LOAD BEARING CAPACITY OF HYBRID SUGAR PALM/ GLASS FIBER-REINFORCED POLYESTER COMPOSITES SUBJECTED TO A THREE-POINT BEND LOADING

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ABSTRACT

One of the drawbacks of natural fiber-reinforced polymer composites including sugar palm fiber-reinforced polymer composites is their low mechanical properties. In order to improve their mechanical properties, incorporation of natural fiber with higher strength synthetic fiber was used as reinforcement to produce hybrid fiber-reinforced polymer composites. This research aimed at finding out the influence of glass fiber substitution for sugar palm fiber on flexural properties of hybrid sugar palm/glass fiber-reinforced polyester composites. The specimens were cut from composite plates produced using press mold technique, and subjected to a three-point bending test according to the ASTM D790 standard. Whilst the total fiber volume fraction ($V_{\text{f-tot}}$), was kept constant at ~32%, the hybrid ratio (r_{h}), the ratio between glass fiber volume to total fiber volume, was varied at 0.0, ~0.1, ~0.2, ~0.3, ~0.4, and the span-to-depth ratio (S/d) was also varied at ~16, ~24 and ~32. The result shows that lateral load-deflection relations were found being non-linear up to close to failure. The magnitude of lateral load increases with the increase of glass fiber content. Substitution of 40 vol% of unidirectional glass fiber for sugar palm fiber in tension side can increase the load bearing capacity of the beam specimen up to 364% with respect to randomly oriented chopped sugar palm fiber-reinforced polyester composite specimens. Failures of sugar palm fiber-reinforced polyester composites were initiated at tensile face propagated toward compressive face leading to catastrophic failure. Those of the hybrid fiber-reinforced polyester composite specimens are characterized by separation of glass fiber/polyester layer from sugar palm fiber/polyester layer producing longitudinal in-plane crack followed by breakage of glass fibers.

Keywords: *Sugar palm fiber, glass fiber, hybrid fiber-reinforced polyester, load bearing capacity*.

1. INTRODUCTION

Sugar palm fibers have widely been used in manufacturing industries. According to Munandar *et al* (2013), annual sugar palm fiber production of Indonesia is 164.389 tons, while Lampung province produces 2004 tons per annum. The large amount of sugar palm fiber is a high potential for being reinforcing materials in producing natural fiber composites. Considering its higher biodegradability and eco-friendliness in comparison with those of synthetic fibers, natural fibers, including sugar palm fiber, has been gaining wider acceptance for reinforcement for polymer matrices to produce natural fiber composites (Al-Madeed and Labidi, 2014).

Widodo (2008) reported that the highest tensile strength of randomly oriented sugar palm fiber/epoxy composites being 5.538 kgf/mm^2 (54.33 MPa) at fiber weight fraction (W_{f}) of 40%. In addition, the highest impact toughness was also reported being 33,395 J/mm^2 at W_{f} = 40%. Another investigation by Prasetyo (2007) reported that the highest flexural strength and modulus of sugar palm fiber/polyester composites being 62.76 MPa and 1.269 GPa, respectively, both at V_{f} = 40%, while their highest tensile strength and modulus being 13.72 MPa and 2.00 GPa, respectively, for the same fiber content.

Sitorus (1996) has investigated the properties of sugar palm/glass fiber hybrid-reinforced polyester composites. It was reported that the highest tensile and impact strengths being 56,04 MPa and 46,18 kJ/m^2, respectively. Sapuan et al (2013) have reported tensile, flexural and impact properties of hybrid glass/sugar palm fiber-reinforced unsaturated polyester composites. They incorporated strand glass fiber mat and sugar palm fiber mat in various proportions.

Although a number research on natural fiber composites including the utilization of sugar palm fiber as reinforcing material have been reported, the use of combined sugar palm fiber synthetic fiber as reinforcement to produced hybrid fiber composites are still very limited in number. This work was carried out to investigate the lateral load bearing capacity of sugar palm/glass fiber hybrid-reinforced polyester composites.

