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ORIGINAL ARTICLE

Mechanical Properties of Pineapple Leaf Fiber/Epoxy Composites with 0°/0°/0°/0° and 0°/90°/0°/90° Fiber Orientations

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ABSTRACT – Pineapple leaf fiber can replace synthetic fiber because of its environmentally friendly and abundant availability in Indonesia. The purpose of this study was to obtain the mechanical properties of the pineapple leaf fiber/epoxy composite with 0°/0°/0°/0° and 0°/90°/0°/90° fiber orientations. Pineapple leaf fiber from Subang Indonesia was pre-treated through alkalization. The composites were fabricated by hand lay-up, followed by the vacuum bagging method. The results showed that the flexural properties of both composites were higher than the tensile properties of both composites. The flexural strength and modulus of 0°/0°/0°/0° composites were higher than those of 0°/90°/0°/90° composites, with the values of (109.57 ± 8.12) MPa and (7.08 ± 0.62) GPa respectively. Morphological observations using a Scanning Electron Microscope (SEM) showed that pineapple leaf fiber and epoxy had strong interfacial bonds and few voids. According to SNI 01-4449-2006 for fiberboard, pineapple leaf fiber/ epoxy composites with 0°/0°/0°/0° and 0°/90°/0°/90° fiber orientations were categorized as high-density fiberboard type T2 45, because both composites had a density higher than 0.84 g/cm^3 and a flexural strength higher than 45 MPa.

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INTRODUCTION

Nowadays, composite raw materials in Indonesia have obtained from non-renewable natural resources. Therefore, it is necessary to develop composite reinforcement materials that are renew-able and environmentally friendly, such as natural fibers [1]. There are a lot of natural fibers in Indonesia that can be used as composite reinforcements, such as coconut fiber, pineapple leaf fiber, banana fiber, bamboo fiber, and others [2]. Natural fibers have many advantages over synthetic fibers, such as being environmentally friendly, biodegradability, and abundant availability. In addition, natural fibers have low density, high strength, and high stiffness [3].

Pineapple leaf fiber (PALF) is a plant fiber derived from the leaves of the pineapple plant. In Indonesia, the pineapple plant (Ananas comosus) has been widely cultivated, especially on the is-lands of Java and Sumatra. The pineapple plant will be replaced with a new pineapple plant at harvest time, leaving the leaves as a waste [4]. Pineapple leaf fiber exhibits high strength and stiffness associated with high cellulose content. Pineapple leaf fiber contains 70–82 wt% cellulose [5]. Due to the abundant waste and its good properties, pineapple leaf fiber has the potential to be used as a composite reinforcement.

The mechanical properties of composite depend on fiber and ply orientation. Gama et al [6] studied the effect of fiber volume fraction and fiber orientation on the flexural properties of PALF/methyl methacrylate (MMA) composites. The fiber was treated with alkaline 6% NaOH. The results showed that for all fiber volume fractions, 0° fiber-oriented composites had the highest flexural strength. In 0° fiber-oriented composites, the PALF/ methyl methacrylate (MMA) composite with 40 vol% fiber produced the highest flexural strength, which was 50.2 MPa. Doddi et al [7] reported the effect of PALF orientation (0°, 30°, 45°, 60°, and 90°) on the mechanical properties of PALF hybridized with basalt reinforced epoxy composites. Their investigation concluded that a hybrid compo-site with 0° PALF-oriented as a core had the maxi-mum tensile strength, flexural strength, tensile modulus, and flexural modulus values. The tensile and flexural properties of the composites decreased with increasing fiber orientation up to 45°–60° and an increase was found with further increase in fiber orientation. Similar results have been obtained in other studies of natural fiber reinforced composites [8], [9].

Research on Subang pineapple leaf fiber reinforced epoxy composites with fiber orientation of 0°/0°/0°/0° and 0°/90°/0°/90° has never been done. In this research, pineapple leaf fiber/ epoxy composites with fiber orientations of 0°/0°/0°/0° and 0°/90°/0°/90° were manufactured using hand lay-up followed by vacuum bagging method. The mechanical properties of pineapple leaf fiber/epoxy composites were investigated in this study. This composite is used as a fiberboard which refers to the Indonesian National Standard 01-4449-2006.

