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FABRICATION OF FUNCTIONALLY GRADED NATURAL FIBRE/EPOXY CYLINDER USING CENTRIFUGAL CASTING METHOD

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ABSTRACT

In this study, functionally graded natural fiber/epoxy (FGNF/epoxy) hollow cylinders are fabricated using the centrifugal casting method. The natural fiber (NF) used is banana trunk. Due to difference in density of NF and epoxy causes the NF particles in the epoxy liquid moves to the outside radius of the mold during casting. As a result, the hollow cylinders of FGNF/epoxy with different natural fiber content along the cylinder thickness are produced. NF is mixed with epoxy at three different fiber compositions which is at 2.5, 5 and 7.5 mass %. As the reference, the epoxy cylinder without fiber was fabricated. Three different speed rotating mold, i.e. 1145, 1187 and 1240 rpm are studied. In order to characterize the FGNF/epoxy cylinders fabricated, the hardness, density and compression test are carried out. Moreover, the microstructures of the FGNF/epoxy cylinders fabricated are observed using optical microscope. From the results, it is found that the NF particles can be graded from inner to outer surface of the FGNF/epoxy cylinders by centrifugal casting. The graded distribution in the FGNF/epoxy cylinders is significantly affected by the mold rotation speed and NF composition. Based on the result, the higher value of hardness, density and strength along the cylinder are located from the outer surface reduce gradually to the inner surface. It is because the NF composition of the outer was higher than that at the inner surface. In conclusion, it appears that FGNF/epoxy with a gradient in NF composition is superior to the homogeneous composite.

Keywords: functional graded material, centrifugal casting, natural fiber.

INTRODUCTION

A recent year, the natural fiber (NF) is a quite new material in the various applications such as construction and building industry compared to concrete and steel (Azwa & Yousif, 2013). Natural fibers can be obtained directly from an animal, vegetable, or mineral source and convertible into non-woven fabrics such as felt or paper or, after spinning into yarns, into woven cloth (Sivaraj & Rajeshkumar, 2014). Natural fibers present advantages such as low density, appropriate stiffness and mechanical properties, good thermal and high disposability and renewability (Samrat *et al.* 2008; Ticoalu *et al.* 2010). Plant fiber is a natural fiber and can be classified into four types such as seed, bast, fruit and leaf fibers, depending upon the source (Saheb & Jog, 1999; Bongarde & Shinde, 2014).

Natural fiber is an alternative material have been proven and emerged as a substitute to the glass-reinforced or carbon reinforced polymer composites because these fibers have serious drawbacks such as not environmentally friendly and greenhouse effected (Al-Oqla & Sapuan, 2014; Garcia-Espinel *et al.* 2015). Reduced use of carbon and glass fiber can improve our quality environment and extend the life span of natural fibers.

Functionally graded materials (FGM) refer to the varying composition resulting in changes material properties (Kieback *et al.* 2003). FGM can be produced, whether by heat treatment or combination material (Udupa *et al.* 2014; Yu *et al.* 2013). A composite is a material made from two or more different constituent materials having different physical or chemical properties which do not merge in the finishing structure (Bhanot & Singh, 2013). The concept of FGM was first introduced in Japan. The material produced has specific functions and applications such as advanced aircraft and aerospace engines to computer circuit boards (Tarlochan, 2012; Aboudi *et al.* 1999). The concept of FGM structures can be produced through a variety of processes. The concept of FGM structures can be produced through a variety of processes such as approaches process particle processing, processing bodies, processing layer and centrifugal casting processing (Mahamood *et al.* 2012).

Centrifugal casting is one of the techniques to obtain the graded structure in composite material (Stabik & Dybowska, 2007). The casting process has been mainly used for obtaining thin-walled cylinder part. It is famous for high quality products mainly control the exact metallurgy and crystal structure. There are essentially three basic types of true centrifugal casting machine such as the horizontal type which rotates about a horizontal axis, the vertical type, which rotates about a vertical axis and inclined centrifugal casting (Wei & Lampman, 2008). Horizontal centrifugal casting machines are generally used a pipe, tubes, bushing and cylindrical casting that are simple in shape. The application of vertical centrifugal casting machines is considerably wider: gear blanks, pulley sheaves, wheels, impeller, plug, brackets and electric motor rotors (Rajeswari *et al.* 2014).