2. EXPERIMENT

2.1 Constituent Materials

Sugar palm fiber and E-glass fiber were selected for being reinforcement. The sugar palm fiber was locally available. First, the fiber was separated from its bunch by pulling out one by one, selected of the approximately similar diameter and cut into length of ~20 mm. Second, the short sugar palm fibers were alkaline-treated by soaking them in a 5 wt% sodium hydroxide solution for two hours, neutralizing them by immersing them in plain water for 8×6 hours. Next, rinsing them in flowing water, and draining. Last, letting them to slowly dry at room temperature for two days to avoid any possible surface defect due to imbalanced drying rate between their inner and outer parts leading to generating longitudinal stress.

Unsaturated polyester 108 resin combined with methyl-ether ketone peroxide (MEKP) catalyst was selected as matrix. This matrix along with the catalyst was supplied by P.T. Justus Kimia Raya Indonesia. Approximately 1 wt% of catalyst was mixed with the resin as recommended by the supplier.

2.2 Specimen Preparation

Specimens were prepared according to the ASTM D790 standard (ASM Int., 2007). The homogeneously prismatic bar specimens were cut using a circular silicon carbide-tipped cutter rotating at ~6000 rpm from 250×300×4 mm3 composite plate panels. The plates were produced using press molding technique where the fibers were manually hand laid-up. A compressive pressure of ~15 kPa was applied when the mixture has been in jelly state. Total fiber volume fraction, Vf-tot, was kept constant at ~32%, while the hybrid ratio, $r_h = V_{fg}/V_{f\text{-tot}}$, was varied at 0.0 as reference, 0.1, 0.2, 0.3, and 0.4, where glass fiber/polyester layer(s) was placed in tension sides. In addition, three different span-to-depth ratios, S/d, of ~16, ~24, and ~32 have also been used, such that the length of every individual specimen was also varied accordingly. The width and thickness of the specimens were 12.7 mm and 4 mm, respectively.

2.3 Mechanical Testing and Evaluation

According to the adopted ASTM D790 standard, the specimens were subjected to three-point bend loading configurations, as has been illustrated in Fig. 1.

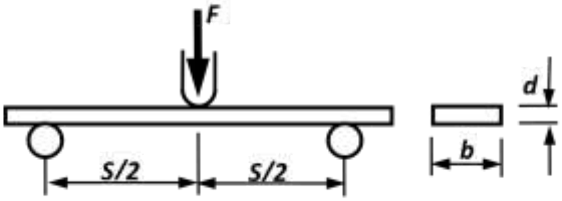


Fig. 1. Three-point bend loading configuration

Considering that the thickness of the specimens, d, is ~4 mm and S/d was varied at ~16, ~24 and ~32, the support span was set at 64 mm, 96 mm and 128 mm for those span-to-depth ratios, respectively. Crosshead speed was set such that it produced a strain rate of ~1% per minute that can be calculated according to Eq. (1). According to the adopted standard, the magnitude of flexural strength can be calculated using the following Eq.(2a) or Eq.(2b) depending upon each individual S/d of the specimens.

$$v = \frac{\varepsilon_f S^2}{6d} \qquad (1)$$

$$\sigma_f = \begin{cases} \dfrac{3FS}{2bd^2}; & \dfrac{S}{d} \leq 16 \qquad (2a) \\ \dfrac{3FS}{2bd^2}\left[1 + \dfrac{6D^2}{S^2} - \dfrac{4Dd}{S^2}\right]; & \dfrac{S}{d} > 16 \qquad (2b) \end{cases}$$

where:

v = crosshead speed [mm/min]
ε_f = flexural strain rate = 0.01 [mm/mm/min]
S = support span [mm]
d = specimen thickness [mm]
F = lateral force [N]
b = the width of specimen [mm]
D = mid-point deflection [mm]

After being tested until fail, a representative specimen from each variation was randomly selected and prepared for micrograph capturing under a microscope. Each pair of photo micrographs and its *F-D* graph obtained from flexural test were closely observed to evaluate its failure mode.

3. RESULTS AND DISCUSSION

3.1 Load-Displacement Response

Representative load-displacement responses of specimens of various test parameters have been presented in Figs. 2-4. The figures show that partial substitution of higher strength glass fibers for sugar palm fiber placed at the tensile face of the beams significantly increase the load bearing capacity of the beams.

