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Research article

Investigation of the mechanical properties of bio-composites based on loading kenaf fiber and molding process parameters

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Abstract: We aimed to obtain the mechanical properties of the resulting bio-composite material. Mechanical properties of bio-composite materials are greatly influenced by the fiber content and molding process parameters used. We used kenaf fiber as reinforcement and epoxy resin as a binder. Molding parameters such as molding time, molding pressure, and molding temperature were implemented to get the best bio-composite material. We used two types of kenaf fibers at content of 20 wt.%, which consisted of long fiber (first filler) and short fiber (second filler) as reinforcement, at compositions of 10:10, 12.5:7.5, 15:5, and 17.5:2.5 based on weight percentage (wt.%), respectively. Our results showed that the fiber content and molding process parameters used had a significant effect on the resulting mechanical properties. The highest flexural strength value was obtained at a fiber content of 5 wt.%, amounting to 44.77 MPa. By applying the molding process parameters, the flexural strength value obtained was successfully increased up to 58 MPa at a molding pressure of 270 kg/cm^2. The scanning electron microscope (SEM) results showed that the fiber content of 5 wt.% could be distributed well throughout the matrix, as well as increasing the molding pressure successfully reducing the voids formed during the molding process of the resulting bio-composite material.

Keywords: mechanical properties; molding time; molding pressure; molding temperature; bio-composites

1. Introduction

Renewable energy and environmental impacts are major concerns for researchers in producing engineering products based on natural resources. Kenaf plants are among the natural resources used as reinforcement or filler for composite materials [1]. Kenaf is a light natural fiber that has the potential to be used as a filler in composite materials. The diameter of this plant can reach 2 to 4 cm in 2 months with a height of more than 2 meters [2]. However, the properties of natural fiber materials are highly depend on the content, type, shape of the fiber, and the matrix used as a binder [3]. Raja et al. [4] conducted research on the impact of kenaf fiber load and molding temperature with a chemical reaction to kenaf fiber, using polylactic acid (PLA) as a matrix. Woven kenaf fiber using alkaline chemical treatment is applied to get the best results. They found the optimum tensile strength and flexural strength to be 72.81 and 94.45 MPa respectively. This result was obtained at 35 vol.%, and molding temperature 170 °C. Optimizing the interfacial bond between fibers as reinforcement and polymer matrix as binder is the most important thing in formulating composites. The fiber-matrix interface is the area where two parts or phases move or react with each other. The adhesion of the fiber and matrix interface is a key factor in determining the mechanical properties of the resulting composites [5,6].

The inhomogeneous nature of natural fibers results in varying fiber quality. Poor mechanical properties, hydrophilic properties, incompatibility, aggregation tendencies in hydrophobic polymer matrices, water absorption behavior, poor thermal stability, and complicated processing capabilities are challenges when compared to synthetic fibers [7,8]. Different natural fiber positions will produce different mechanical and thermal properties of bio-composite materials [9,10]. Dispersion and distribution of fibers in the matrix are the most important challenges in producing bio-composite materials [11,12]. Experiments in improving mechanical properties (flexural strength, tensile strength, and impact strength) by combining different fibers, namely kenaf fiber, hemp fiber, and multiwall carbon nanotubes (MWCNTs), have also been carried out [13]. These experiments have shown that the mechanical properties produced were significantly influenced by the combination of fibers used. The best composition based on weight percentage (wt.%) for all mechanical properties tested (tensile, flexural and impact strength) was obtained at a composition of 11 wt.% hemp fibers, 14 wt.% kenaf fibers, and 0.5 wt.% MWCNTs. The maximum tensile strength obtained in this composition was 42.33 MPa. Davoodi et al. [14] used a combination of kenaf fiber and glass fiber as reinforcement in an epoxy matrix. The results obtained showed an increase in tensile strength exceeding 100% and flexural strength by 57%. However, the impact strength was found to be lower than glass mat thermoplastic (GMT) by 50% (25 J/m). Several other studies also found the same thing where a significant increase in mechanical properties was found using kenaf fiber as reinforcement and unsaturated polyester resin and epoxy resin as binders [15,16]. Research on the mechanical properties of composites using polypropylene (PP) and untreated kenaf fiber has been done. Research results show good thermal stability and increased tensile strength, with the highest value reaching 692 MPa. Based on the results obtained, they recommend the use of kenaf fiber as an alternative reinforcing material to produce automotive spare parts [17].

The behavior of alpha and gamma nano-alumina/epoxy composite materials regarding the mechanical properties produced using the vacuum-assisted resin transfer molding (VARTM) method has been studied [18]. They added nano alumina grade alpha and gamma 1 to 6 wt.% into the epoxy resin. They found maximum flexural and tensile modulus in alpha and gamma nano-alumina composite at 6, 4 wt.%, and 4, 5 wt.%, respectively. Moreover, the maximum toughness for alfa and gamma nano composites were obtained at 4 and 3 wt.% loading concentration. Xia et al. [19] conducted research on natural fiber composites for electromagnetic interference (EMI) shielding using VARTM and Cu film magnetron sputtering. They found that contact the angle increased from 49.6 to 129.5° after 0.5 h sputtering. When the coating time is increased to 3 h, the contact angle decreases to 51.0° as the surface roughness of the composite decreases with the increase in coating time. Rassmann et al. [20] investigated the mechanical properties and water absorption of laminated kenaf fiber reinforced polyester using resin transfer molding. They found that Processing conditions had little influence on the obtained mechanical properties except air pressure. At low fiber volume fractions, there is an increase in tensile and flexural strength and a decrease in water absorption. This is caused by failure lamination due to fiber pulling. The properties of the bio-composite material produced are greatly influenced by the reinforcing material type and the matrix used, as well as the composition of the matrix, reinforcement and the manufacturing process used. Although research in producing bio-composite materials using natural fibers as reinforcement is quite extensive and popular, the combination of different fiber lengths and orientations of kenaf fibers in the epoxy matrix has not been carried out. The novelty of this study is a bio-composite material produced using a combination of long fibers (horizontal direction) and short fibers (random direction) with a predetermined composition. A hot-press machine with variations in molding time, molding temperature, and molding pressure is used to produce bio-composite specimens. Therefore, an in-depth study is needed to determine how well this fiber pattern can be used to strengthen the resulting bio-composite material.

