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Bending Strength of Polyester Composites Reinforced with Stitched Random Orientation and Plain Weave Abaca Fiber

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Abstract. This paper discusses the bending strength of Fiber Reinforced Polymer (FRP) composite made from polyester resin matrix and abaca fiber. The abaca fiber was prepared in the form of stitched random orientation and plain weave woven fabric. The abaca FRP composite was produced by using hand-lay-up method with the variation of weight percentage of the fiber. The weight density of the FRP composite was measured to determine the effect of fiber percentage to the weight density of the composite panel. The three points bending test was performed in order to examine the maximum bending force and flexural strength of the abaca FRP composite. The result of the experiment shows that the fiber weight percentage gave significant effect to the weight density and flexural strength of the abaca composite. Furthermore, the comparison between the two types of fiber form shows that the abaca plain weave woven fiber produces higher flexural strength compare to stitched random orientation woven fiber at all levels of fiber contents.

1. Introduction

The use of natural composite in industry has been growth in the present years due to their advantages such as higher specific mechanical properties, lower weight, better insulating and thermal resistance, lower cost and biodegradability compare to synthetic fiber [1-3]. The amount of natural composite used in America and Europe has increased more than 20% in 2010 to 2015 compared to the earlier five years range. The applications of natural fiber reinforcements have grown faster as well due to the improvement of manufacturing technology and process treatments. As first being produced to building interior panels in 1950s, lately the natural fiber has been used to produce car door panels (from flax-sisal fiber mat reinforced epoxy), car rear shelf trim panels (from flax fiber reinforced polypropylene composite), ceiling and partition boards in structural applications [4, 5].

The composition properties of natural fiber and polymer synthetic matrix material significantly contributes to the performance of the natural fiber reinforced composite. The fiber mostly contributes to the strength and stiffness of the structural load whereas the matrix contributes to the shape, surface and environment resistance. Many researchers reported that adding the fiber content increasing the strength of the FRP composite. However, the fiber is bounded by the polymer matrix, therefore increasing the fiber content decreases the fiber-matrix bonding [6].

Abaca fiber is a bast fibre and is obtained from the pseudo-stem of banana plant (Musa textiles) that belongs to the Musacea family of plants [7]. The fibre is extracted from the trunk of the plant and went several manual processes, i.e. decorticating, washing, drying and cleaning. The banana plant growths naturally 2 m to 4 m tall in tropical forests (see figure 1. a), in Filipina, Indonesia, Thailand and Vietnam. Traditionally, it has been used to make twins and ropes for hundreds years but nowadays it is gaining importance as a good material for tea bag, bank note, food pack and reinforcement for composite material. Abaca fiber is also known as Manila hemp since Filipina supplies almost 60% of the world market demand of abaca fiber. Indonesia, Thailand, Vietnam and other countries share the rest of 40% market demand.

The development of fiber structure become major method to improve the performance of fiber reinforced composites. Stitching, knitting, braiding and weaving has become alternative technologies in increasing through thickness mechanical properties of laminate composites, improving the impact resistance of fiber reinforced composites and reducing fabrication cost [6, 8, 9].

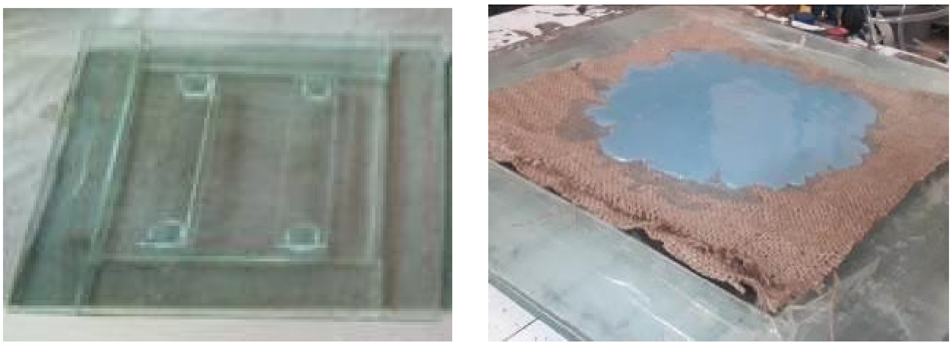
The study by Ghazilan et al [10] shows that the tensile properties of stitched empty fruit bunch oil palm reinforced epoxy composite has better performance in both tensile strength and tensile modulus compared to unstitched one. Reis et al [11] reported that fiber orientation affected the growth of delamination and the extension shear coupling effects. The delamination growth divides the composite into sublaminate, resulting in a higher occurrence of delamination buckling failures. The extension shear coupling effects induces the damage accumulation in the matrix, which result in the non-linear compressive response of the composite subjected to off-axis loading conditions. Dahale et al [12] studied the effect of weave parameters to the mechanical properties of woven glass composites. They reported that higher weft density specimens showed a more compact structure with less crimp that resulted in higher tensile and compressive properties of the weave fiber composite.