All the plots demonstrate that load-deflection relation do not possess any perfectly linear parts. In other words, load-deflection patterns of the samples are dominated by that of the polyester matrix. The increase of fiber content results in the increase of the slope of each plot which is proportional to flexural modulus. In other words, an increase of fiber content results in the increase of flexural modulus.

S/d ~ 16. Load-deflection relations of short beams at S/d ~ 16 for various hybrid ratios was presented in Fig. 2. Generally speaking, the incorporation of continuous glass fibers with chopped sugar palm fibers increases the magnitude of lateral forced. The more sugar palm fiber being replaced, the larger the increase of the magnitude of lateral force that can be supported by the beams.

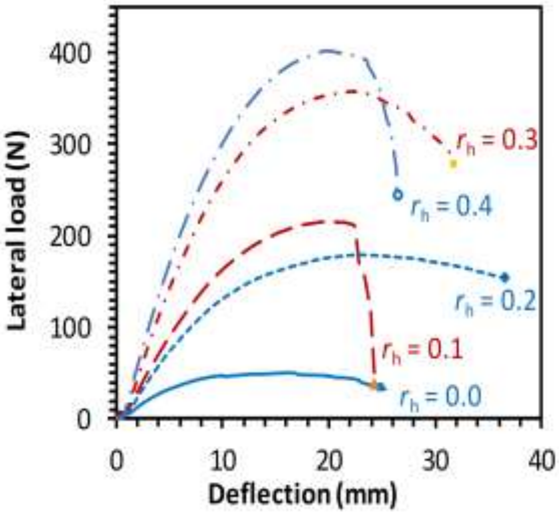


Fig. 2. Load-deflection responses of short beams, *S*/*d* = 16, specimens

It can be seen in Fig. 2 that *F* increases from ~81.5 N for r_h = 0.0 to ~381.5 N for r_h = 0.4. The magnitude of the increase varies from 120% (r_h = 0.2) to 368% (r_h = 0.4) with respect to the sugar palm fiber/polyester composite samples, r_h = 0.0, as reference.

***S/d* ~ 24.** Fig. 3 shows load-deflection plots of longer beams at *S*/*d* ~24 for various hybrid ratios. It shows that partial substitution of continuous glass fibers for chopped sugar palm fibers increases the load bearing capacity of the beams. The magnitude of lateral load increases with the increase of glass fibers content.

It can be seen in Fig. 3 that 10 vol% substitution of glass fibers for sugar palm fibers (r_h = 0.1) resulted in the increase of the magnitude of the lateral load from ~58.2 N for r_h = 0.0 to ~134.7 N for r_h = 0.1, where an increase of 131% can be obtained. Further increase of fiber content up to 40 vol% resulting in the increase of lateral force to ~249.7 N or an increase of 329% with respect to that of reference beam at r_h = 0.0.

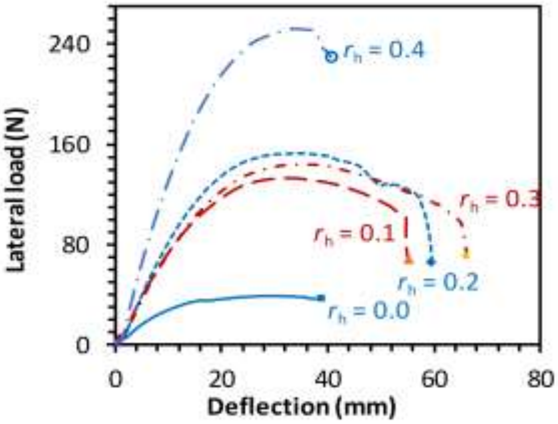


Fig. 3. Load-deflection responses of long beams, *S*/*d* = 24, specimens

***S/d* ~ 32.** Load-deflection plots of specimens at *S*/*d* ~32 for various hybrid ratios can be observed in Fig. 4. It shows that the magnitude of loaf increases with the increase of randomly oriented chopped sugar palm fiber being substituted with continuous glass fiber. An increase *F* of 180% (from ~31.1 N to ~87.2 N) was obtained for 10 vol% substitution of continuous glass fiber for chopped sugar palm fiber at the outermost tensile face of the beams. Further increase of glass fiber content up to 40 vol% would result in the increase of the magnitude of lateral load from ~31.1 N for r_h = 0.0 to ~144.4 N for r_h = 0.4, or an increase of 364%.