2. Materials and methods

2.1. Materials

The reinforcement material used is kenaf fiber (Grade B) with light brown color and humidity <12%, by Kenaf and National Tobacco Board (NKTB), Malaysia [21]. Epoxy resin is used as a binder at viscosity of 6 poise (635 thin epoxy resin) from US Composites with a ratio of epoxy resin to hardener of 3:1, as recommended by the manufacturer [22].

2.2. Fabrication of bio-composites

Fabrication of bio-composite consists of three stages. Stage 1, epoxy resin and hardener with a ratio of 3:1 as recommended by the manufacturer are stirred using (RW-IKA) at a speed of 200 rpm, 30 s. Stage 2, long fibers as the main reinforcement according to the length of the mold based on the standards used ASTM D 790 (flexural strength) and ASTM E 23 (impact strength) with the length of the first reinforcing fibers being 12 and 5.5 cm, respectively. In stage 3, the second kenaf fiber (3 cm length) as the predetermined loading concentration namely 2.5, 5, 7.5, and 10 wt.%, stir a mechanical stirrer with a rotational speed of 200 rpm and 30 s stirring time. Then, the resulting mixture is poured into molds and placed in a hot press machine with a variation molding time of 30, 45, and 60 min;

molding temperatures of 50, 70, and 90 °C; and molding pressure 170, 220, and 270 kg/cm^2. These molding parameters were determined based on the preliminary study. The preliminary study showed that the best temperature for producing bio-composites was above ambient temperature and slightly below 100 °C. Therefore, we used temperatures in the range of 50, 70, and 90 °C. Moreover, a higher molding pressure of 270 kg/cm^2 caused the mixture of epoxy resin and kenaf fiber to overflow from the mold. Thus, it was determined to use molding pressures of 110, 220, and 270 kg/cm^2 in the fabrication process. Illustrations of the fabrication process and composition of first fillers and second fillers based on weight percentage (wt.%) of the bio-composites material are shown in Figure 1 and Table 1, respectively.

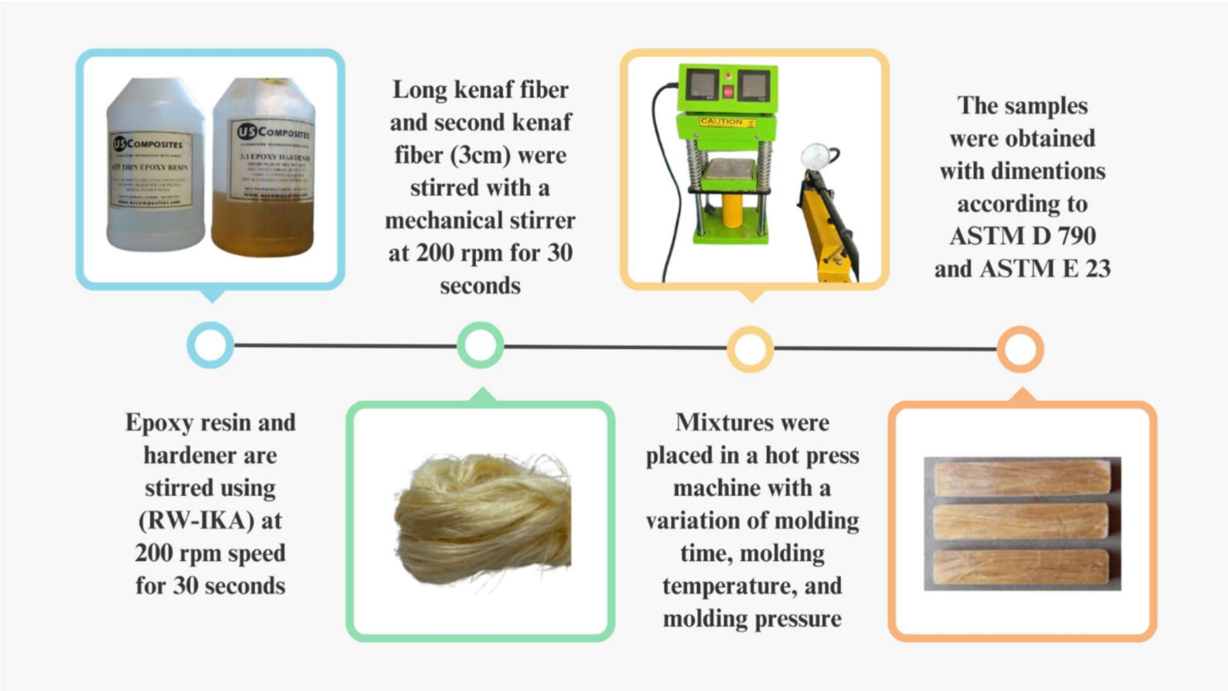

Figure 1. Illustrations of the fabrication process of bio-composites.

Table 1. Composition of bio-composites based on weight percentage (wt.%).

