Mechanical Properties and Morphological Characterisation of Waste Natural Fiber Composites Reinforced Polyester: Gelam (Melaleuca Leucadendra)

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Abstract. The mechanical (tensile, flexural, and impact) tests and morphology observation were investigated on Natural Fiber Composites (NFCs) formed by strengthening Gelam as a fiber into the polyester as a resin matrix. The samples were prepared up to a maximum volume fraction of 0.70 from the fibers in powder form, hand lay-up method, and compared with pure Gelam and pure polyester. The synthesis results indicate for adding Gelam fiber in volume fraction that the optimum composition is at the addition of 0.70 fiber, with a tensile strength of 14.77 MPa, bending strength of 53.12 MPa, and the impact strength of 755.48 MPa. It was investigated that the impact strength and tensile strength of Gelam-polyester composite increase compare to pure Gelam. However, the result of flexural strength is decreased that can be associated with many factors such as incompatibility between matrix and fiber, instability of the hand lay-up method.

1. Introduction
The combination of two materials including reinforcing and matrix phase defines as a composite. The reinforcing phase form of sheets, particles, or fibers and is embedded with the matrix phase. Both the reinforcing and the matrix can be multiphase metal alloys, ceramics, or polymers [1]. Composites frequently have a fiber phase that is stronger than the continuous matrix phase [2]. Lately, wood and natural fibers have become engineering and commercial interest to produce new classes of NFC. The interest in NFC is developing very fast both in terms of industrial applications and fundamental research. Scientists and technology experts have been interested in natural fibers for applications in consumer goods, cheap housing and other civil structures [3].

Natural fiber reinforcements have exhibited proper results in fatigue strength and impact toughness. Their availability, renewable power, low density, economic aspect, and satisfying mechanical properties make them become ecologically attractive. Natural fibers consist of cellulose, hemicellulose, lignin, wax, and some water-soluble compounds. The main components are cellulose about 60% until 80%, hemicellulose about 5% until 20%, lignin, and moisture about 20% [4]. Natural fiber reinforced polymer composite materials grow well in terms of their industrial applications and fundamental research. Plants such as hemp, flax, cotton, sisal, kenaf, pineapple, bamboo, banana, and wood are used a long time ago as sources of lignocellulose fibers [5]. The use of NFCs related the short palm lignocellulose tree fiber as the reinforcing phase in the polyester and epoxy matrix has been
reported [6]. The results of tensile strength showed that composites with treated fibers did not have significantly different properties on untreated fibers and the impact results showed that treatment with H_2O_2 allowed an increase in the impact resistance of polyester resin composites with fiber. That experiment had a ratio of 10% fiber by weight. Palm betel composites were prepared in a form that is not treated and treated with different fiber volumes up to 9% [7]. The flexural properties and impact strength of palm betel composite increased with the addition of fibers up to 7 vol.% and a decrease in flexural properties were observed in 9 vol.% fibers. Composites made from polyester by combining elephant grass fibers were extracted by different processes with and without treatment investigated for tensile properties [8]. Previous research showed that the chemically extracted tensile strength and modulus of composite elephant grass fiber had increased 1.45 times compared to elephant grass fiber composites extracted by retting. It was concluded that there was an effect of adding fiber volume from NFC and chemical treatment with reinforcement phases in polyester.

Gelam or (Melaleuca Leucadendra), one of NFCs, are found in peat swamp forests that affected by the tidal ebb and flow in Kalimantan. This wood has good strength and durability. It commonly used as a support buffer, firewood, wood charcoal and bridge floor (particle board). The potential of Gelam in Kalimantan is abundant thus the price is still affordable. This is the main reason why Gelam is highly used in the most common industrial [9]. However, the utilization of Gelam produces considerable waste as well. Gelam waste is usually wasted away without any utilization, causing the accumulation of waste that could potentially aggravate the aesthetics of the environment. Therefore, one of the utilization of wood waste is done with composite synthesis using waste with the polyester mixture. Polyester is used because of its cheap price with good characteristics as a matrix. Polymers are mostly chosen because of their easily fabricated, light, strong, and corrosion resistance. Using a reinforcing fiber to produce unsaturated polyester composites definitely enhances the tensile and flexural properties. Inorganic fillers are mostly used to enhance stiffness and to lower cost [10].

Hence, the overall objective of this paper is to provide the mechanical property profiles of the NFCs material by varying the volume fractions of fiber by measuring the tensile strength, bending strength and impact strength. Additionally, there’s a lack study about NFCs using waste Gelam reinforced polyester. Experimental in this study is a tensile test using ASTM D638 standard, bending test using ASTM D790 standard and impact test using ASTM D6110 standard. Unsaturated polyester used in this study. The addition of Gelam’s fiber is with variations of 0, 10, 30, 50, and 70 wt.%.

2. Materials and Method

2.1 Materials

The unsaturated polyester resin (Yukalac 157-BQTN, Indonesia) and catalyst methyl ketone peroxide (MEKPO, Indonesia) were supplied by UD, Mahakam Fiber Glass Samarinda. The waste of Gelam, shaped powder mode, obtained from the timber industry. The Gelam fiber was formed into powder using a crab machine with 30 mesh.

