig. 7 - Modulus of rupture of composites for 28 days curing / *Rezistența la rupere a compozitelor după 28 zile de întărire.*

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 fibre. It was also observed that by increasing the curing time, the value of MOR is also increased. The reference sample without coconut fibre showed the lowest value of MOR compared to the composite. Its strength was due to the only internal bond of cement in cement matrix which acts as an adhesive that control the strength [8].

Coconut fibre reinforcement was found to increase the strength of cement matrix. Pehanich *et al*. also observed that MOR of cement composite increased with the addition of kraft fibre [11]. Ramakrishna and Sundararajan reported the same result in their study which summarized that the addition of natural fibres has increased the impact resistance by 3–18 times than that of the reference sample (plain mortar slab). They found that coconut fibre gave the best performance compared to sisal, jute and hibiscus cannebinus [12].

3.3 Thermogravimetric analysis

Figure 8 shows the Thermogravimetric analysis (TGA) and Derivative Thermal analysis (DTA) analysis of coconut fibre. The TGA curve shows two stages of decomposition where the first stage around 100 ºC refers to moisture elimination. The second stage is between 226 ºC and 380 ºC. This stage represents to the decomposition of organic materials which is superposition of two parallel curves (refer DTA curve of Figure 8). In this step, mass loss caused by organic species presents in the raw material such as lignin, cellulose, and hemicelluloses. The residue is about 2.22% of initial sample mass. It was heated from room temperature to 1000°C at a rate of 10°C/min in normal atmosphere.

Similar trend results were observed by Cheila and Iara [13]. They have characterized sugarcane and coconut fibres by thermal analysis. The results showed that the decomposition of coconut fibres has two stages: the first stage around 50°C corresponds to moisture elimination and the second one between 250 and 370°C correspond to decomposition of organic materials. The residues are about 20% of initial sample mass.

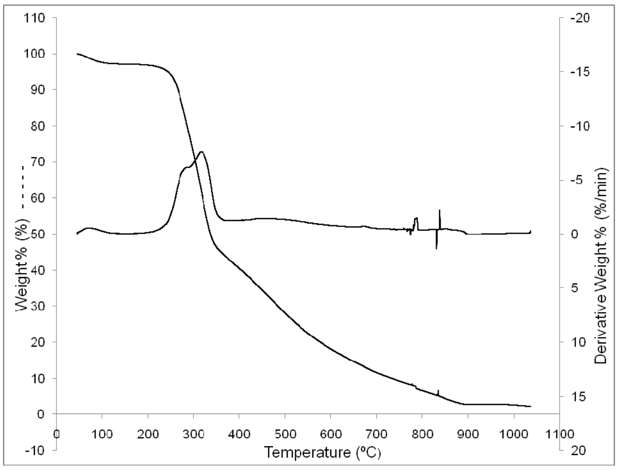

Fig. 8 -TGA and DTA analysis of coconut fibre / *Rezultatul analizei TG şi TD pe fibrele de cocos.*

3.4 Compressive strength

Figure 9 depicts the result of average value of compressive strength of the composites after 7 days of curing. From the graph, it shows that the composite cement reinforced with 9 wt. % of coconut fibre gives the highest compressive stength which is 31.08 MPa and the lowest compressive strength is 27.34 MPa given by the composite cement reinforced with 3 wt. % of coconut fibre.

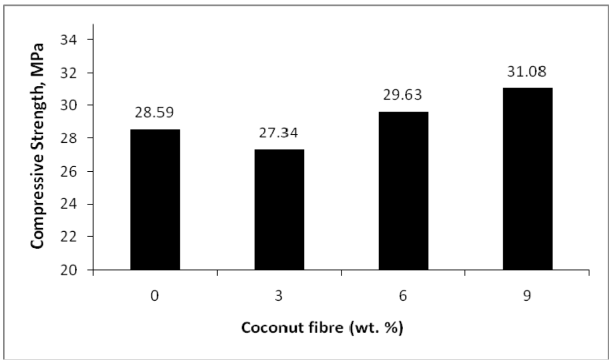

Fig. 9 - Compressive strength of cement panel for 7 days curing / *Rezistența la compresiune a compozitelor după 7 zile de întărire.*

Figure 10 shows the result of average value of compressive strength of the composites after 14 days of curing. From the graph, similar trend was observed in which the highest content of coconut fibre in the composite represents the highest value of compressive strength (39.08MPa). Again, composite cement with low content of coconut fibre gives lowest value of compressive strength (30.09MPa).