	First kenaf fiber (long fiber)	Second kenaf fiber (short fiber)	Epoxy
Bio-composites	17.5	2.5	80
	15	5	80
	12.5	7.5	80
	10	10	80

2.3. Characterizations

The characterization carried out on the resulting bio-composites material were flexural strength, impact strength, shore hardness, and scanning electron microscopic (SEM) image. For flexural strength testing using ASTM D 790 standard, Universal Testing Machine (UTM) made in Italy, Cesare Galdabini Gallarate Machine brand, while impact strength testing using ASTM E 23 standard. Flexural strength test using specimens with dimensions of 12 × 2.5 × 0.6 cm^3 and dimensions of 5.5 × 1 × 1 cm^3 for impact strength test. Both measurements were conducted at room temperature. A crosshead speed of 1 mm/min is used in the flexural strength.

The flexural and impact strength values obtained are an average of 3 tests for each predetermined content and molding process parameters. Moreover, the shore hardness value for bio-composite materials is the average of 5 tests carried out on the composition and molding process parameters that have been determined. To see the dispersion and distribution of reinforcing fibers in the epoxy matrix, SEM (JSEM-6510 LA) was used on the fracture surface of the test specimen with magnification 100× and 500× for each content of the bio-composite material obtained.

3. Result and discussion

3.1. Loading of kenaf fiber on bio-composites

The amount of reinforcing material in the matrix significantly influences the mechanical properties of the resulting bio-composite material [3,23]. Figure 2a shows the effect of kenaf fiber addition as second kenaf fiber on the content of 2.5, 5, and 7.5 wt.% up to 10 wt.% of the flexural strength and shore hardness of kenaf fiber bio-composites.

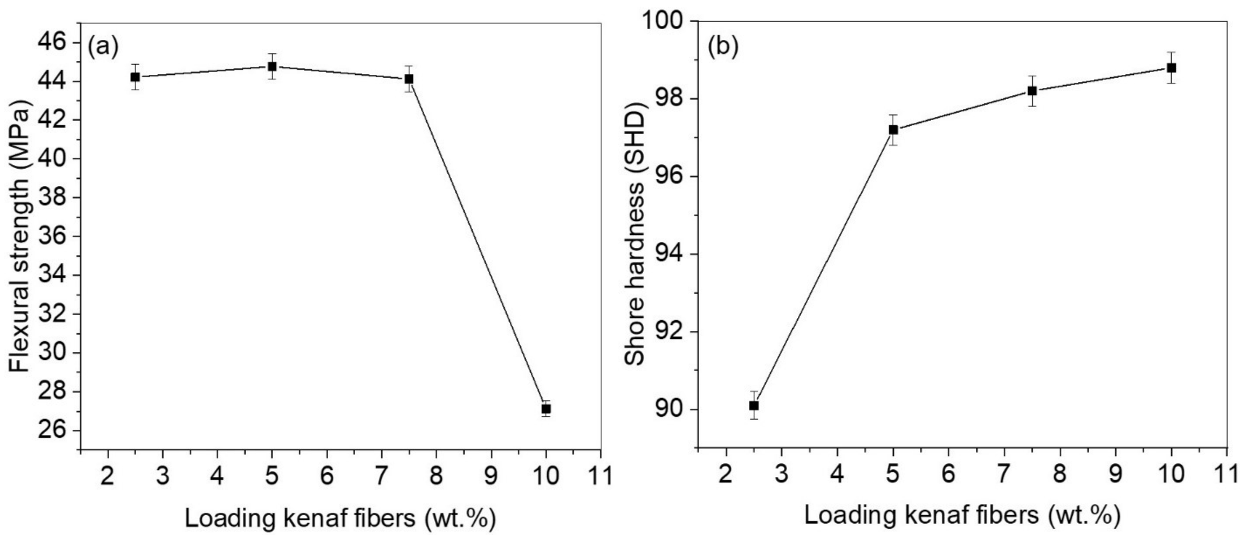

Figure 2. Loading of second kenaf fibers on (a) flexural strength; and (b) shore hardness.

Flexural strength at fiber content of 2.5 and 5 wt.% shows a slight increase, namely 44 and 44.77 MPa. At a fiber content of 7.5 wt.%, the value of flexural strength obtained tends to decrease. A drastic decrease occurs at a fiber content of 10 wt.% from the highest value obtained at a fiber content of 5 wt.% (44.77 MPa) to 27 MPa. This is because at a fiber content of 10 wt.%, kenaf fiber can fill only part of the matrix, so that the matrix cannot bind the reinforcement (kenaf fiber) properly [2,24]. Significantly different results were seen in the effect of loading concentration of fiber on shore hardness (see Figure 2b). The shore hardness value increases as the fiber content in the epoxy matrix increases. The shore hardness value was successfully increased from 90.1 shore hardness (SHD) at 2.5 wt.% to 97.2 SHD at a fiber content of 5 wt.%. The shore hardness value continues to increase slightly from 97.2 SHD (7.5 wt.%) to 98.8 SHD at a fiber content of 10 wt.%.

Figure 3 shows SEM images of bio-composites at 100 and 500× magnification at 5 and 10 wt.% of second filler content. Figure 3a shows that kenaf fiber with red circle can fill the matrix, although some voids are formed during the molding process. The yellow circle provides information that at 5 wt.% kenaf fiber is pulled out of the epoxy resin at the fracture surface. Higher magnification (500×) shows that short kenaf fiber (3 cm) can fill part of the long fiber (12 cm long), although voids are clearly visible (green circle) during the molding process as shown in Figure 3b. This is supported by SEM images in Figure 3c, showing that 10 wt.% kenaf fiber has more voids compared to 5 wt.%. The large number of voids results in a significant decrease in flexural strength. Therefore, the best flexural strength value for the bio-composite material produced is obtained at a composition of 5 wt.%.