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EXPERIMENTAL METHOD

The materials used in this study were pine-apple leaf fiber as reinforcement and epoxy resin as matrix. The pineapple leaf fiber was obtained from Subang, West Java, Indonesia. EPR 174 epoxy resin matrix and EPH 555 hardener were purchased from Justus Kimiaraya Ltd. with the physical prop-erties are shown in Table 1. NaOH flakes were purchased from Merck Ltd.

The sample preparation was divided into two stages, they were fiber treatment and fiber weaving. The pineapple leaf fiber was prepared by cutting them according to the size of the mold length. The fiber was treated with an alkaline treatment. The alkalization process of pineapple leaf fiber was as follows [10]: a) Dried and cleaned pineapple leaf fiber was immersed for 5 hours in 5% NaOH solution. b) The fiber was washed with distilled water, approximately 7–15 times until the water was colorless (clear). c) The fiber was dried at room temperature for 24 hours. d) The fiber was dried for 24 hours at 65ºC. The treated fiber is shown in Figure 1. The properties of the treated pineapple leaf fiber are listed in Table 2 [10]. The fiber was woven in Pekalongan, Central Java, Indonesia. The woven pineapple leaf fiber is shown in Figure 2.

Table 1. Physical properties of epoxy EPR 174, hardener EPH 555, and cured epoxy

Physical Properties	Epoxy [11]	Hardener [12]	Cured Epoxy (Current Result)
Density (25°C) (g/cm^3)	1.17 ± 0.01	1.01± 0.00	1.13 ± 0.00
Viscosity (25°C) (mPa.s)	13,000 ± 2,000	50 ± 100	NA

Table 2. Properties of treated pineapple leaf fiber [10]

Properties	Value
Density (25 °C) (g/cm^3)	1.49 ± 0.00
Tensile Strength (MPa)	378.94 ± 101.70

Figure 1. Alkaline-Treated Pineapple Leaf Fiber

Figure 2. Woven Pineapple Leaf Fiber

The pineapple leaf fiber/epoxy composites were fabricated of epoxy resin mixed with a hardener in a ratio of 2:1 (with the physical properties as in Table 1) and four plies of fiber arranged in 0°/0°/0°/0° and 0°/90°/0°/90° orientations. The four plies woven fiber had 35 wt% reinforcements to meet the optimum fiber composition of 40 wt% pineapple leaf fiber from previous result [10]. The composites were fabricated using hand lay-up followed by the vacuum bagging method. The vacuum bagging process was carried out for 24 hours with a pressure of 52 cmHg. The samples were pre-cured at ambient temperature for 24 hours while the post-cured process was done for 30 minutes at 110ºC. Pineapple leaf fiber reinforced epoxy composites with 0°/0°/0°/0° fiber orientation were identified as EP/0/0PALF, while the composites with 0°/90°/0°/90° fiber orientation were identified as EP/0/90PALF (Figure 3).

Composite density was measured by the Archimedes method with a specimen of dimension of 12.7 mm x 12.7 mm x 4 mm. The tensile test was conducted based on ASTM D638 standard, with a test speed of 5 mm/min. The specimen dimensions for the tensile test were 115 mm in length, 19 mm in width and 4 mm in thickness. The flexural test procedure and specimen size were referred to ASTM D7264, with a test speed of 1 mm/min. The specimen dimensions for the flexural test were 153.6 mm in length, 13 mm in width and 4 mm in thickness. Both the tensile and flexural tests were conducted using a Universal Testing Machine (UTM).

To compare the surface morphology before and after each test, both on the tensile and flexural test specimens, morphological observations were conducted. Scanning Electron Microscope (SEM) Hitachi-SU3500 was used to study the fibre-matrix bonding, fiber arrangement, and the failure modes of composites.

