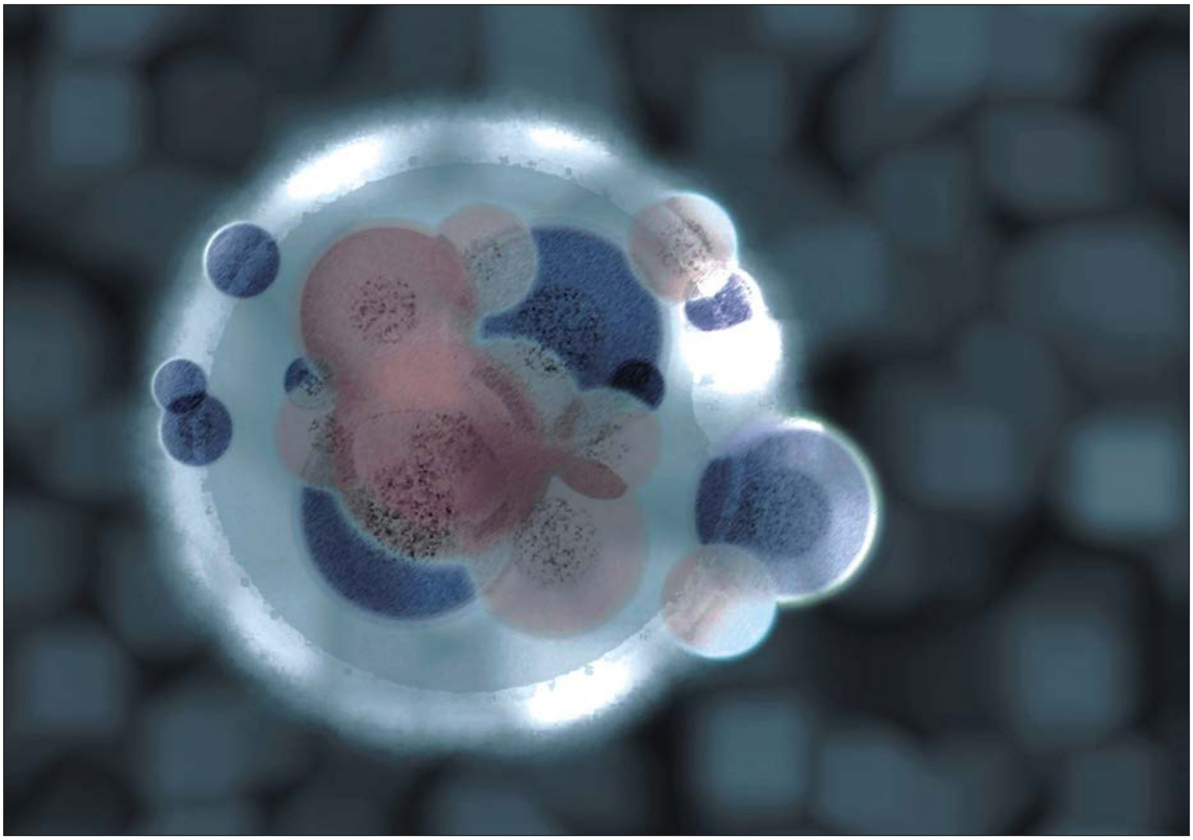

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Effect of Oil Palm Empty Fruit Bunch Fiber on the Physical and Mechanical Properties of Fiber Glass Reinforced Polyester Resin

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Abstract: In this study, oil palm (*Elaeis guineensis*) empty fruit bunch (EFB) fiber was incorporated with glass fiber in polyester composite by wet-lay up process. Mechanical and physical properties of composites were evaluated. Flexural strength and density decreased with increasing EFB fiber but the addition of EFB fiber volume fraction around 40-70% increases flexural strength of polyester resin, by about 350%. The addition of 40% volume fraction EFB fiber resulted in the similar flexural strength with glass fiber/polyester composites but showed lower density. This suggests that EFB fiber have a potential to replace glass in many applications that do not require very high load bearing capabilities. Water absorption and thickness swelling ability tend to increase with the increasing EFB fiber addition. Fiber length showed no significant effect on the flexural strength and density of composites, but shorter EFB specimen is able to absorb water and change the dimension of composites higher than the longer fiber.