The results obtained were used as an initial design to determine the fiber content that will be used on further research. Because the fiber content of 5 and 10 wt.% show significant differences trend in flexural strength and shore hardness values, the following researchers used fiber content of 5 and 10 wt.% kenaf fiber to investigate three parameters of the molding process used in producing bio-composite materials, namely molding time, molding pressure, and molding temperature.

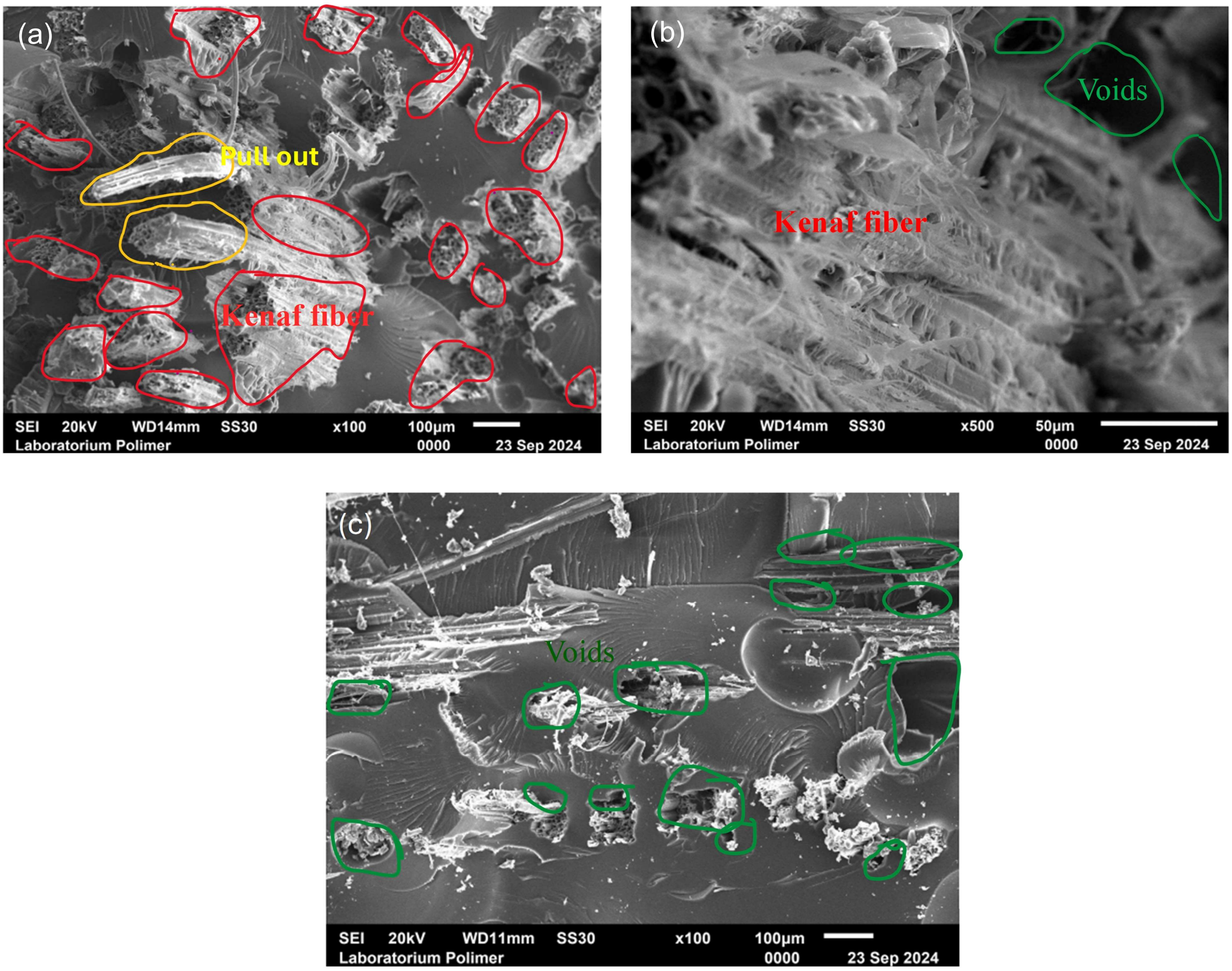

Figure 3. SEM images of second kenaf fiber in bio-composite material: (a) 5 wt.%, 100×; (b) 5 wt.%, 500×; and (c) 10 wt.%, 100×.

3.2. *Effect of molding time on bio-composites*

Molding time is an important molding process parameter in producing quality bio-composite materials because the amount of reinforcing material used in the matrix influences the molding time required [6,25]. Figure 4a shows the effect of molding time on flexural and impact strength for compositions of 5 and 10 wt.% bio-composite material. In both compositions, the flexural and impact strength values have the same trend, namely an increase in mechanical properties with an increase in molding time from 30 to 45 min molding time. The highest flexural strength value was obtained from a composition of 5 wt.% kenaf fiber with a value of 54 MPa with a molding time of 45 min. Increasing the molding time to 60 min resulted in a decrease in the flexural strength value to 42.5 MPa. The results obtained are close to the tensile strength value of the bio-composite obtained at a composition of 10 wt.% which requires a molding time of 60 min, namely 43 MPa. This proves that the reinforcing material content in the matrix has a significant effect on the molding time required to produce bio-composite materials [17,26]. In contrast to the flexural strength values, the impact strength of bio-composites in both compositions (5 and 10 wt.%) increased significantly with the increasing molding time from 30 to 60 min. The highest impact strength value was obtained at a composition of 5 wt.% of 625 J/m^2 with a molding time of 60 min. At the same molding time (60 min), a different composition, namely 10 wt.%, the impact strength value at different composition obtained was much lower, namely 350 J/m^2 (see Figure 4b). This condition is caused by the kenaf content, as reinforcement (10 wt.%) is unable to be completely bound by the epoxy resin as a matrix [6,27].