In this study, the cylinders FGNF/Epoxy are produced by horizontal centrifugal casting method with the purpose to investigate the effect of material composition and mold rotating speed on the microstructure and mechanical properties of FGNF/Epoxy. The centrifugal force applied to a mixture of the molten

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polymer and reinforcement particle under differential speed rotation. The particles are arranged gradually along the radial direction (centrifugal direction) due to the density difference between the molten polymer and reinforcement particle. According to Stabik & Dybowska (2007), the centrifugal casting is an effective method to fabricate the FGNF/epoxy cylinders. The hardness, density and compression test are carried out to determine the mechanical properties of the cylinder fabricated.

METHODOLOGY

The centrifugal casting methods are used to produce cylinder FGNF/Epoxy. There are several processes that need to be conducted in fabricating the specimen. Firstly, the alkaline treatment process for natural fiber. The treatments are intended to remove a certain amount of lignin, wax and oils covering the external surface of the fiber cell wall. The fibers are immersed in sodium hydroxide (NaOH) with ratio 1:10 of water for 24 hours. Then, the fibers are rinsed with clean water to remove dirt and chemical solutions and dried in an oven for 12 hours at temperatures of 50 °C. After dried, the fibers are crushed using a grinder machine to get average fiber length of 5 mm. The procedure of the treatment process is shown schematically in Figure-1. Meanwhile, the composition of natural fibers (banana trunk) and epoxy is shown in Table-1.

Figure-1. Fiber treatment process; a) immersed in NaOH solution, b) dried in oven, c) banana fiber after drying and d) banana fiber after crushing.

Table-1. Material composition.

Specimen	Banana trunk fiber (%)	Epoxy (%)
A	0	100
B	2.5	97.5
C	5.0	95.0
D	7.5	92.5

The NF and epoxy are weighed using the digital weighing scales before homogeneously mixed by stirred manually. The mixture of NF and epoxy is then poured into rotating mold. The wall of cylindrical mold was covered with wax as a release agent before casting. It was found that the time between mixing and pouring the composition should not be longer than 20 minutes to avoid the mixture not able to flow into the mold. After pouring, the mold is kept rotates for two hours before the specimen can be removed from the mold. The outer surface of the specimen was shaped by the mold surface, while the inner surface of the specimen shaped by centrifugal force and gravity. Figure-2 shows a schematic diagram of horizontal centrifugal casting equipment.

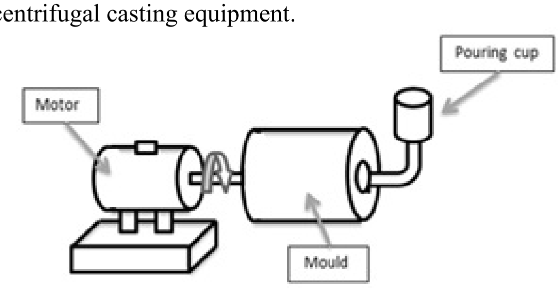

Figure-2. Horizontal centrifugal casting schematic.

In this study, the specimens were fabricated by centrifugal casting under different rotating speed. Three different rotating speeds used are 1145, 1187 and 1240 rpm to fabricate FGNF/Epoxy cylinder with different composition of natural fiber and epoxy. Figure-3 shows the procedure of specimen preparation in schematically.

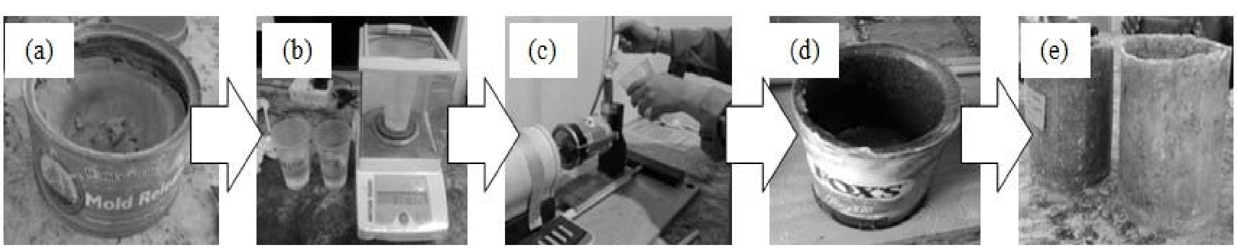

Figure-3. Specimen preparation; a) mold surface painted with a release agent to facilities specimen removed from mold, b) the banana fiber and epoxy weighed using digital scales, c) the mixture poured into mold, d) the specimen hardened and formed and e) FGNF/epoxy cylinder fabricated.