(a) (b)

Figure 1. (a) The banana tree in Aceh, Indonesia (b) the abaca fiber.

(a) (b)

Figure 2. The abaca fiber (a) stitched random orientation, (b) plain weave woven.



(a) (b)

Figure 3. The fabrication of abaca FRP composite (a) the mould (b) the process.

This study aimes to investigate the bending strength of abaca Fiber Reinforced Polymer composite. The fiber was prepared in two different types, i.e. the stitched random orientation and plain weave woven type in order to compare the bending strength of the composite configuration from two different fiber types. The fiber content varies as 17, 19 and 21 of weight percentage. The weight density and the bending strength of each weight percentage level was investigated to find out the fiber weight percentage that gives the highest bending strength.

2. Methods

The abaca fiber was supplied by CV Royal Nanggrou Diamond, Aceh, Indonesia. The fiber was originally from the banana field that naturally growth in Lhok Nibong, North Aceh District, Aceh Province, Indonesia, as shown in figure 1 (a) and 1 (b). The fiber was manually produced by local farmers using decorticator machines, washed in well or river water and dried naturally under the open sun light. No chemical treatment was applied to the fiber in both the farm processes and laboratory experiment. According to the regular users and traders, the said fiber is one of the best quality abaca fiber that produced in Aceh.

Two forms of abaca fiber were prepared for the filler of the abaca FRP composite, i. e. stitched random orientation and plain weave woven form, as shown in figure 2(a) and 2(b) respectively. The stitched random orientation fabric was made by laying the raw abaca fiber in random orientation. The fiber then sewed using cotton sewing thread to keep the fiber uniform in similar size with the composite mould. Sewing lines provided only to one direction with 50 mm interval in order to make sure that the sewing thread does not affect the fracture force of the abaca composite. The plain weave woven fabric was made by manual weaving process using 300 mm x 300 mm wood frame. The yarn consists of one layer of abaca fibers with 5 mm width. The weaving process was conducted line by line to produce intermittent pattern with 90^0 orientation.

(a) (b)

Figure 4. Abaca composite panels (a) with stitched random orientation fiber, (b) plain weave woven fiber.

(a) (b)

Figure 5. Samples of abaca composite specimen (a) with stitched random orientation fiber, (b) plain weave woven fiber.

The FRP composite was made using hand-lay-up method in an open mould. The mould was made from acrylic with the open pocket dimensions of 200 mm x 170 mm x 10 mm depth, as shown in figure 3(a). The process started by applying a thin layer of wax to the surfaces of the mould pocket. Polyester resin (with 4% of hardener) was poured into the mould until 1 mm thickness. The fiber then was put into the mould followed by resin until the mould pocket was full, as shown in figure 3(b). The fiber and resin was chopped smoothly using a soft painting brush to make sure the fiber and resin were mixed uniformly.

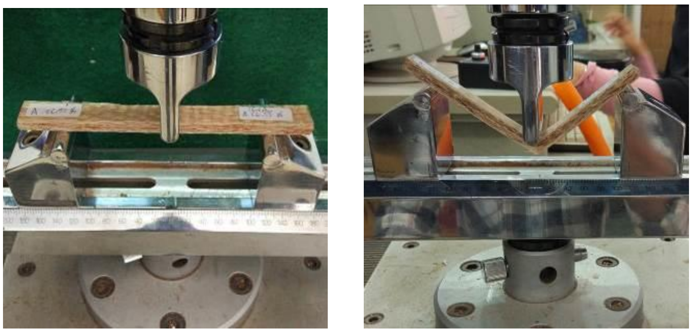
The cover acrylic plate was put on the top of the mould pocket. Five kg of load was put on the cover plate to press it down to the target thickness (5 mm). Some of the resin licked out from the mould pocket through the small gap between the cover plate and the side plate of the mould pocket. The bubbles inside the resin were removed by sliding a yarn under the cover plate. After natural curing process for 8 hours, the abaca composite could be easily removed from the mould pocket. The abaca composite panel with random fiber and woven fiber were shown in figure 4(a) and 4(b) respectively.

Three different levels of fiber weight has been prepared for the composite panel, i.e. 30 gr, 40 gr and 50 gr, resulting the composite panels with the fiber weight percentage of 17.11%, 18.9% and 20% respectively. Each panel was cut into 9 specimens with 165 mm x 19 mm x 5 mm as per ASTM D790 using Bosch GDC 120 semi auto cutting machine. Samples of abaca composite specimen from random fiber and woven fiber are shown in figure 5 (a) and 5 (b) respectively. Three specimens were selected randomly from each group for weight density measure and bending test. The average of the three measures was taken as the result.

The weight density of the composite specimen was calculated using the following equation:

$$\rho = m / v \tag{1}$$

Where ρ is density (gr/ m3), m is the mass of the specimen that measured using weighing scale, and v is the volume of the specimen that measured using standard scale glass. Three points bending test was carried out at Hung Ta HT-8503 universal testing machines with constant speed of 22 mm/min, as shown in figure 6. The applied flexural stress was automatically recorded during the bending test and the stress vs strain of the test could be plot for further analysis.



