Effect of kenaf short fiber loading on mechanical properties of biocomposites

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Abstract. The research of biocomposite product with kenaf (Hibiscus cannabinus) short fiber as a filler and Acrylonitrile Butadiene Styrene (ABS) as the matrix had been done to understand the mechanical properties of this material. Kenaf short fiber was obtained from mechanical sieving after doing the mechanical milling. TAPPI method has been done to determine the chemical properties. In order to form a granular biocomposite a single screw extruder was performed with a variation of particle loading 10 and 15%. The original of acrylonitrile butadiene styrene (ABS) has been used as matrix. The fabrication of specimen had been done by molding injection process. Mechanical properties test was done by ASTM standarization. The results showed the density of the fibers of 1.008 g/cm³ with a fiber length of 897.07 µm and a diameter of 66.38 µm. Tensile strength of kenaf short fiber loading 10 and 15% was 23.522 ± 8.36 MPa and 20.739 ± 6.79 MPa, respectively. The tensile properties showed a decreasing trend as the fiber loading was increased. The values of impact strength were 68.657 ± 4.89 kJ m⁻² and 82.090 ± 5.56 kJ m⁻², respectively and the hardness values were 96.60 ± 6.03 HR and 105.20 ± 13.17 HR, respectively. Kenaf fiber can be a good reinforcement candidate for high performance polymer bio-composites.

1. Introduction

In recent years, natural fiber composite has attracted attention in the sector of composite application. This composite provides many advantages compared with synthetic fibers such as low density, abundance, lower cost, renewable, and biodegradable [1,2,3]. The contents of natural fiber are generally composed of cellulose, hemicellulose, and lignin. One of fiber plants that contain high cellulose is kenaf [4]. Kenaf (Hibiscus cannabinus) is a species of plant that is easily cultivated in tropical region such as Indonesia. It has short growing season (3-4 months) and long stem of approximately 4 m. Kenaf fiber utilization in Indonesia is still limited as a material for rope and burlap sack but nowdays it has replaced by plastic thus the economic’s value of kenaf fiber are decreasing. One way to increase the economic’s value of kenaf fiber is its utilization as a filler material in a composite.

Utilization of kenaf fiber as filler composite material has been researched and applied in industry. Recently, there are some observation report in various condition to make an optimum kenaf fiber composite. For example, Edeerozey et al. [5] dan Nosbi et al. [6] reported some microstructural image of kenaf fiber to examine the surface morphology. Morphological microscopic analysis of the fiber surface is very important to describe the structural changes that occur in the treatment. Edeerozey et
al. [5] shows that the surface morphology of untreated and treated kenaf fiber have some differences in the features of smoothness and roughness of the surface. Jonoobi et al. [7] characterized kenaf (Hibiscus cannabinus) nanofiber which was obtained from the unbleached and bleached pulp isolation with a combination of chemical and mechanical treatment.

The kenaf nanofiber was characterized by using environmental scanning electron microscopy (ESEM) and transmission electron microscopy (TEM). Thermogravimetric analysis (TGA) showed that both types of pulp and nanofiber have a higher thermal stability than the raw kenaf. Fourier transform infrared (FTIR) spectroscopy also showed that the content of lignin and hemicellulose decreased during the pulping process while lignin was almost lost during bleaching. Liu et al. [8] observed the effect of processing methods and fiber length on biocomposite soy based kenaf fiber.

On the other hand, thermoplastic materials, Acrylonitrile butadiene styrene (ABS) is an important engineering copolymer widely used in industry due to superior mechanical, chemical resistance, ease of processing and recyclability [9]. ABS has wide application and because of that there is a great need to develop material using ABS polymers. Therefore, in this study ABS was used as a matrix polymer to compound with the kenaf fiber for the purpose of manufacturing the biocomposites. The addition of kenaf fiber on ABS polymer and reuse into biocomposite products will increase the economic value of the two materials. Fiber loading can affect mechanical properties of polymer composites. The opportunity to design composite with specific mechanical properties makes this subject become great interest to be observed. This research aims to study the effect of kenaf short fiber loading on the mechanical properties of biocomposites. Biocomposites with filler kenaf short fiber are expected to have superior quality due to its ability to protect the matrix of cracks in composite application.

2. Material and Method

2.1. Materials

Fresh stem kenaf was obtained from kenaf plantation in PT Global Agrotek Nusantara, Pekanbaru, Sumatera, Indonesia. Kenaf fibers with a length of 4 m was obtained by soaking dynamically in water for 2 weeks and then sun dried. Furthermore, kenaf fiber were cutted with a uniform length, ie ± 1 cm and oven dried (Tipe YNC-OV, YENACO, China) at 40 °C for 24 h until a constant weight. The dried kenaf was taken from oven then milling mechanically until totally smooth by using a milling tool (Model MDY-1000, FOMAC, China). After milling, the sample was sieved by using 20 mesh sieve. In this study, the sample used was a sample that passes 20 mesh (short fiber). The Original Acrylonitrile Butadine Styrene (ABS) polymer was imported from Malaysia.