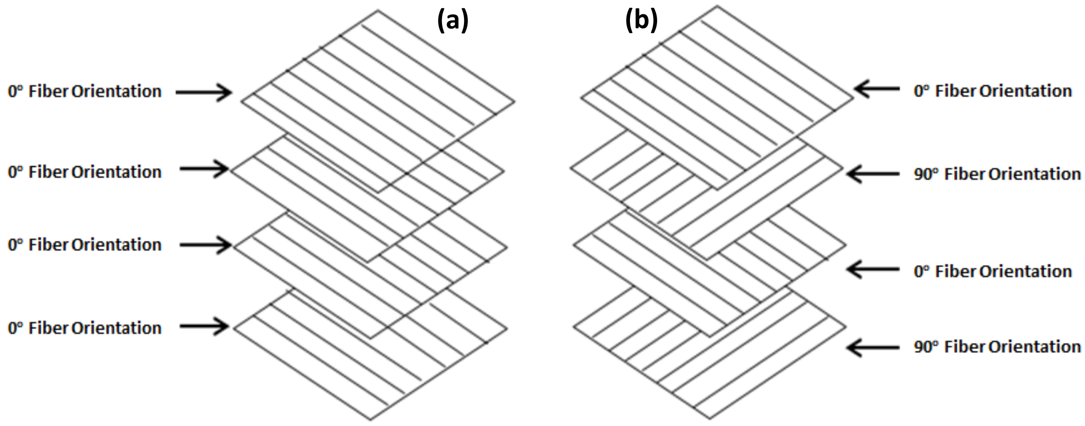

Figure 3. Fiber Orientation of Composites (a) EP/0/0PALF (b) EP/0/90PALF

RESULT AND DISCUSSION

Tensile Properties

Figure 4 shows a typical tensile stress versus tensile strain of EP/0/0PALF and EP/0/90PALF composites, while Table 3 summarizes the average values of tensile strength and tensile modulus of the composites. From Figure 4, it is obvious that the both average values of ultimate tensile strength (UTS) and tensile strain of EP/0/0PALF are greater than that of EP/0/90SPALF. This result was in accordance with the research of Lasikun et al [8] which stated that the 0° fiber orientation has the greatest elastic modulus compared to the 15°, 30°, 45°, 60°, 75°, and 90°. According to Figure 4, the initial curves of the two samples are linear (Hooke area). The EP/0/0PALF stress-strain curve is in concave shape, while the EP/0/90PALF stress-to-strain curve is in convex shape. The difference in this curve was caused by differences in the load distribution that occurred in the composite. This indicated the 90° fiber plays an important role when the load is applied in the 0° fiber (longitudinal) direction. The load distribution on the EP/0/0PALF composites was evenly distributed to the fiber direction, which is the same direction as the load. Meanwhile, on the EP/0/90PALF composites, the 90° fiber restrained the stress in the transversal direction.

Table 3. Tensile properties of pineapple leaf fiber/epoxy composites

Name of Sample	Average Tensile Strength (MPa)	Average maximum strain (%)	Average Tensile Modulus (GPa)
EP/0/0PALF	93.82 ± 22.48	7.49 ± 0.92	4.24 ± 0.83
EP/0/90PALF	51.90 ± 3.06	5.42 ± 0.76	3.35 ± 0.84