RESULT AND DISCUSSIONS

Figure-4 shows the FGNF/Epoxy cylinder fabricated by the centrifugal casting method. From the observation on the fiber distribution along the thickness of FGNF/Epoxy cylinder is found that the outer radius of cylinder contains more NF than the inner radius. The aggregation of NF occurs along the thickness of cylinder as the results of mold rotating speed. Due to the density of NF is higher than the density of the epoxy, NF move faster to fill the outer space. Meanwhile, Figure-5 shows the microstructures of FGNF/Epoxy as observed using optical microscope (OM).

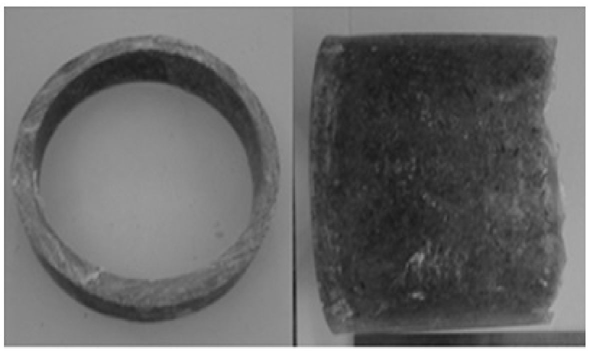

Figure-4. Specimen of gradient material made by centrifugal casting.

From Figure-5, there are similarities in the NF distribution along thickness of FGNF/Epoxy cylinders fabricated under different mold rotating speed. Fiber aggregation occurs because the percentage of fiber content increases. In addition, the porosity is growing from the inner to the outer area of the specimen. Porosity exists because bonding between the matrix and the fiber are weak due to unbalance mixture of fiber and epoxy. The outer periphery of casting shows a higher concentration of fiber than the interior of the casting.

Figure-6 shows the result of the hardness test. From the observation, the average value of hardness is directly proportional to the percentage accretion of fiber mixture. The typical hardness of the FGNF/Epoxy cylinder is in the range of 70 to 77.33 shore D. Meanwhile the hardness of epoxy without fiber mixed is 70 shore D. The mold rotating speed also affects the hardness value where the hardness of specimens fabricated under 1145 rpm is the highest. In addition, specimens will be harder when the bond between the matrix and the fibers are strong and uniform. The low hardness values of specimen containing fibers recorded are due to the weak bonding between the matrix and the fibers. This is because the fiber serves as catalyst for the reinforcing the bond between the matrix and fiber.

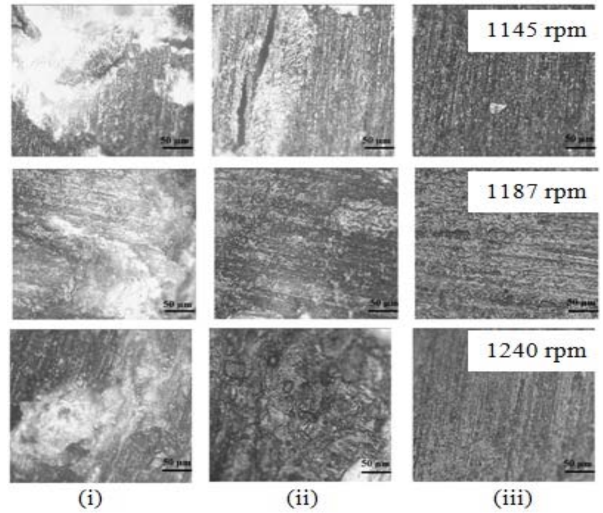

Figure-5. Microscope optical (OM) specimen D from three different areas; (i) outer; (ii) center; (iii) inner.