2.2. Chemical Properties of Kenaf Fiber

Chemical composition of kenaf fiber was determined by using TAPPI test standart. Five measured chemical composition have been evaluated, such the cellulose, hemicellulose, holocellulose, lignin and extractive content.

2.3. Density Test

The basic method to calculate the kenaf fiber density is by Archimedes law, as :

\[
\rho = \frac{m_1}{(m_1-m_2)} \times \rho_{\text{water}}
\]

(1)

where \( \rho \) denotes material density (g/cm\(^3\)), \( m_1 \) was the initial mass during exist in air (g), \( m_2 \) is the final mass when treated in water (g), and \( \rho_{\text{water}} \) denotes water density (g/cm\(^3\)).
2.4. Fiber Dimension and Morphology Structure of Biocomposite
Dimension of kenaf fiber was calculated from images captured by a light microscope (Model BX51, Olympus, Japan) combined with the software Olympus DP2-BSW and DP25 Olympus Microscope Camera. The biocomposite morphology structure was observed under the light microscope.

2.5. Preparation of Biocomposite
Granular biocomposite was formed by the mixing of kenaf short fiber as a filler, ABS polymer as a matrix, maleic acid as coupling agent and primary antioxidant with the compositions that showed in Table 1.

| Sample  | Kenaf Short Fiber | Original ABS Polymer | Additive | Compatibilizer Maleic Acid |
|---------|------------------|----------------------|---------|---------------------------|
| KSF10%  | 10 %             | 2000                 | 87 %    | 17400                     | 1%    | 200  | 2%    | 400   |
| KSF15%  | 15 %             | 3000                 | 82 %    | 16400                     | 1%    | 200  | 2%    | 400   |

All sample were fabricated with the single screw extrusion (Model HXSJ-125/125, Kai Xin, China) with a total mass of 20,000 g. The next stage was to create a standard American Society of Testing Material (ASTM) test pieces by molding injection (Model HC-250, Hwa Chin, China). As much as 5 kg samples of granular biocomposite were put into the hopper of molding injection then preheating in 60 °C. Heating barrels of molding injection was done in 5 zones (120 °C - 200 °C).

2.6. Mechanical Test
The resulting test piece was tested in mechanical properties based on ASTM standarization. Tensile test specimen were made in accordance with ASTM D-638 to measure the tensile properties. The samples were 164 mm long, 13.05 mm wide and 4.02 mm thick. Izod impact test specimens were prepared in accordance with ASTM D-256 to measure the impact strength. The specimens were 64 mm long, 13 mm deep, and 10 mm wide. A sharp file with angle of 45º was drawn across the centre of the saw cut at 90° to the sample axis to obtain a consistent starter crack. Hardness test specimen were prepared in accordance with ASTM D-785 to measure the Rockwell hardness number. The samples were 49 mm and diameters 6.03 mm thick.

3. Results and discussion
3.1. Density and chemical composition of kenaf fiber
Testing the density can be done with reference to the law of Archimedes where objects that are partially or wholly in the fluid always gets the upward force of weight of the fluid displaced. The tools used to perform this test is a technical balance and water as media controls. The density of the kenaf fiber is 1.008 g/cm³. In Table 2, it is presented kind of carbohydrate component contents and the standard methods that we used. The plant cell wall is composed of cellulose, lignin, hemicellulose, holocellulose, and the extractives. Thus, the surface energy of the plant material must be some combination of the surface energies (γ) of these components (Liu and Rials, 1998). Therefore, quantitative amount of these components especially in the surface of fiber will influence the properties of the fiber biocomposites.
Table 2. Chemical composition of Kenaf fiber

| Content        | (%)  |
|----------------|------|
| Cellulose      | 66.47|
| Lignin         | 2.39 |
| Holocellulose  | 75.43|
| Hemicellulose  | 9.43 |
| Extractive     | 2.11 |

3.2. Fiber dimension and morphology structure of biocomposite

The average of kenaf short fiber dimension was length 897.07 µm and diameter 66.38 µm with aspect ratio 13.50. Figure 1 showed the morphology structure from biocomposites, where the image can be seen that there are pores in biocomposites. This was due to the absence of additional alkali in the synthesis process of kenaf fiber up to that pores still contained in biocomposites.