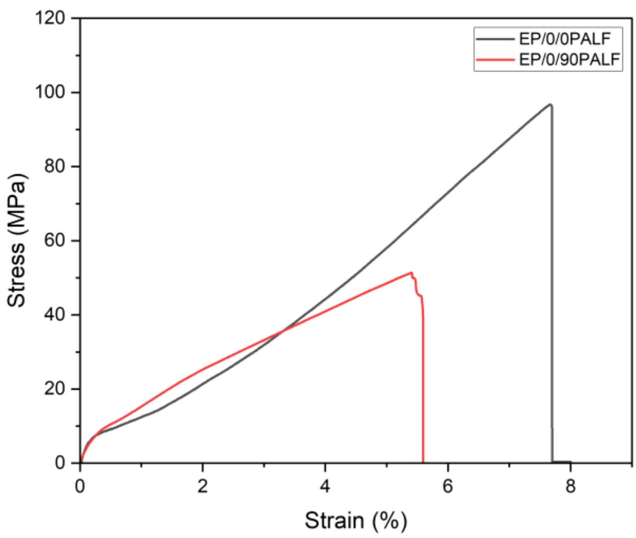

Figure 4. Tensile Stress-strain Curves of EP/0/0PALF and EP/0/90PALF Composites

Table 3 shows that the average ultimate tensile strength (UTS) of EP/0/0PALF and EP/0/90PALF composites were (93.82 ± 22.48) MPa and (51.90 ± 3.06) MPa, respectively. The average tensile modulus of the EP/0/0PALF and EP/0/90PALF composites were (4.24 ± 0.83) GPa and (3.35 ± 0.84) GPa, respectively. The ultimate tensile strength of EP/0/0PALF is higher than that of EP/0/90PALF. It proves that the arrangement of the fibers in the same direction as the loading direction increases the tensile strength of the composites. Tensile strength of composites decreases with increasing degrees of fiber orientation. These results were similar to the research conducted by Doddi *et al.* [7] regarding the effect of pineapple leaf fiber orientation in hybrid composites. In Doddi's research, composite with 0^o fiber orientation had the highest tensile strength and modulus with the values of 262 MPa and 10.9 GPa, respectively [7]. The difference in value is caused by the hybridization reinforcement of pineapple leaf fiber and basalt fiber. Composites that have a fiber arrangement in the same direction as the loading direction, the load is received by the matrix and passed on to the fiber easily. Table 3 also shows that the average maximum strain of EP/0/0PALF is greater by 38% compared to EP/0/90PALF, it was due to the EP/0/90PALF has a strain in transversal direction. The 90^o fiber caused the composite unable to stretch in the longitudinal direction.

Tensile Properties

Figure 5 shows a typical flexural stress versus flexural strain of EP/0/0PALF and EP/0/90PALF composites. Table 4 lists the average values of flexural strength and flexural modulus of composites. The average flexural strength and modulus of EP/0/0PALF were (109.57 ± 8.12) MPa and (7.08 ± 0.62) GPa, respectively, while EP/0/90PALF were (79.04 ± 24.20) MPa and (4.50 ± 1.29) GPa, respectively. EP/0/0PALF has 38% higher average flexural strength compared to EP/0/90PALF. This was because the direction of the fiber greatly affects the flexural strength of the composite as suggested by Doddi et al [7] who obtained the highest composite flexural strength at 0^o fiber orientation with a value of 292.23 MPa. Changes in the direction of fiber orientation affect the contact area between the matrix and the fibers which ultimately affects the effectiveness of the stress transfer between the matrix and the fiber [7]. The curvature of the EP/0/0PALF and EP/0/90PALF composites was similar because the load distribution to both the 0^o and 90^o fibers is the same. Based on Table 4, the maximum strain of EP/0/90PALF composites was slightly higher than that of EP/0/0PALF. This was due to both longitudinal and transversal fibers restrained similar load point so that both composites similarly stretched.

Table 4. Flexural properties of pineapple leaf fiber/epoxy composites

Name of Sample	Average Flexural Strength (MPa)	Average maximum strain (%)	Average Flexural Modulus (GPa)
EP/0/0PALF	109.57 ± 8.12	3.73 ± 0,23	7.08 ± 0.62
EP/0/90PALF	79.04 ± 24.20	4.34 ± 0,15	4.50 ± 1.29