Figure 11 shows the result of average value of compressive strength of the composites after 28 days of curing. The composite cement reinforced with 9 wt. % of coconut fiber gives the highest value of compressive stength which is 43.84 MPa and the lowest value is 33.73 MPa given by the composite reinforced with 3 wt. % of coconut fibre.

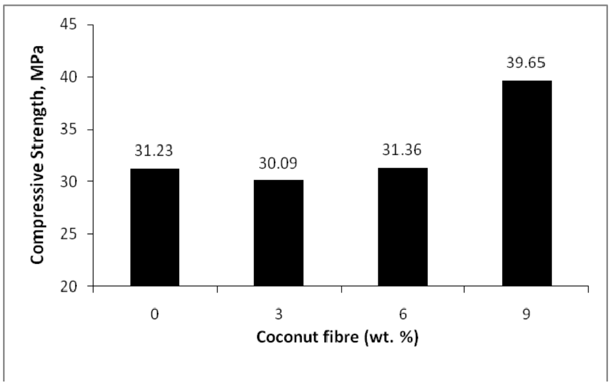

Fig. 10 - Compressive strength of cement panel for 14 days curing / *Rezistența la compresiune a compozitelor după 14 zile de întărire.*

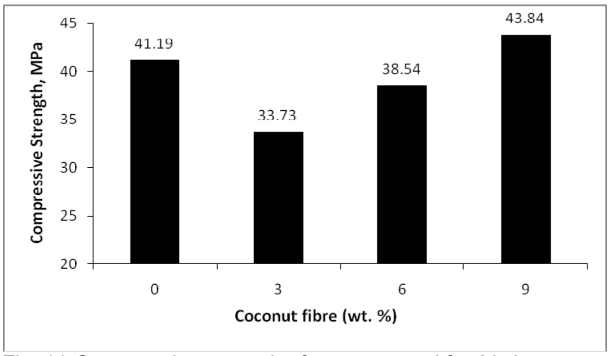

Fig. 11-Compressive strength of cement panel for 28 days curing / *Rezistența la compresiune a compozitelor după 28 zile de întărire.*

From all the compressive strength results after 7 days, 14 days and 28 days of curing, it is indicated that the compressive strength increased with increasing coconut fibre content in the composite. The highest compressive strength (43.84 MPa) recorded is for the composite cement reinforced with 9 wt. % of coconut fibre after 28 days of curing. The lowest compressive strength (27.34 MPa) is given by the composite reinforced with 3 wt. % of coconut fibre after 7 days of curing.

It was observed in this work, when the amount of coconut fibre is fixed at 3 wt. %, workability and uniformity of the composition 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 [14].

However, when the fibre content is increased, the mixing ratio becomes more compatible and workable. The strength also increased with the curing days due to hydration of cement in the composites.

3.5 Fracture behaviour

The fracture surface of the composites and the reference sample after modulus of rupture test was investigated by using stereo microscope. Figure 12 presents the microstructures image of the reference sample without coconut fibre indicating some voids distributed in the sample and large void can be seen on the top of the micrograph. The formation of voids might come from the air bubbles during processing. These voids will reduce the strength of this sample.