Considering that cross sectional dimensions of the specimens are considerably constant, it can be infered that the increase in flexural strength may have similar pattern with the increase of the magnitude of lateral load. Thus, by substitution of 40 vol% of continuous glass

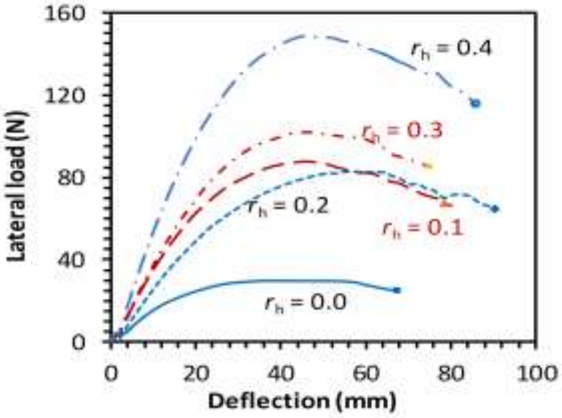
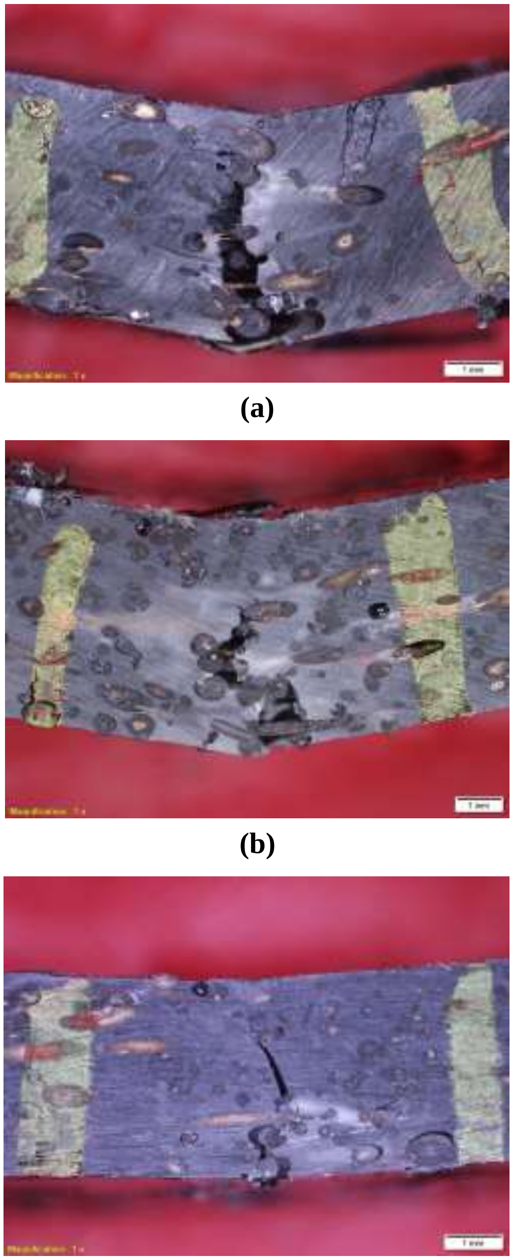


Fig. 4. Load-deflection responses of longer beams, *S*/*d* = 32, specimens

fiber for chopped sugar palm fiber, an increase of up to 364% of flexural strength can be achieved.

Considering Figs. 2-4 and using Eq. 2(a) and (b) as appropriate, the highest flexural strength of each S/d would be obtained at $r_h = 0.4$. These magnitude would be 170.6 MPa, 220.0 MPa and 231.8 MPa for $S/d = 16$, 24 and 32, respectively. For long beams, $S/d > 16$, these values are comparable with those of hybrid jute/glass fiber-reinforced epoxy at $r_h = 0.5$ previously reported by Sanjay and Yogesha (2016).