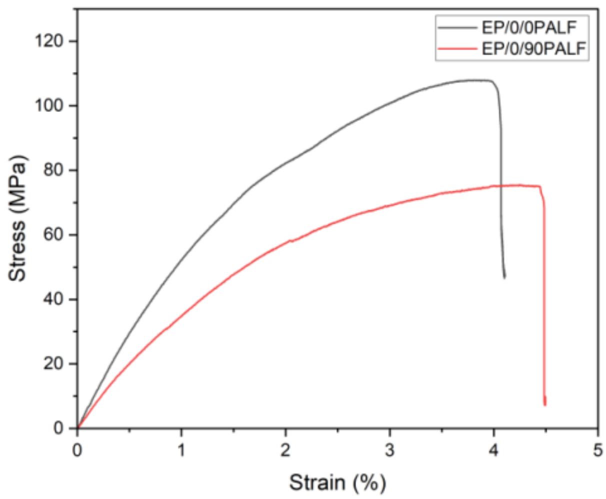

Figure 5. Flexural Stress-strain Curves of EP/0/0PALF and EP/0/90PALF Composites

Based on the results of the tensile and flexural tests, EP0/0PALF has tensile and flexural strengths of (93.82 ± 22.48) MPa and (109.57 ± 8.12) MPa, respectively. EP/0/90PALF has tensile and flexural strengths of (51.90 ± 3.06) MPa and (79.04 ± 24.20) MPa, respectively. The tensile and flexural strength values of EP/0/90PALF are lower than those of EP/00PALF because the 90° fiber which is transversely drawn. In the 0°/90°/0°/90° laminate, the 90° lamina withstands the greatest flexural load as shown in Figure 6 so that it relies on matrix bonds to withstand the load [13].

Comparing the values of tensile and flexural strength, as well as the tensile and flexural modulus, it is revealed that the flexural properties are better than the tensile properties for both composites. Moreover, the flexural modulus is almost twice higher than the tensile modulus of EP/0/0PALF composite (see Table 3 and 4). The flexural strain is almost half value of the tensile strain of both composites. This occurred because the 90^o fiber restrain the load that applied to the composites. From these two mechanical test results, it indicates that both composites performed well on the flexural properties.

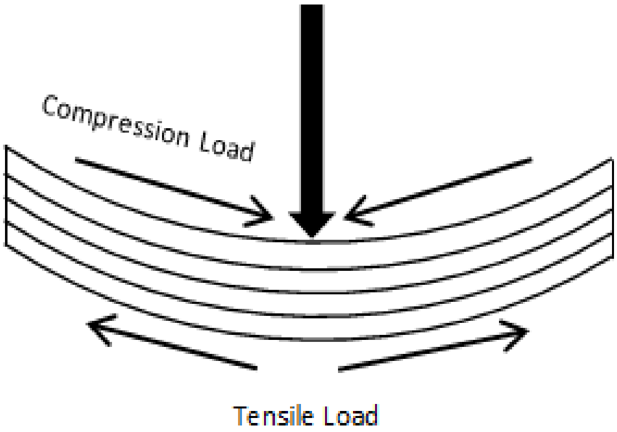

Figure 6. Flexural Test Scheme

Composite Density

Table 5 shows the density and void content of EP/0/0PALF and EP/0/90PALF composites. Referring to the Indonesian National Standard 01-4449-2006 for composite fiberboard, EP/0/0PALF and EP0/90PALF were categorized as T2 45 type high-density fiberboard because they had density greater than 0.84 g/cm^3 and flexural strength higher than 45 MPa [14].

The density of EP/0/0PALF composite is similar than that of EP/0/90PALF. The difference in the orientation of the fibers does not have a significant effect on the density of the composite. However the void content of EP/0/0PALF is lower than that of EP/0/90PALF. This slightly difference may occur due to the manufacture of composites using the hand lay-up method, which creates unevenness of the matrix applied to the fibers. The theoretical density of composite was obtained using the ROM method. The theoretical density is greater than the experimental density. This difference occurs due to the voids that were trapped during fabrication process (Table 5) [15].

Table 5. Density of pineapple leaf fiber/epoxy composites

Name of Sample	Experimental Density (g/cm^3)	Theoretical Density (g/cm^3)	Void (%)
EP/0/0PALF	1.18 ± 0.02	1.23	4.07
EP/0/90PALF	1.05 ± 0.06	1.23	14.63

Morphological Analysis

Figures 7 (a) and (b) show the SEM images of composite cross-sections before mechanical tests. It can be seen that on the EP/0/0PALF surface, pineapple leaf fiber was aligned in the 0° orienta-tion. Meanwhile, on the EP/0/90PALF surface, pineapple leaf fiber was completely arranged in the 0° and 90° orientations.