Figure 1. The observation of morphology structure of biocomposites used light microscope (a) Kenaf Short Fiber Loading 10% (b) Kenaf Short Fiber Loading 15%

3.3. Mechanical properties of biocomposite

Both of the matrix and the fiber properties are important in improving mechanical properties of the biocomposites. The chemical coupling method is also one of the important chemical methods, which improve the interfacial adhesion. In this method the fiber surface was treated with a compound which able to form a chemical bonds as bridge between fiber and matrix [10]

3.3.1 Tensile strength

Young’s modulus is also called the modulus of elasticity (E). The key is to know the difference between elastic and plastic deformation. Young’s modulus describes the relationship between stress and deformation of materials. Analytical model for the modulus of elasticity was derived from the Hooke Law and can be calculated by dividing the stress with strain. It is given as [11]:

\[ E = \frac{\sigma}{\varepsilon} = \frac{F/A_0}{\Delta L/L_0} = \frac{F}{A_0\Delta L} \]

where E is modulus of elasticity (MPa). E is a direct measurement of the strength of the electron bonds between atoms/molecule. It indicates how much the force is required to stretch these bonds (without breaking then and without moving atoms / molecules around). From the definitions of stress and strain, we should see that stress corresponds to load and strain corresponds to extension. Variabel F and ΔL obtained from experimental data. Dimensions of the specimen is constant, L₀ (gauge length = 50 mm) and A₀ = w.h, where w is the width of the plate = 13.05 mm and h is the plate thickness = 4.02 mm.
The value of tensile strength, modulus of elasticity and ductility which can be seen in Table 3.

| Sample   | Ultimate Tensile Strength (MPa) | Modulus of Elasticity (MPa) | Ductility (%)  |
|----------|--------------------------------|-----------------------------|----------------|
| KSF 10%  | 23.522 ± 8.36                  | 439.94 ± 26.48              | 4.50 (brittle) |
| KSF 15%  | 20.739 ± 6.79                  | 408.67 ± 18.32              | 3.50 (brittle) |

Based on observations of test piece fracture after tensile testing known that the fracture was shaped pull out (due to withdrawal of fracture where it appears fibers) and broken fiber. Generally, the fiber composite was practically elastic influenced by the pull. Fiber-matrix interactions did not occur at the atomic level where the fiber harder and rigid compared to matrix so that its mechanical properties depend on the interface strength of the fiber and matrix.

The orientation also affected to tensile strength randomly oriented fiber had small reinforcement that there was no transfer stress. The more elasticity of sample that given more tensile force to. KSF 10 and 15% was brittle due to the deformation less than 5%.

Fiber loading of bio-composite also influence the value of tensile strength. As seen in Table 3 that the higher fiber loading given tendency to decrease the value of tensile strength. This due to at the synthesis of kenaf fiber without addition alkali treatment so that in granular biocomposite there was pores which due to the tensile value decreases. In addition, natural fiber composites were anisotropic high maximum properties would be achieved when the entire fiber aligned in the direction of the axis of the fiber.

### 3.3.2 Impact strength

The value of impact strength was energy total that can be absorbed by materials result of sudden imposition which was the materials deformed. The Impact energy can be calculated using the equation below:

$$\Delta E = Wl (\cos \beta - \cos \alpha)$$

Where $\Delta E$ was total energy absorbed (kJ), W was weight of pendulum (N), $\alpha$ the initial angle (°) and $\beta$ was the end angle (°). To determine the impact strength ($I_s$) so the total energy absorbed divided by cross-sectional area of specimen (A), which was described in the equation below:

$$I_s = \frac{\Delta E}{A} = \frac{Wl (\cos \beta - \cos \alpha)}{A}$$

$I_s$ was the impact strength (kJ m$^{-2}$)

| Sample   | Impact Strength (kJ m$^{-2}$) | Impact Energy (J) |
|----------|-------------------------------|-------------------|
| KSF 10%  | 68.657 ± 4.89                 | 0.223             |
| KSF 15%  | 82.090 ± 5.56                 | 0.255             |

Table 4 shows that kenaf short fiber loading in as balance as the impact strength. The higher of fiber loading, so the higher of impact strength.

### 3.3.3 Hardness

Effect of kenaf short fiber loading on hardness was tested. The result show that the number of Rockwell of biocomposite increase since the loading of kenaf short fiber which can be seen in Table 5. The increase of fiber loading properties means proper interaction between the fibers and matrix mutually helped in the transfer of load from latter to the former [12].
Tabel 5. The results of hardness test

| Sample    | Rockwell Hardness Number (HR) |
|-----------|-------------------------------|
| KSF 10%   | 96.60 ± 6.03                  |
| KSF 15%   | 105.20 ± 13.17                |

4. Conclusions
The effect of fiber combination of Original ABS polymer as a matrix on mechanical properties like tensile strength, impact strength and hardness behavior were studied. The results of mechanical properties test of biocomposite was influenced by the kenaf short fiber loading. The tensile properties showed a decreased trend as the fiber loading was increased. As the kenaf short fiber loading increased in the biocomposites, the value of impact strength and Rockwell hardness number also increased.

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