Key words: Oil Palm, empty fruit bunch, fiber glass, polyester, composites

INTRODUCTION

Over the past few decades, polymers have replaced many of the conventional metals/materials in various applications. This is possible because of the advantages of polymers offer over conventional materials. The most important advantages of using polymers are the ease of processing, productivity and cost reduction. Collectively, polymer composites are light, stiff, strong and allow both large and small scale production at lower energy costs. The light weights of these composites also increase the energy efficiency for machinery and transportation (Foulk *et al*., 2006).

In most of these applications, the properties of polymers are modified using fillers and fibers to suit the high strength/high modulus requirements. One of the main categories of polymer composites is represented by polymers filled with glass fibers, which fit to a number of applications. The use of glass fiber resulted in the high modulus, high strength and good moisture resistance composites (Joshi *et al*., 2004), but the density of glass fiber used for composites is 2.6 g cm^{-3} higher than natural fiber such as flax fiber and the glass fiber is costly, its price between \$1.30 and \$2.00 kg^{-1}. In comparison, flax fibers have a density of 1.5 g cm^{-3} and cost between \$0.22 and \$1.10 kg^{-1} (Foulk *et al*., 2000). In addition, in assembly and production areas of the factory where glass fiber components are trimmed or mounted, workers increasingly complain about skin irritations and respiratory diseases caused by the inhalation of fiber dust. However, the increase in environmental concern has pointed out how it is also necessary to reduce and rationalize the use of polymeric materials, not only due to their non-biodegradability, but also because their production is not renewable. The manufacture, use and removal of traditional composite structures usually made of glass, carbon and aramid fibers are considered critically because of the growing environmental consciousness (Mohanty *et al*., 2000).

Since the last decade, composites consisting natural fibers and synthetic thermoplastics have received substantial attention in scientific literature as well as industry (Sanadi *et al*., 2002), primarily due to improvements in process technology and economic factor. Natural fibers reinforced composites combine good mechanical properties with a low cost, low density, acceptable specific properties, ease of separation, enhanced energy recovery and biodegradability (Mishra, 2003). Several types of natural fibers such as flax, jute, banana, hemp, coir and others have been investigated as possible reinforcement for polymeric materials (Mohanty *et al*., 2000).

Among the natural fibers available, oil palm empty fruit bunch (EFB) offers an interest possible utilization. Oil palm (*Elaeis guineensis*) is one of the major plantation commodities in Indonesia, which has a great contribution for national income. Crude Palm Oil (CPO) as the main product of oil palm fruit can be used in many different

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industries. In the line with the development of CPO production, oil palm EFB as one of the solid wastes produced by palm oil mill is readily available in large amount throughout the year. The palm oil industry must dispose about 1.1 ton of EFB for every ton of CPO produced. These EFB consists of high cellulose content and is a potential natural fiber resources but its applications account for a small percentage of the total potential production. Several studies showed that EFB of oil palm with the average of cellulose content of 14-20% (Ramli *et al*., 2002) has the potential to be an effective reinforcement in thermoplastics and thermosetting materials (Sreekala *et al*., 2002; Khalil *et al*., 2001) but the use of natural fibers can be limited in the industrial applications due to some well-known drawbacks that may lead to composites with final poor properties. The polar and hydrophilic properties of natural fibers and the non-polar of unsaturated polyesters resin, resulted in the poor compatibility and poor interfacial adhesion. Then several efforts have been done for mechanical and physical properties improvement such as pre-treatment of fiber surface with chemicals (Khalil *et al*., 2001; Hill and Abdul Khalil, 2000).

In order to enhance mechanical and physical properties of natural fiber reinforced composites and to substitute glass fiber content so that gives more economical composites, glass fiber and empty fruit bunch of oil palm were combined in polyester composites by resin transfer molding (Khalil *et al*., 2007) in which EFB fiber mats and glass fiber mats were stacked together with the layer of glass fiber mats sandwiched in between the layer of EFB fiber mats. Different from the above finding, this study aims to evaluate the effect of fiber specimen length and fiber loading of EFB on the physical and mechanical performance of glass fiber-polyester composites by wet/hand lay up in which the stacks were arranged so that amount and position of glass fiber and/or EFB layers varied.