Figures 8 (a) and (b) exhibit the SEM im-ages of tensile fractured surfaces of EP/0/0PALF and EP/0/90PALF respectively. It is clear that the failure modes of EP/0/0PALF were fiber fracture and fiber pull-out. Some voids are also observed on the SEM images in Figures 8 (a) and (b). In addi-tion, it also can be seen that EP/0/0PALF had a good fiber-matrix adhesion. A few fiber pull-out and void cause the different values of theoretical and experimental densities. In the case of EP/0/90PALF, fiber pull-out, debonding, delamina-tion, and void were the main causes of failure dur-ing tensile load. As shown in Figure 8 (b), EP/0/90PALF composite had quite a lot of voids. It causes a lower composite density as shown in Ta-ble 5. The presence of voids can also cause debonding. Debonding will cause delamination. The difference in the composite failure mode may be due to differences in fiber orientation [16]. Therefore, it can be concluded that the tensile strength of EP/0/0PALF was higher than EP/0/90PALF.

Figures 9 (a) and (b) present the flexural fractured surface of EP/0/0PALF and EP/0/90PALF respectively. It can be seen that the failure modes of EP/0/0PALF were fiber fracture, fiber pull-out, and debonding, while the failure modes of EP/0/90PALF were fiber pull-out, debonding, and delamination. Delamination is usually found on the flexural fractured surface of composite with 0°/90° fiber orientation due to the shear stress that oc-curred during the test. High level of fiber pull-out in EP/0/90PALF results in poor flexural properties. Voids are also observed on both images and the presence of void confirmed by the values of densi-ties in Table 5. It can be observed that there was no matrix failure in the composites after the tensile and flexural tests. It indicated that the matrix can properly transfer the load to the fiber.

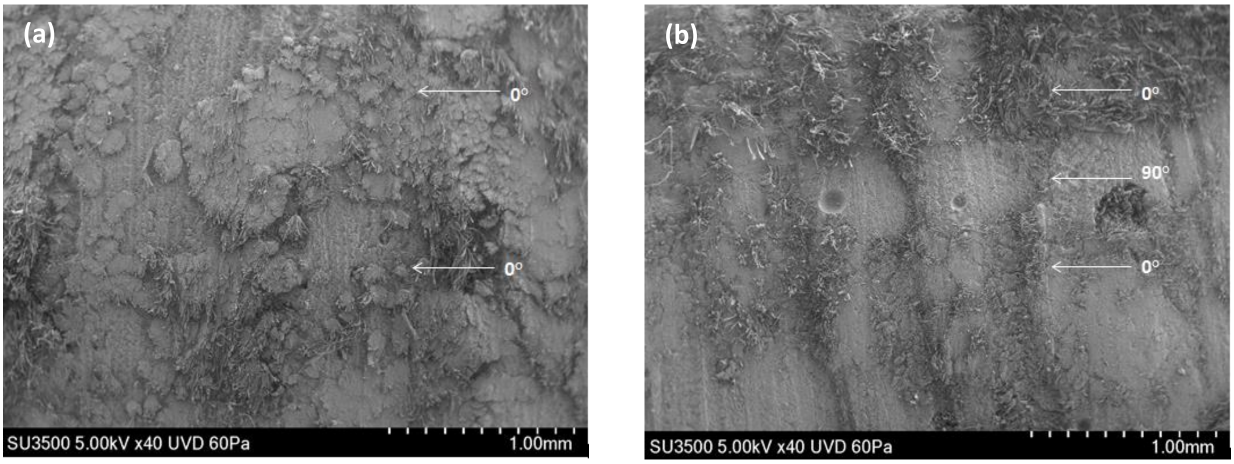

Figure 7. SEM micrographs of pineapple leaf fiber/epoxy composites before mechanical test (a) EP/0/0PALF, (b) EP/0/90PALF