(a)

(b)

(c)

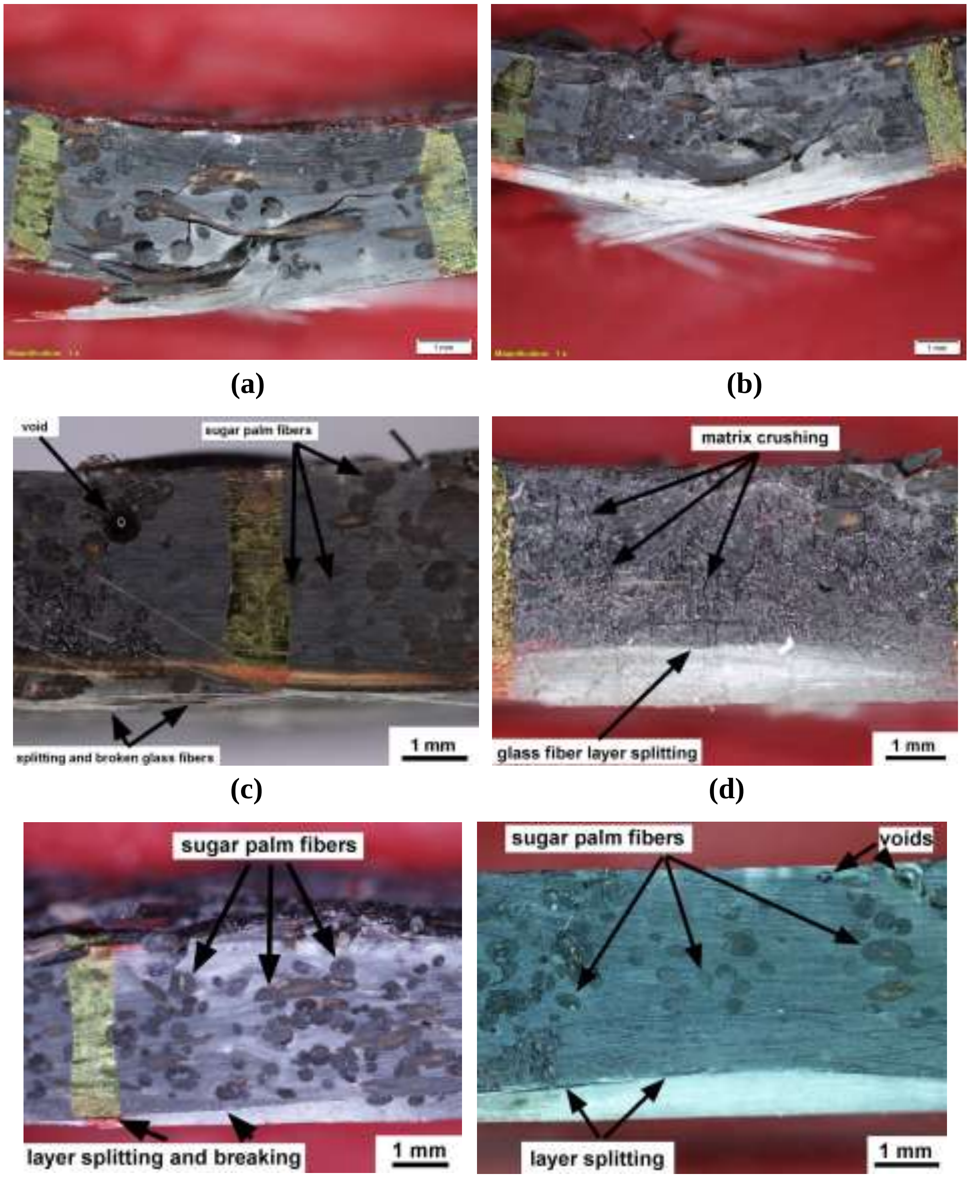
Fig. 5. Failure modes of sugar palm fiber/polyester composites ($r_h = 0.0$): (a) $S/d = 16$, (b) $S/d = 24$, (c) $S/d = 32$

3.2 Failure Modes

Failure modes of the specimens can be classified into two groups, which are very much different one from the other. These two groups are those of randomly oriented chopped sugar palm fiber-reinforced polyester composites in one group, and those of hybrid randomly oriented chopped sugar palm/ unidirectional glass fiber-reinforced polyester composites in the other group.