(a) (b)

Figure 6. Three points bending test (a) the starting position (b) the ending position.

Table 1. Result of the experiment.

No	Fiber Content (%)	Weight Density (gr/m^3)	Flexural Strength (MPa)	
			Stitched random orientation fiber	Plain weave woven fiber
1	17	1,260	50,11	54,01
2	19	1,150	34,11	41,48
3	21	1,090	27,95	31,38

The flexural strength σ_f (maximum bend stress) was calculated for test specimen using the following equation:

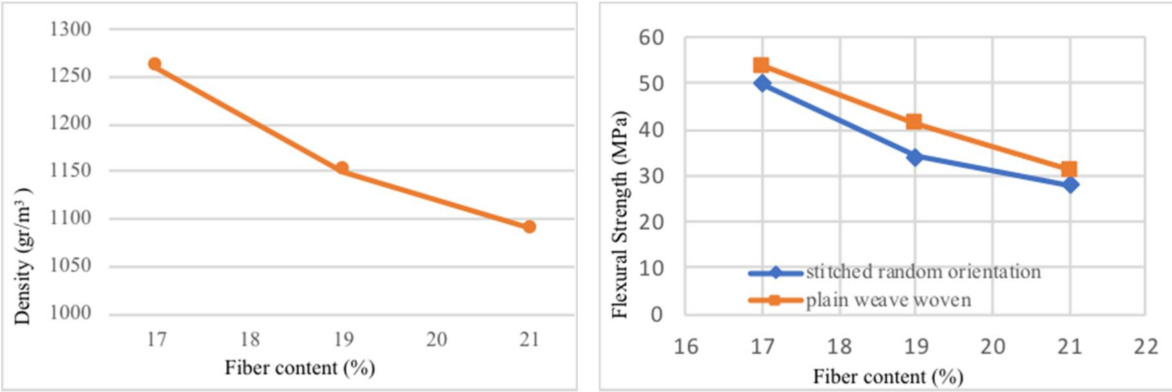
$$\sigma_f = (3\ F_m\ L) / (2\ h\ d^2) \tag{2}$$

Where Fm is the applied flexural force, L is the distance between the support points (110 mm for all the testes), h is the specimen width (19 mm for all the specimen) and d is the specimen thickness.

3. Result and Discussions

Based on the result of the experiment, the weight density and the flexural strength were calculated, as presented in table 1. The density of the abaca composite panels was greater than 1 for all of the fiber content levels, which is higher than the density of abaca fiber. However, they varied from one level to the others. In order to show the effect of the fiber content, the density was plot into a graph as shows in figure 7(a). It was clearly seen that the increasing of the fiber content reduced the density of the abaca composite. It is because the density of the abaca fiber is lower than the density of the polyester resin and increasing the fiber content will decrease the resin content in the composite panel.

Figure 7(b) shows the flexural strength of the abaca FRP composite with stitched random orientation fiber (blue line), and abaca FRP composite with plain weave woven fiber (red line) for the three fiber content levels. It is clearly seen that the fiber content gave significant effect to the flexural strength of the abaca composite panels for both fiber forms. The increasing of the fiber content decreases the flexural strength of the abaca composite panel. The possible reason was because the properties of the abaca fiber is lower than the properties of the polyester matrix, therefore higher content of fiber decreases the flexural strength. Contrary, when the properties of the fiber is higher than the properties of the matrix, higher content of fiber increases the flexural strength. As reported in references [5, 13, 14], the authors used glass or carbon fiber where its properties are higher compared to the polyester or epoxy matrix, therefore higher content of fiber increases the flexural strength of the composite. However, more experiments are need to be conducted in the future, in order to find the optimum fiber content for the better mechanical properties of the abaca composite panel.



(a) (b)

Figure 7. Effect of fiber content to (a) the density (b) the flexural strength of the abaca composite.

Figure 7(b) also shows the comparison between the flexural strength of abaca FRP composite with stitched random orientation fiber and abaca FRP composite with plain weave woven fiber. It could be seen that the flexural strength of plain weave woven fiber is higher than the flexural strength of stitched random orientation one at all fiber content levels. It is because the weaving pattern in woven form produce a higher bounding force among the fiber compare to the one in the random form [6, 12]. However, plain weave woven fiber requires more production process, longer production time, and extra production cost. In the case where the flexural strength is sufficient for product requirements, the stitched random orientation fiber would be economically recommended due to a small difference of flexural strength with woven one.

4. Conclusion

The study of the bending strength of abaca FRP composite has been reported. The result of the experiment show that the bending strength decrease continuously when the fiber content increase from 17% to 21%. The comparison between different fiber woven type shows that the plain weave woven fiber has higher bending strength compare to the stitched random orientation type. The authors wish to thank Ministry of Research, Technology and Higher Education Republic of Indonesia and Syiah Kuala University, Banda Aceh, Indonesia for financial support for this research project.

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