MATERIALS AND METHODS

Materials: EFB of oil palm (*Elaeis guineensis*), was kindly supplied by PT Condong Garut Estate Crop, Garut, West Java. General purpose polyester resin (PL07ME) used as the matrix and glass fiber mat (density: 2.59 g cc^{-1}) were obtained from local supplier. Polyester resin density was determined by picnometer. The resin density was found to be 1.14 g cc^{-1}.

Fiber preparation methods: All empty fruit bunches were manually dismantled into bundles of virgin fiber. The bundled fibers were air dried at room temperature before being cut to 2-5 cm as shorter fiber and 8-10 cm of length as longer fiber, respectively using a carding. Fibers were then soaked in 2% NaOH solution at 100°C for 30 min and dried at 60°C for 24 h. Density of EFB fibers is 1.15 g cc^{-1}. Each of longer and shorter EFB fiber was then set on the aluminum sheet randomly and pressed at 1 MPa to give thin EFB fiber sheet crossing one another. Weight of inner, middle and outer layer are based on the weight of commercial glass fiber layers used in composites (Fig. 1), namely 19.6, 26.1 and 45.2 g.

Composite preparation: EFB fiber mats and glass fiber mats were stacked together with polyester resin using closed aluminum mold size of 270×270×4 mm by hand lay up method. Composites having a different volume fraction of EFB fiber and glass fiber were stacked together. Volume fraction of EFB fiber and glass fiber in each composites are is shown in Table 1. Polyester resin composites were made as a control sample. The mold is first polished and then a mold-releasing agent is applied on the surface. General-purpose polyester resin is mixed with 0.4 wt-% methyl ethyl ketone peroxide solution in dimethylphtalate as catalyst, 2 wt% of synthetic hydrophilic amorphous silica (Wacker HDK N20), 0.5% pigmen and 40% talcum. The resin mixture then poured on the mats placed in the mold. When the mats are completely wet by the resin, the

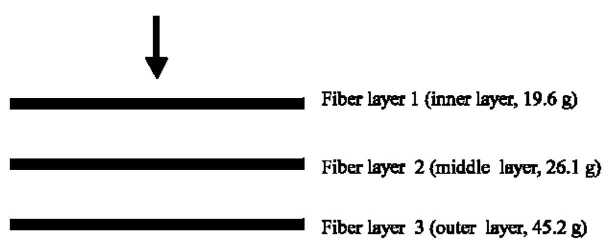

Fig. 1: Position of each fiber layer

Table 1: Weight and volume fraction of EFB and glass fiber of composites

Sample No.	Composite type	Weight fraction between two fibers (%)		Volume fraction based on composites (%)		Volume fraction between two fibers (%)	
		EFB	Glass fiber	EFB	Glass fiber	EFB	Glass fiber
1	GF/GF/GF	0.0	100.0	0	12	0	100
2	EFB/GF/GF	21.6	78.4	6	9	40	60
3	EFB/EFB/GF	50.3	49.7	14	6	70	30
4	EFB/EFB/EFB	100.0	0.0	18	0	100	0

Table 2: Mechanical and physical properties of composites

Sample No.	Composite type	Flexural strength (MPa)		Density (g cc^{-1})		Water absorption (%)		Thickness swelling (%)	
		Longer fiber	Shorter fiber	Longer fiber	Shorter fiber	Longer fiber	Shorter fiber	Longer fiber	Shorter fiber
1	GF/GF/GF	165.4		1.56		0.8		1.20	
2	EFB/GF/GF	165.9	163.3	1.36	1.34	1.4	2.3	1.74	1.69
3	EFB/EFB/GF	143.0	146.7	1.26	1.24	2.2	2.7	2.03	2.39
4	EFB/EFB/EFB	36.8	33.9	1.24	1.24	3.1	3.4	2.46	2.64
5	Polyester Resin	43.3		1.26		0.6		1.04	

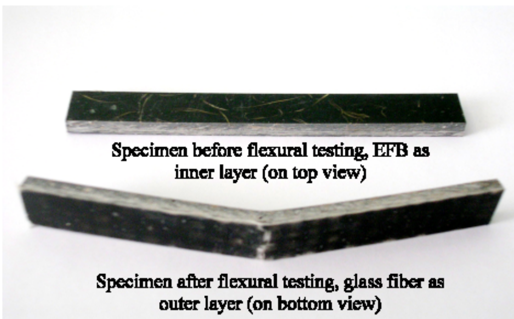

Fig. 2: Specimen before and after flexural testing

mold is closed and placed on the lower movable platen of the hydraulic press. The mold is then pressed at 7.4 MPa and cured at room temperature for 24 h.