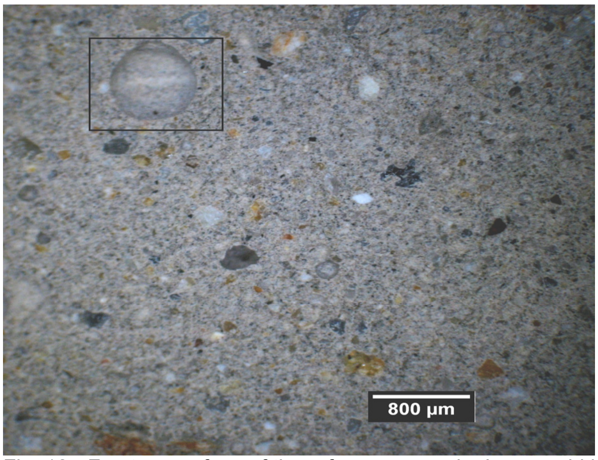

Fig. 12 - Fracture surface of the reference sample. Large void is indicated by rectangular shape / *Suprafața în ruptură a probei de referință. Forma rectangulară marchează un gol mare.*

Figure 13 shows the fracture surface the composite cement reinforced with 9 wt. % of coconut fibre. The fracture surface reveals crack bridging that strengthen the composite and small holes due to fibre pull out. Fracture behaviour is almost similar with fracture behaviour found in concrete. Several authors have reported [15-17] that in fracture process of fibre-reinforced concrete, crack bridging effects induced by fibres can improve resistance to crack propagation and crack opening. From the image, it can be seen that there is a big crack at the edge of the sample but this crack does not propagate because of fibre still holds the sample. It was also observed that no cracks propagate across the centre of the composite. Long grooves also can be observed that due to delamination of the fibre.

Figure 14 and Figure 15 show two sides of fracture surface from the composite cement reinforced with 9 wt. % of coconut modulus of rupture test. These micrographs show the position of fibre in the composite. The large hole in Figure 15 (indicated by an oval shape) represents the hole in which the largest fibre (indicated by circle) in Figure 14 has been pulled out during fracture. However, crack bridging still can be seen in Figure 14 (indicated by circle) that hold the crack

Fig. 13 - Crack bridging, small holes and long grooves on the fracture surface of composite cement reinforced with 9 wt. % of coconut fibre / *Interconectarea crăpăturilor, goluri mici şi şanțuri lungi la suprafața de ruptură în cazul compozitului armat cu 9% fibre de cocos.*

Fig. 14 - Fibre pulls out, fibre push out and small holes due to fibre pull out on the fracture surface / *Fibre smulse, îngropate şi goluri lăsate de fibrele smulse în suprafața de ruptură*

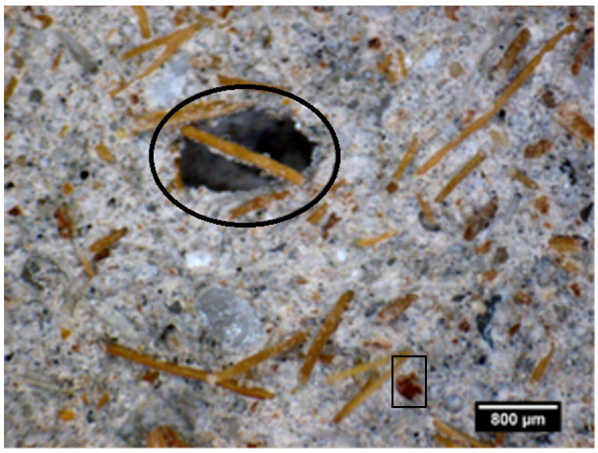

Fig. 15 - Large hole, fibre pull out, crack bridging and fibre push out on the fracture surface / *Gol mare, fibre smulse, fisuri interconectate şi fibre îngropate la suprafața de rupere.*

propagation. Both micrographs also reveal the fibre push out indicated by small rectangle. This crack behaviour also acts as crack resistance to the composite.

4. Conclusions

Coconut fibre can be used as reinforcement and to substitute sand in the development of coconut fibre based-green composite. Increasing content of coconut fibre will increase the modulus of rupture and compressive strength of the composites. The fracture behaviour of composite with high content of fibre consists of crack bridging and fibre push out that responsible to resist crack propagation and improve the strength of the composite. Fracture behaviour likes small holes due to the fibre pull out and long groove due to the fibre delamination are also observed in this study.

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