In contrast to the flexural and impact strength values obtained, the best shore hardness values were obtained at a content of 10 wt.% kenaf. Trend of shore hardness value bio-composites material obtained for both kenaf contents (5 and 10 wt.%) (Figure 4c) is the same, with decrease at a molding time of 45 min but increase at a molding time of 60 min. The highest shore hardness value was 99 SHD at 10 wt.% content and 98.2 at 5 wt.% fiber content. This condition is caused by the distribution of fiber with a higher fiber content (10 wt.%) in the matrix which has the potential to be better in filling the matrix [2,15].

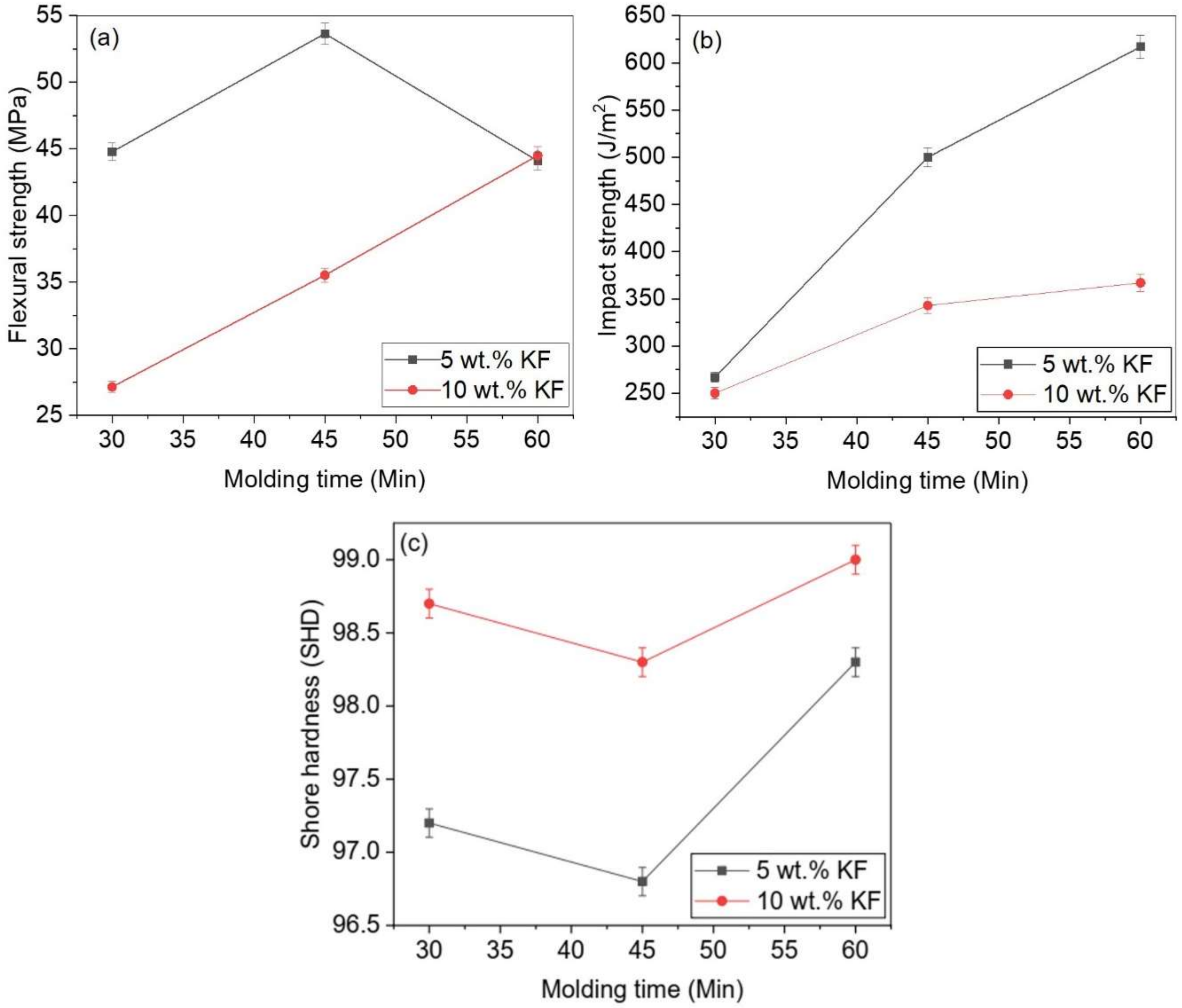

Figure 4. Effect of molding time on (a) flexural; (b) impact strength; and (c) shore hardness of bio-composites.