Flexural (bending) test: Prior to flexural test, samples were shaped according to ASTM D-790 of 4×10×80 mm then conditioned at 23°C, RH 50% for a minimum 40 h before testing. Flexural test was performed on a Universal Testing Machine (Orientec UCT-5T) using 5 specimens in a adjusted room condition (23°C, 50%RH). Composites specimen before and after flexural testing are shown in Fig. 2.

Density: The density (d) of composites was measured by a picnometer and calculated as follow :

$$d = \frac{a}{v} \quad \left(g\,cm^{-3}\right)$$

Where:
a = Mass of the composites,
v = Volume of the composites.

Mass determination was carried out by weighing the composites on an analytical balance. All samples were oven-dried at 50°C for 24 h. After oven drying, the experimental samples were cooled in desiccators over granulated silica gel before mass and volume determination was conducted.

Water absorption and thickness swelling: Specimens of 50×25×3 mm of size were prepared from composites. All samples were oven-dried at 50°C for 24 h. After oven drying, the samples were cooled in desiccators over granulated silica gel before water absorption determination was conducted. Water a sorption test were conducted by submerging the specimens in boiling water for 2 h and measuring the increase in weight and thickness as compared to the original oven dry weight of the specimens. Water absorption was determined by weighing the samples after 2 h of immersion in boiling water. Five specimens of each type were tested in a adjusted room condition (23°C, 50% RH) and the results averaged. Water absorption and thickness swelling were calculated as indicated by the equation shown below:

$$\text{Water absorption} = \frac{W_1 - W_0}{W_0} \times 100\% \qquad (1)$$

Where:
W_0 = The weight of specimens before immersion,
W_1 = The weight of specimens after 2 h of immersion in boiling water.

$$\text{Thickness swelling} = \frac{T_1 - T_0}{T_0} \times 100\% \qquad (2)$$

Where:
T_0 = The thickness of specimens before immersion,
T_1 = The thickness of specimens after 2 h of immersion in boiling water.

The dimensions of the samples before and after treatment were measured using a digital micrometer.

This study was conducted in Polymer Testing Laboratory, Division of New Materials and Research Center for Physics, Indonesian Institute of Sciences, Bandung, Indonesia from May 2006 to November 2006.

RESULTS AND DISCUSSION

Flexural strength: The effect of EFB fiber loading with glass fiber on the flexural strength is shown in Table 2. The flexural strength decreases as the fiber loading increasing. However, in general, the higher volume fraction of EFB fiber up to 70% (sample 2 and 3) increases flexural strength, compared with of EFB fiber/polyester composites (sample 4) and polyester (sample 5). Normally the EFB fiber can not withstand the heavy load which, leads to the failure of the fiber resulting in the failure of the composite. This exceptional behavior of the composite at 40% volume fraction of EFB fiber will be due to the fact that at this particular loading, the EFB oil palm fiber can effectively transfer the load from the glass fiber. Hence, comparatively less volume fraction of fiber glass with the EFB fiber reinforcement results in composites of a more enhanced performance than the 100% EFB fiber reinforced composites. By the addition of EFB fiber volume fraction of 40-70%, flexural strength of EFB/glass polyester composites increases by around 350% compared with the polyester resin. The significant decrease in the flexural strength is observed at the highest EFB fiber volume fraction of 100% which is due to the increased fiber-to-fiber interactions and dispersion problem which results in low mechanical properties of composites (Sreekala *et al*., 2002). In other words, the flexural strength decreases as the amount of glass fiber decreasing. Due to superior properties of glass fiber, the mechanical properties of the composites increased with increasing volume fraction of glass fiber. Therefore, in a glass fiber reinforced composite, the property of the composite is mainly dependant on the modulus of the individual reinforcing fiber. The modulus of glass is much higher than that of the EFB fiber, 66-72 GPa and 1-9 GPa, respectively whereas no extent of glass in the composites.