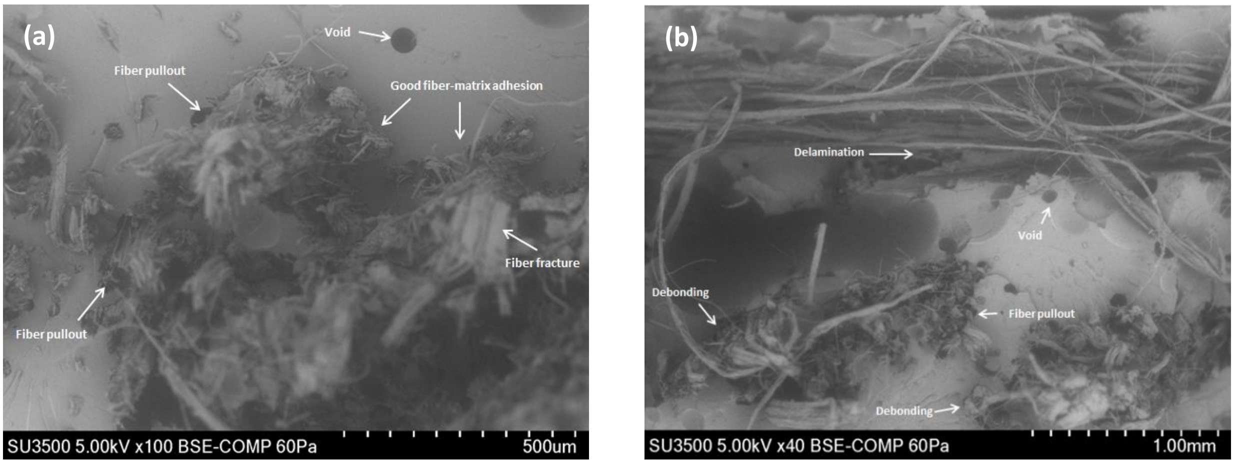

Figure 8. SEM micrographs of pineapple leaf fiber/epoxy composites after tensile test (a) EP/0/0PALF, (b) EP/0/90PALF

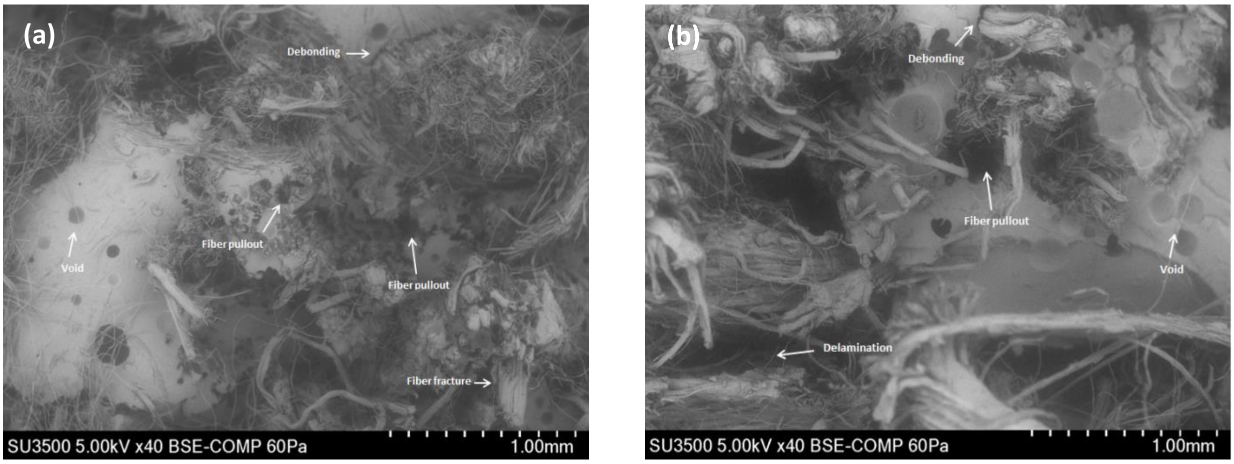

Figure 9. SEM micrographs of pineapple leaf fiber/ epoxy composites after flexural test (a) EP/0/0PALF , (b) EP/0/90PALF

CONCLUSION

Referring to Indonesian National Standard 01-4449-2006 for composite fiberboard, Subang pine-apple leaf fiber/ epoxy composites in both 0°/0°/0°/0° and 0°/90°/0°/90° arrangements were categorized as a T2 45 type high-density fiber-board. Comparing the values of tensile and flexural properties, the flexural properties are higher than the tensile properties for both composites. The val-ues of flexural strength and flexural modulus of the 0°/0°/0°/0° composite were higher than those of the 0°/90°/0°/90° composite, with the of values of (109.57 ± 8.12) MPa and (7.08 ± 0.62) GPa, respec-tively. The results were supported by Scanning Electron Microscope (SEM) observations of the composites which showed good fiber and matrix adhesion and few voids were observed on both composites.

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