2.2 Extraction of fibers

Gelam is cleaned from the epidermis and sticking dirt. The wood is formed into a powder. The Gelam powders are dried to reduce water content. Furthermore, the fiber is sieved according to the specified size and weighing of the fiber material that is carried out with digital scale in accordance with the specified volume fraction. The extraction of NFC was explained in the earlier work [11].

2.3 Composite preparation

In this study, the NFC of Gelam-polyester was prepared by the hand-lay-up method. The waste of Gelam fiber in the form of powder dried for three days then sifted with the size of 30 mesh. The sieved
fiber will be inserted into the plastic site to be weighed according to the volume fraction used. Fiber and volume configuration are the two most important factors that affect composite properties. The volume fraction of the fiber used is 10% by weight, 30% by weight, 50% by weight and 70% by weight. The composite manufacturing process begins the fibers are mixed with polyester and stirred until well blended or homogenate. The mixture is given by catalyst as much as 8-10 drops to enhance the reaction. Further, the mixture is poured into the molded specimen and dried at room temperature. Molds are coated with aluminum foil for easily removable composite.

2.4 Testing of composites

The mechanical test of the samples was done by three tests consist of: tensile test with ASTM D638 standard, bend test with ASTM D790 standard and impact test with ASTM D6110 standard. All tests based on ASTM (American Society for Testing and Materials) International. For the tensile test, each composite specimen was prepared by mounting on a tensile test specimen prints with a gauge length, width, and overall length of 50, 19, and 165 mm respectively. Three equal samples were prepared for each volume fraction.

Three until five-point bend tests were prepared to measure flexural properties. The samples dimensions were 128 mm long, 25 mm wide, and 4 mm thick. The flexural strength was calculated. Tensile test and bend test were tested in the pharmaceutical department of Airlangga University, Indonesia. The impact test serves to determine the toughness of the composite made. Testing was carried out by one sample for each volume fraction in Kalimantan Institute of Technology, Indonesia.

2.5 Microscope analysis

In this study, micro observation uses an optical microscope. This measurement aims to monitor the distribution and dispersion of fibers as reinforcement NFCs and polyester on the tensile specimen after testing. In addition, the indications can be accessed through fiber withdrawal seen during testing.

3. Result and Discussion

3.1 Tensile properties

Figure 1 shows an increase slightly in composite tensile strength in the addition of volume fraction. Composites with Gelam powder filler at 70 wt.% have the highest tensile strength. The volume fraction of fiber influences the interaction between matrix and filler. Where the inter-phase reaction will increase with the higher volume fraction of fiber in the composite that makes the interaction between the filler and matrix relative strength. The highest value obtained by the composite filler powder which volume fraction of 70 wt.% with tensile strength value of 14.77±2.58 MPa. While the pure polyester has the lowest value of 5.43±0.09 MPa. Other values are 6.52±0.94 MPa, 13.11±3.97 MPa, 14.59±1.31 MPa, and 14.65±1.13 MPa for pure Gelam, 10 wt.% fiber, 30 wt.% fiber, and 50 wt.% fiber respectively. The optimum fiber volume fraction, 70 wt.% fiber, improve almost three times greater than the original materials both pure Gelam and pure polyester. It seems the enhancement reached the top on 70 wt.% fiber indicated by small increase from 50 wt.% fiber to 70 wt.% fiber.

It is indicated that the tensile strength of the natural fiber polymer composites, in this case, Gelam-polyester is depended on fiber volume fraction. The composite of Gelam-polyester indicated stronger than the pure Gelam and pure polyester in tensile properties. The tensile strength enhances with enhancing fiber weight ratio up to 70 wt.% If the fiber weight ratio enhances going to the optimum limit, a load is distributed to more fibers, which are well bonded with resin matrix resulting in better tensile properties [12]. This new investigation revealed just only without chemical treatment. In the further experiment, the examination about adding chemical treatment could be conducted to analyze
the effect of tensile properties. In addition, the study about a fiber particle size of Gelam wood in composite should be done in the future to ensure the effect of size and distribution.

Figure 1. The tensile strength of pure polyester, pure gelam, and polyester-powder (volume fraction 10 wt.%, 30 wt. %, 50 wt.%, 70 wt.%)

3.2 Flexural properties

In this study, this test uses a load of about 1100 kN. The bending test has function to know the elasticity of the composite. Flexural strength is one of mechanical property material that defined as the stress just previously it yields in a flexure test. The flexural strength performs the maximum stress experienced at the material at its moment of yield.