From these results, it can be suggested that composites with the high flexural strength from EFB and glass fiber can be produced with the position of glass fiber in the outer layer of composites (Fig. 1). Table 2 shows that composite with the addition of EFB fiber volume fraction of 40 and 70% shows the similar flexural property with that of composites without EFB fiber addition. This suggests that natural fiber composites have a potential to replace glass in many applications that do not require very high load bearing capabilities and we can produce economically viable composites having high performance. The result also indicates that the fiber specimen length does not affect the flexural strength of composites since shorter fiber gives similar effect to composites filled with longer fiber.

Compared to the previous finding (Khalil *et al*., 2007) it could be concluded that by the same EFB weight fraction, the present result shows the higher flexural strength due to the position of glass fiber in the outer layer other than in between EFB fiber layer.

Density: The density of composites filled with EFB and glass fiber is shown in Table 2. The density of composites decreases with the increasing of EFB fiber. As the fiber content increases, the resin may be difficult to wet fiber completely and resulted void formation inside the composite (Hill and Abdul Khalil, 2000). These voids may occur in the matrix, at the fiber-matrix interface, or within the fiber lumens which then will affect the composite performance and decreases the density. This is also due to the matrix density which has dominant effect over the fiber. Density of EFB fiber is 1.14 and density of polyester resin is 1.41. Stacking EFB fiber into matrix reduces composites density since EFB density is lower than matrix. On the other hand, the density increases as the amount of glass fiber increasing. This is mainly due to the higher density of the glass fiber of 2.6 g cm^{-3} compared with matrix, of about 1.4 g cm^{-3} . The result indicates that the fiber specimen length does not affect the flexural strength composites since shorter fiber gives similar effect to composites filled with longer fiber.

Water absorption: Table 2 shows the value of water absorption by EFB//Polyester and EFB/Glass Fiber/Polyester composites. It indicates clearly that water absorption of composites increased with increasing amount of EFB fiber. This is due to the hydrophilic nature of EFB having cellulose and lignin containing free hydroxyl group. These groups absorb water easily. The amount of hydroxyl groups is definitely caused by the high cellulose and lignin content in EFB, 44% and 20%, respectively (Ramli *et al*., 2002). These hydroxyl groups can take water molecules easily through hydrogen bonding in the fiber cell wall. Therefore, the higher the EFB content in the composites, the higher the hydroxyl content, the higher water absorption (Ismail *et al*., 2003). Table 2 shows that the addition of EFB fiber fraction volume up to 100% (sample 4) resulted in the highest value of water absorption. In addition to this phenomenon, the increased absorption of composites at higher amount of EFB fiber can be attributed to the poor compatibility between the EFB and glass fiber and between EFB fiber and the polyester matrix. As the amount of EFB fiber, micro-level processing of the composites become difficult and may caused to the fiber layering out which creates micro-void and cracks within the composites, caused the flow of water molecules along the fiber matrix interface, resulted the diffusion from the interface into the matrix and fibers (Sreekala *et al*., 2002). On the other hand, by stacking glass fiber in EFB/Polyester composites, water absorption ability of composites decreases. As consequence of the decreasing amount of EFB, the quantity of hydroxyl groups in composites decreases and leads to the lowering water absorption. Table 2 also indicates that the fiber size affects water absorption of composites. The shorter fiber holds much water than the longer fiber in composites due to the amount of surface area of shorter fiber much higher than longer fiber which enable to contact with water. This leads to the higher water uptake ability of shorter fiber than the longer fiber.

Thickness swelling: The water uptakes ability of EFB fiber is due to the hydroxyl groups which able absorb water molecules. This ability guides to swell the fiber and fiber-matrix interface in the composites and attributed to the dimensions change of EFB/Polyester and EFB/Glass Fiber/Polyester composites. Thickness swelling of composites is shown in Table 2. The table shows that thickness swelling increases with the increasing of the quantity of EFB fiber in composites. Composites with the highest amount of EFB fiber tends to have the highest thickness swelling. The increase quantity of EFB leads to the high amount of cellulose that absorb water higher, thus changes the dimension of composites. Table 2 also indicates that the fiber specimen length affects dimension stability of composites. Due to the higher surface area that enable to contact with water molecules, shorter fiber holds much water than the longer fiber in composites and resulted to the higher thickness swelling of composites.