Sugar palm fiber/polyester composites ($r_h = 0.0$). Fig. 5 shows failure modes of randomly oriented chopped sugar palm fiber/polyester samples for the three span-to-depth ratios as references. Failure modes of short beams ($S/d = 16$, Fig. 5(a)), longer beam ($S/d = 24$, Fig. 5(b)) and the longest beam ($S/d = 32$, Fig. 5(c)) show considerably similar failure modes. A transverse crack initiated at tension face (bottom face) propagated upward causing catastrophic failure can be observed in each macrograph. Unlike high strength synthetic fiber-reinforced composites subjected to three-point bend loading configuration that commonly fail in their compressive faces by fiber local buckling followed by kinking due to lower compressive strength in comparison with tensile strength (Dong and Davies, 2012), these randomly oriented chopped sugar palm fiber composite samples underwent failure initiated in their tensile faces (bottom face) propagated upward very much similar with common failure modes of low strength natural fiber composites including coir fiber-reinforced concrete as reported by Yan and Chouw (2014).

Hybrid randomly oriented chopped sugar palm/unidirectional glass fiber-reinforced polyester composites. Failure modes of the hybrid fiber-reinforced polymer composite specimens for the three S/d have been depicted in Figs. 6 in the following page. Figs. 6(a) to (f) show high similarity among them. They confirm that the substitution of glass fiber for sugar palm fiber in tension side has change the failure mode from that of sugar palm fiber/polyester composite system (Figs. 5) to multiple-plane failure of hybrid sugar palm/glass fiber-reinforced polyester composite systems of various span-to-depth ratios where glass/polyester layers were separated from sugar palm fiber layer due to the existence of discontinuity generating high in-plane shear stress on the interface. Further loading would increase the nornal stress in the tension side resulting in fiber breakage. Considering that that the tensile modulus of glass fiber/polyester composites, 72,83 GPa (Sapuan et al, 2013), is much higher than that of sugar palm fiber, 3.69 GPa (Sapuan et al, 2013), when the glass fiber/polyester system underwent fiber breakage, the strain in its adjacent sugar palm fiber/polyester system had not been large enough to initiate transverse crack as can be observed in Fig. 5(a), instead, in-plane shear stress was relatively large to generate longitudinal in-plane crack (dark-color arrows) as can be observed in Figs. 5(b), (d) and (e). Partial substitution of unidirectional glass fiber placed in tension side for sugar palm fiber changes the failure mode into that of hybrid GFRP/CFRP composites where fiber breakage combined with interlayer delamination were observed (Sudarisman et al, 2009).



(a) (b)

(c) (d)

(e) (f)

Fig. 6. Failure modes of hybrid randomly oriented chopped sugar palm/unidirectional glass fiber-reinforced polyester composites. (a) S/d = 16 and r_h = 0.1, (b) S/d = 16 and r_h = 0.3, (c) S/d = 24 and r_h = 0.2, (d) S/d = 24 and r_h = 0.4, (e) S/d = 32 and r_h = 0.1, and (f) S/d = 32 and r_h = 0.4.

4. CONCLUSIONS

The effect of incorporation of glass fiber into sugar palm fiber being used for reinforcement in producing hybrid fiber composite has been investigated. It revealed that lateral load-deflection relations were found being non-linear up to close to failure. The magnitude of lateral load increases with the increase of glass fiber content up to 40 vol%. The highest increase of the magnitude of lateral load was found being 364% with respect to randomly oriented chopped sugar Failures of sugar palm fiber-reinforced polyester composites was initiated at tensile face propagated toward compressive face leading to catastrophic failure. Those of the hybrid fiber-reinforced polyester composite specimens are characterized by separation of glass fiber/polyester layer from sugar palm fiber/polyester layer producing longitudinal in-plane crack followed by breakage of glass fibers. palm fiber-reinforced polyester composite specimens.

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PHOTOS AND INFORMATION

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