Figure 2. Bending strength of pure polyester, gelam, polyester-powder (volume fraction 10 wt.%, 30 wt. %, 50 wt.%, 70 wt.%)

Figure 2 shows the value of bending strength with the various volume fraction of Gelam fiber. The results showed that the bending strength of the composites was lower than the ingredients (118.32±25.8 MPa for pure Gelam and 82.24±7.83 MPa for pure polyester). The highest value from the composite is 53.12±17.4 MPa with 70 wt.% volume fraction. Fluctuating values in the test results can also show that the increase in volume fraction does not affect the increase in bending strength. In general, Gelam-polyester shows worse mechanical properties than the pure polyester and pure Gelam. However, in this study, the neat 10 wt.% volume fraction composites of flexural strength (47.82±5.93 MPa) was higher than 30 wt.% volume fraction (33.6±8.85 MPa) and 50 wt.% volume fraction composites (36.24±10.6 MPa) and this may be associated with the composites preparation process as well as incompatibility between the fiber and chosen matrix whereby plant fiber is hydrophilic but polyester is hydrophobic in nature. In addition, the decrease of composite strength with increasing
fiber volume fraction can be associated with many factors such as incompatibility between matrix and fiber, improper manufacturing processes, fiber degradation and others [13]. Manufacture process and fiber distribution factors may cause a decrease in the elasticity value of the manual hand-lay-up composite. This is because when the process of making composite materials with a manual hand-lay-up method, there will be a tendency of the fiber to gather at a certain point and uneven fiber distribution. Using spray-lay-up method should be recommended for a further experiment to compare the fiber distribution with a hand-lay-up method.

3.3 Impact properties

In this study, the impact test was conducted at the Study Program of Materials and Metallurgical Engineering, Kalimantan Institute of Technology, Indonesia. Impact test has a function to know the toughness of the composite. The optimum value of impact strength was found on pure Gelam of 955.43 MPa and composite with filler powder at a volume fraction of 70 wt.% is 755.48 Mpa. Figure 3 shows the increasing volume fraction of fibers causes increased composite resistance to a shock load. This probably due to the high interfacial bonding between the fiber and the matrix. The higher the value of its impact strength, the higher the value of its toughness [14]. In this research, the value of composite impact strength is lower than the impact strength of pure Gelam but higher than the value of the impact strength of polyester.

![Figure 3. Impact strength of pure polyester, gelam, polyester-powder (volume fraction 10 wt.%, 30 wt.%, 50 wt.%, 70 wt.%)](image)

3.4 Microscope analysis

Microstructure observations in this study used optical microscopes in the Study Program of Materials and Metallurgical Engineering, Kalimantan Institute of Technology, Indonesia. The analysis took after the tensile test. This observation aims to analyze the distribution of fibers in a microstructure and see the presence of fiber pull out in the composite. From some of the images below, there are research specimens that show fiber pullouts.

Figure 4(a) is a view of a fractured specimen of a pure polyester specimen. From the appearance, it appears that the dark color is a resin while the little white one is a reflection of the light of resin. The fracture is a type of ductile fracture because it does not indicate the presence of fibers in the fracture pattern. The fracture seems to absorb the light that showed darker appearance. In addition, the fracture indication of the polyester matrix maintains the ductility in NFCs. The magnification used in taking this picture is a 10 times magnification.

Figure 4(b) is the presence of a fractured composite reinforced 10 wt.% fiber specimen. In the picture, fiber powder is gathered at one point. The bond between the matrix and the filler is good.
because it does not indicate the fiber pull out. The fracture type is brittle and besides reflect the light. Magnification used in the shooting is 10 times magnification.

Figure 4(c) is a view of a composite powder-reinforced composite of 70 wt.%. The picture below was taken with a 10 times magnification. In the picture, it can be seen that the fibers in the form of powder gather at several points. This indicates that the fibers are not spread evenly. This indicates the interaction between the Gelam fiber as a reinforced and polyester as a matrix. When the fiber builds up, the distribution became more irregular. Uneven distribution of fiber will result in not optimal strength produced. It probably due to the method that used in this experiment. The fiber randomizes and spread in several points. The strength was resulted in not balanced condition. The tensile strength composite of 70 wt.% fiber should higher than current research if the distribution of fiber is homogenous in every side position. The better method in manufacturing composite is required in the future experiment. The further study needs Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Diffraction (XRD) to observe chemical properties and phase identification.

Figure 4. Fiber dispersion in samples after tensile test with 10x magnification of (a) pure polyester, (b) Gelam-polyester at 10 wt.%, and (c) Gelam-polyester at 70 wt.%

4. Conclusion

The average tensile strength of Gelam-polyester composite at the highest volume fraction of fiber in the present study is much higher than that of pure Gelam and pure polyester. As the volume fraction of fiber increases in the composite, the specific tensile strength of Gelam-polyester composite is increased in the present study. The highest value obtained by the composite filler powder which volume fraction of 70 wt.% with tensile strength value of 14.77±2.58 MPa. In the flexural properties, the effect of adding volume fraction of fiber decrease the flexural strength of Gelam-polyester composite. The decrease of composite strength with increasing fiber volume fraction can be associated with many factors such as incompatibility between matrix and fiber, improper manufacturing processes. While the properties composite of impact strength is lower than the impact strength of pure Gelam but higher than the value of the impact strength of polyester. The optimum value of impact strength was found on the composite with filler powder at a volume fraction of 70 wt.% with 755.48 MPa. In a microscope, observation indicates there is an interaction between the Gelam fiber as a reinforced and polyester as a matrix after increasing fiber content in Gelam-polyester. The morphology analysis indicates the distribution between Gelam fiber and polyester in a composite.

5. References

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