CONCLUSIONS

Based on the above results, it can be concluded that physical and mechanical properties of fiber glass reinforced polyester resin composites were affected by the EFB fiber specimen length and fiber loading. EFB fiber specimen length showed no significant effect on the flexural strength and density of composites prepared by wet/hand lay up process, but shorter EFB fiber absorbs water and changes the dimension of composites higher than the longer EFB fiber.

The addition of EFB fiber decreases flexural strength and density but increases water absorption and dimension. Flexural strength and density decrease with increasing EFB fiber, but the addition of 40-70% volume fraction of EFB increases flexural strength of polyester resin by about 350%. The incorporation of EFB fiber up to 40% resulted in the similar flexural strength with the glass fiber/polyester composites but with lower density, indicating the possibility to produce light and more economical composite.

High flexural strength composites from EFB and glass fiber can be produced with glass fiber as the outer layer.

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REFERENCES

Foulk, J.D., D.E. Akin and R.B. Dodd, 2000. New low cost flax fibers for composites. SAE Technical paper number 2000-01-1133, SAE, World Congress. Detroit, March 6-9.

Foulk, J.A., Y. Wayne, Chao, E. Danny, Akin, D.B. Roy and A.L. Patricia, 2006. Analysis of flax and cotton fiber fabric blends and recycled polyethylene composites. J. Polymers Environ., 14 (1).

Hill, C.A.S. and H.P.S. Abdul Khalil, 2000. Effect of fiber treatments on mechanical properties of efb or oil palm fiber reinforced polyester composites. Applied Polymer Sci., 78: 1685-1697

Ismail, H., H.B. Hong, C.Y. Ping and H.P.S. Abdul Khalil, 2003. Polypropylene/silica/rice husk ash hybrid composites: A study on the mechanical, water absorption and morphological properties. J. Thermoplastic Compos. Material., 16: 121-137.

Joshi, S.V., L.T. Drzal, A.K. Mohanty and S. Arora, 2004. Are natural fiber composites environmentally superior to glass fiber reinforced composites? Composites: Part A 35: 371-376.

Khalil, A.H.P.S., H. Ismail, M.N. Ahmad, A. Ariffin and K. Hassan, 2001. The effect of various anhydride modification on mechanical and water absorption properties of oil palm empty fruit bunches reinforced polyester composites. Polymers Int., 50 (1-8): 1-9.

Khalil, A.H.P.S., S. Hanida, C.W. Kang and N.A. Nik Fuaad, 2007. Agro-hybrid composite: The effects on mechanical and physical properties of oil palm fiber (EFB)/Glass hybrid reinforced polyester composites. J. Reinforced Plastics Compos. 26 (2): 203-218.

Mishra, S., A.K. Mohanty, L.T. Drzal, M. Misrab, S. Parija, S.K. Nayak and S.S. Tripathy, 2003. Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. Compos. Sci. Technol., 63: 1377-1385.

Mohanty, A.K., M. Misra and G. Hinrichsen, 2000. Biofibres, biodegradable polymers and biocomposites: An overview. Macromol. Mater. Eng., 276/277, 1-24

Ramli, R., S. Shaler and M.A. Jamaludin, 2002. Properties of medium density fiberboard from oil palm empty fruit bunch fiber. J. Oil Palm Res., 14 (2): 34-40.

Sanadi, R. Anand, J.F. Hunt, D.F. Caulfield, G. Kovacsvolgyi and B. Destree, 2002. High fiber-low matrix composites: Kenaf fiber/polypropylene. In: 6th International Conference on Woodfiber-Plastic Composites; 2001 May 15-16; Madison, WI. Forest Products Society, Madison WI., pp: 121-124.

Sreekala, M.S., J. George, M.G. Kumaran and S. Thomas, 2002. The mechanical performance of hybrid phenol-formaldehyde-based composites reinforced with glass and oil palm fibers. Compos. Sci. Technol., 62: 339-353.