3.3. Effect of molding pressure on bio-composites

Molding pressure is needed to produce dense bio-composite material with a small number of voids, or if possible, no voids [4,27]. The effect of molding pressure of 170, 220 and 270 kg/cm^2 used to produce bio-composite material with two different fiber contents (5 and 10 wt.%) is shown in Figure 5. Figure 5a shows that increasing molding pressure results in an increase in flexural strength values for both fiber contents (5 and 10 wt.%) of the bio-composites material produced. The highest flexural strength value was obtained at a fiber content of 5 wt.% with a value of 58 MPa, whereas at a content of 10 wt.% with the same molding pressure (270 kg/cm^2) a lower flexural strength value was obtained, namely 45 MPa. The value obtained was slightly smaller (44.5 MPa) at a lower molding pressure of 220 kg/cm^2 at both kenaf fiber contents (5 and 10 wt.%). This happens because increasing pressure will increase density and reduce the number of voids formed during the molding process of bio-composite materials [1,21,22]. This result is also proven by the SEM image results for both fiber content (5 and 10 wt.%) and different molding pressures, namely 170 and 270 kg/cm^2 as shown in Figure 6. The SEM image in Figure 6a shows that a 5 wt.% second kenaf fiber at a molding pressure of 170 kg/cm^2

produces relatively fewer voids than 10 wt.% (Figure 6b). Increasing the molding pressure from 170 to 270 kg/cm^2 for both second kenaf fibers contents effectively reduces the number of voids formed.

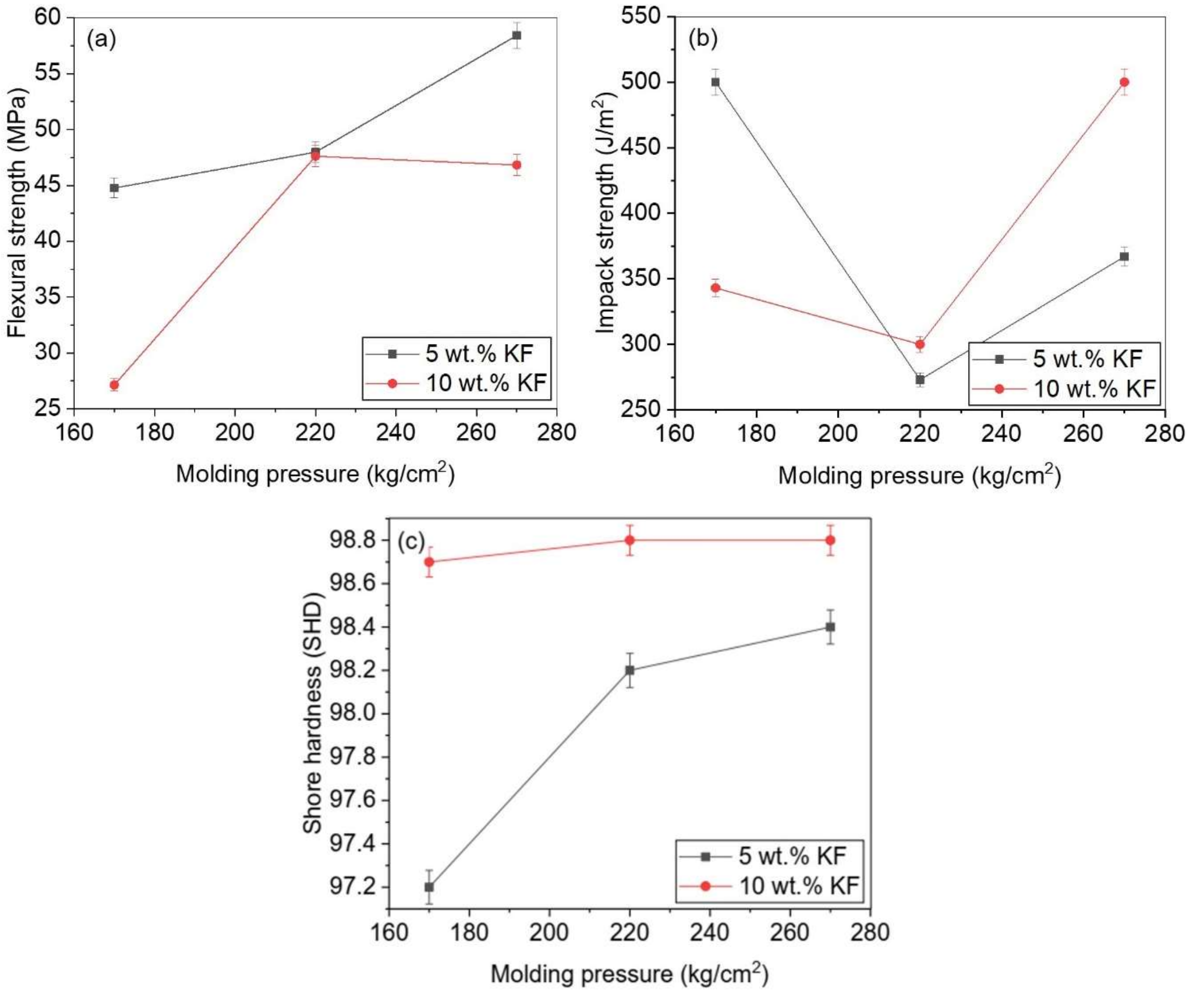

Figure 5. Effect of molding pressure on: (a) flexural; (b) impact strength; and (c) shore hardness of bio-composites.

In contrast to the flexural strength values obtained, the impact strength values of the bio-composites materials produced have a unique trend, where increasing molding pressure from 170 to 220 kg/cm^2 results in a significant decrease in impact strength values. At higher molding pressure (270 kg/cm^2), the impact strength value of the resulting bio-composites material shows the highest value of 490 J/m^2 at a fiber content of 10 wt.% and 375 J/m^2 at a fiber content of 5 wt.% as shown in Figure 5b. Almost the same trend as the flexural strength value, but at different fiber contents is shown in Figure 5c. The highest shore hardness value was obtained at a molding pressure of 270 kg/cm^2 at a fiber content of 10 wt.% (98.8 SHD), while at the same molding pressure with a fiber content of 5 wt.% a shore hardness value of 98.4 SHD was obtained. This proves that the suitability of pressure molding for the resulting mechanical properties is really depend on the fiber content and matrix used as a binder [15,28].