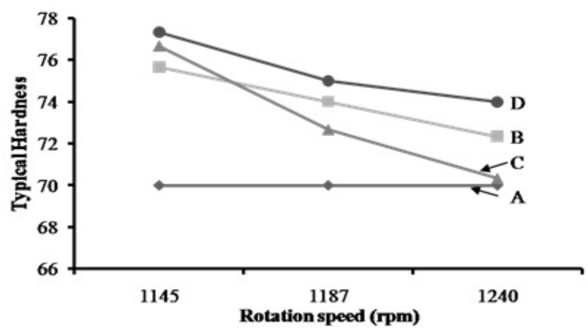

Figure-6. Hardness test results.

The density values of FGNF/Epoxy cylinders measured are shown inn Figure-7. The range of density values of FGNF/Epoxy cylinders recorded is from 1.145 to 1.156 g/cm^3. Meanwhile, the specimen containing only epoxy has density value of 1.136 g/cm^3. It is found that air bubbles are existed in the specimen which content high volume of fiber and fabricated at low mold rotating speed. the fibers not distributed gradually. The existence of air bubbles makes the density value of FGNF/Epoxy cylinder drops. It also makes the weak bond between the matrix and the fiber.

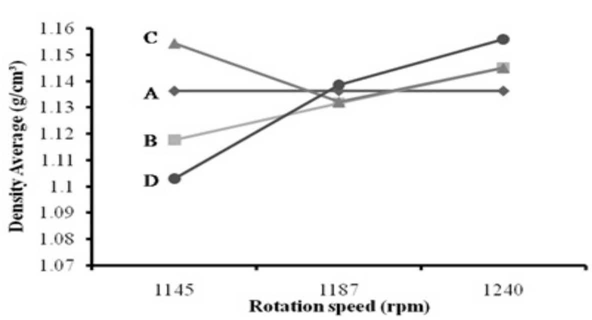

Figure-7. Graph density test.

Figure-8 shows the relationship between stress and strain of FGNF/Epoxy cylinders under compression test. The directly proportional lines begin at point 0 until 1 is the elastic region and the slope is the modulus of elasticity. After the yield point (point 1), the curve decreases slightly for each specimen until point 2. Then, the stress continues increases when the force increased until it reaches the ultimate strength (point 3). From the observation, specimen B has the highest stress-strain relationship.

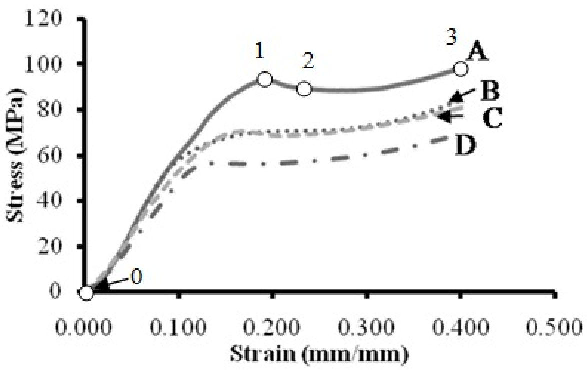

Figure-8. Stress-strain relationship of FGNF/epoxy cylinder under compression test.

As can be seen in Table-2, the ultimate stress is decreasing from specimen A until D. The FGNF/Epoxy cylinder fabricated with 5% of fiber (Specimen C) has the highest Young's modulus. However without fiber (Specimen A) has higher Young's modulus than specimen C. It is due to the existence of many air bubbles in FGNF/Epoxy cylinder which also affect its density value.

Table-2. Young's modulus of FGNF/Epoxy cylinder.

Specimen	Maximum Force (kN)	Ultimate Stress (MPa)	Young's Modulus (GPa)
A	2.460	98.407	2.699
B	2.117	84.679	2.373
C	2.017	80.685	2.595
D	1.736	69.453	1.799

CONCLUSIONS

The effect of gradient composition on a function of the strength of FGNF/Epoxy cylinders fabricated using centrifugal casting method were tested and analyzed. The fibers used are banana trunk fiber. It is found that the hardness value of the specimen is increasing as the fiber content increased. However the increasing of fiber content generates more air bubbles that affect the density value and the strength of FGNF/Epoxy cylinders. In overall, the addition of fiber will give a good impression to the mechanical properties of the polymer composites. Besides that, the rotation speed of mold affects to mechanical properties of FGNF/epoxy.

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