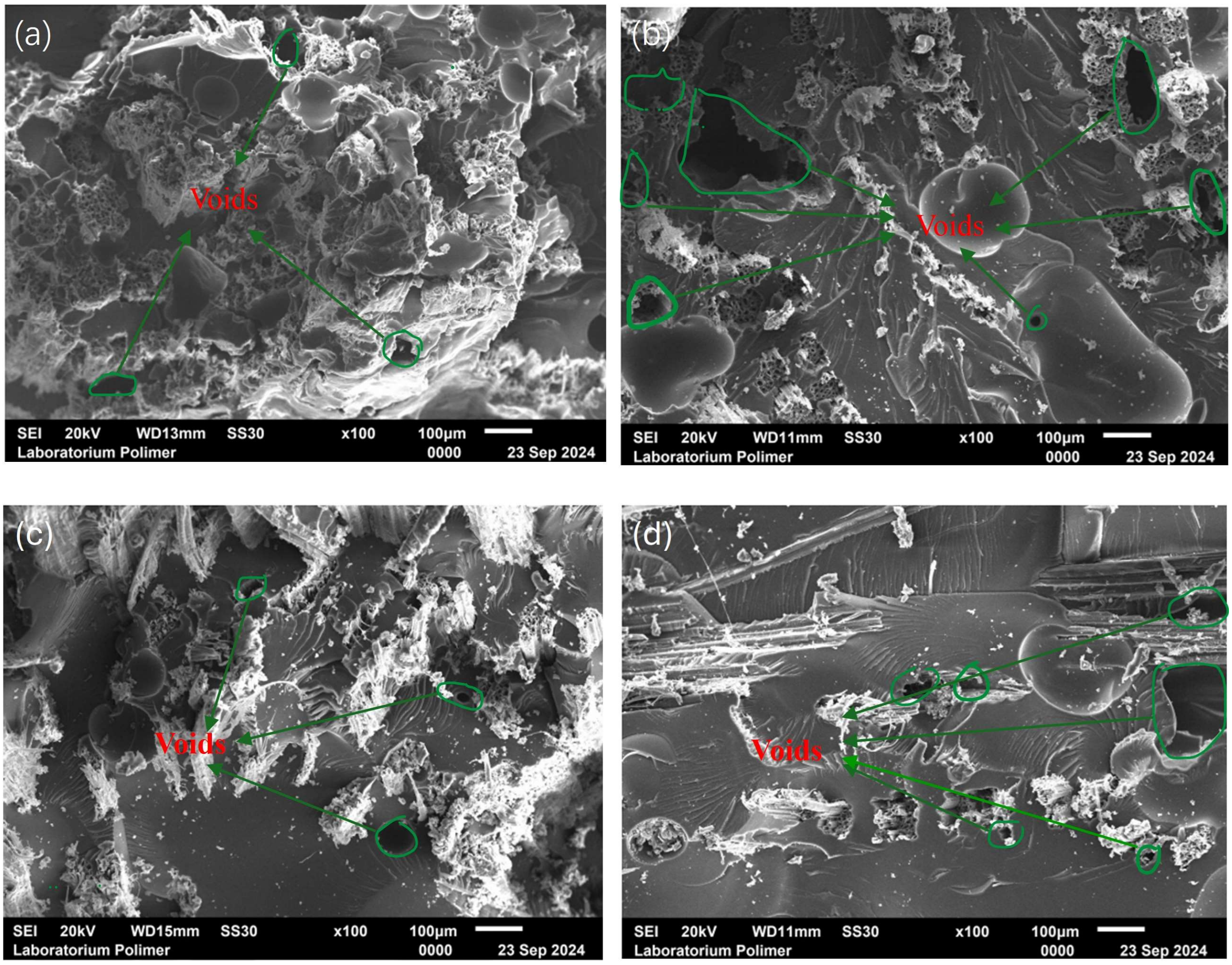

Figure 6. SEM images of molding pressure for both bio-composites material. (a) 5 wt.%; (b) 10 wt.% at molding pressure 170 kg/cm^2; (c) 5 wt.%; and (d) 10 wt.% at molding pressure 270 kg/cm^2.

3.4. Effect of molding temperature on bio-composites

Molding temperature is a molding process parameter that needs to be considered in producing good bio-composite materials, because it will be influenced by the amount of filler content in the matrix [29–31]. Figure 7 shows the effect of molding temperature on flexural (Figure 7a), impact strength (Figure 7b), and shore hardness (Figure 7c) at a content of 5 and 10 wt.% kenaf bio-composite. The content of 5 wt.% bio-composite kenaf fiber shows that increasing the molding temperature in the molding process of bio-composite material from 50, 70, and 90 °C produces decrease flexural strength values, from 44, 41, and 32.5 MPa as shown in Figure 7a. In contrast, to the content of 5 wt.%, at a content of 10 wt.% the flexural strength decreases from 50 to 70 °C molding temperature, namely 44 and 43 MPa, but increases at a molding temperature of 90 °C, namely 45 MPa. This condition confirms that the molding temperature used affects the fiber content in the matrix used as a binder [30,31].

The variation of molding temperature on the impact strength value shows a trend that is almost the same as the flexural strength (see Figure 7b). At a content of 5 and 10 wt.% fiber bio-composite material, lower impact strength values are produced with increasing molding temperature from 50 to 70 °C, and at higher molding temperatures (90 °C), the resulting flexural strength values increased for both bio-composites material compositions. In terms of shore hardness, increasing the molding temperature produces opposite shore hardness values for both fiber contents of 5 and 10 wt.% (Figure 7c). At a fiber content of 5 wt.%, increasing the molding temperature from 50 to 70 °C results in an increase in the shore hardness value from 96.8 to 98 SHD. Increasing the molding temperature to 90 °C does not affect the shore hardness value obtained, which is the same as the molding temperature of 70 °C (98 SHD). However, at a content of 10 wt.%, an increase in molding temperature produces a lower shore hardness value from 98.3 SHD at 50 °C to 97.3 SHD at a higher molding temperature (90 °C).

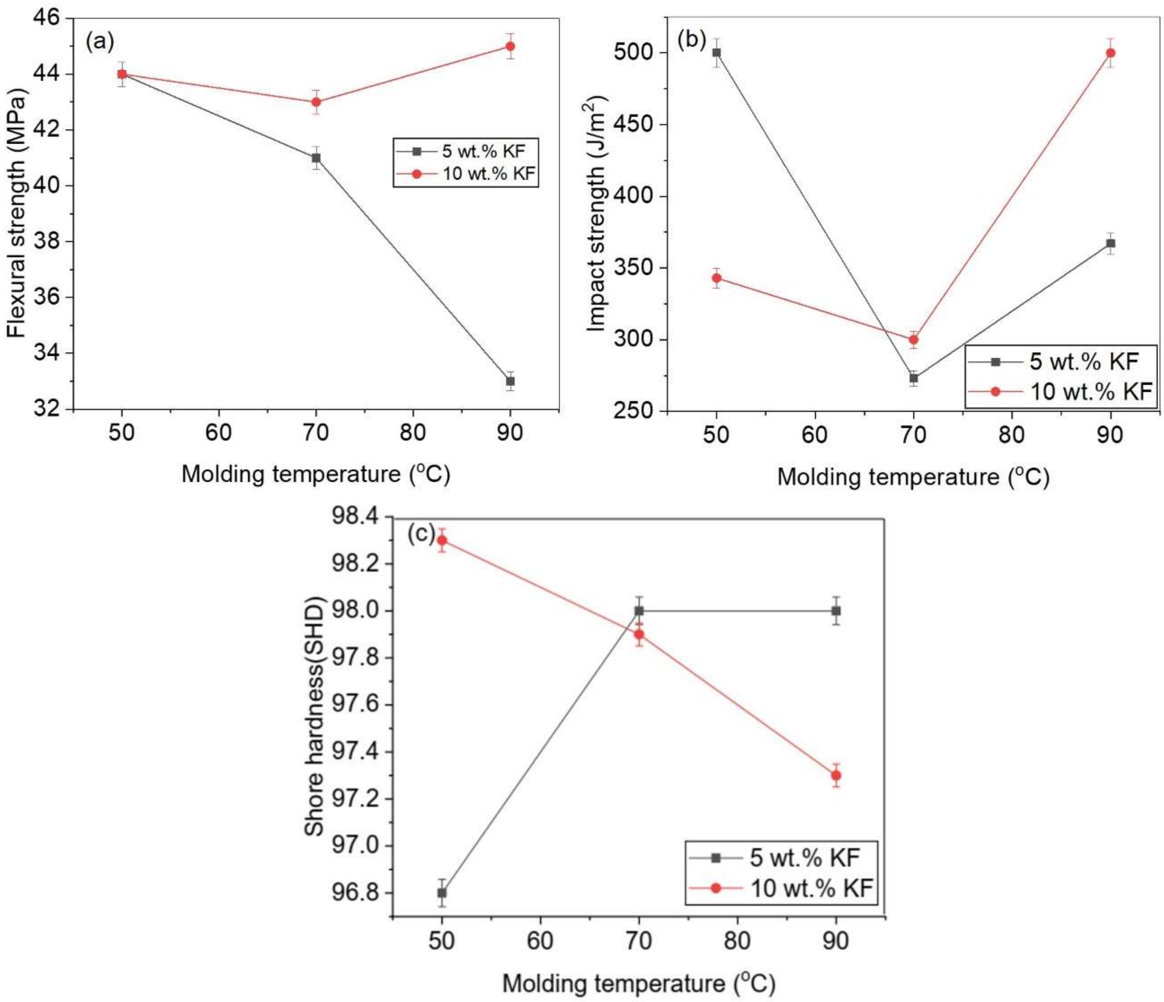

Figure 7. Effect of molding temperature on (a) flexural strength; (b) impact strength; and (c) shore hardness of bio-composites.

4. Conclusions

Molding process parameters such as molding time, molding pressure, and molding temperature have been used to produce bio-composite materials. The results obtained can be concluded as below:

1. The content of kenaf fiber as a reinforcement has a significant effect on the mechanical properties produced.

2. The highest flexural strength was obtained at 5 wt.% second fiber content with a molding pressure of 270 kg/cm^2 of 58 MPa.

3. SEM image shows that kenaf fiber at 5 wt.% content can fill the entire matrix well, resulting the best flexural strength values.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Author contributions

Hendra Suherman and Yovial are involved in conceptualization, methodology and calculations, writing original draft, resources, funding acquisition. Jarot Raharjo and Afdal Zaky are involved in review and editing and discussion. Talitha Amalia Suherman and Irmayani are involved in methodology and validation. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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