Flexural Characterization of Hybrid Palm/Glass Fibers-Reinforced Epoxy Composites

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Keywords:
Flexural stress; flexural strain; flexural failure; hybrid palm/glass fibers; epoxy matrix

Abstract

Natural fiber-reinforced polymer composites are commonly weak in tension causing failure initiated at their tension side when being loaded in flexure. In order to improve such composite beam performance, palm fiber of tension side of such beams has been substituted with E-glass fiber to produce hybrid palm/E-glass fibers-reinforced epoxy composites, and their flexural stress-strain response and failure have been studied. Palm fiber was obtained from local sugar palm trees while the E-glass was selected due to its low cost and availability, and epoxy was used as matrix. Whilst the palm fiber was undergone alkaline treatment, rinsing, slow drying and chopping into ~20 mm long prior to being embedded into the matrix, the E-glass fiber was arranged longitudinally such that its tensile strength can optimally be harnessed. Composite plates with five different hybrid ratios of 0.0, 0.1, 0.2, 0.3, and 0.4, have been fabricated, cut into specimens and tested in three-point bend loading configuration in accordance with the ASTM D790 standard using span-to-depth ratios of 16, 24 and 32. Composite plates were fabricated using hand lay-up and press mold techniques. The specimens were cut from the plates using a diamond-tipped circular saw blade rotating at ~6000 rpm. It was revealed that (i) longer beams exhibited higher flexural but lower strain-to-failure, (ii) flexural strength increses with the increase of glass fiber content, (iii) shorter beams, S/d = *16, demosntrate a decrease in flexural strain to the contrary of longer beams,* S/d = *24 and* S/d = *32, with the increse of glass fiber content.*

1. INTRODUCTION

The increase of environmental awareness has impacted on the limited amount of timber product available [1] for craft and furniture industries during the last few years. Total timber products [2], i.e. logs, sawn wood and plywood, has decreased from 53,669,214 m^3 in 2012 to 40,695,999 m^3 in 2015. The decrease on timber product needs to be substituted in order to meet the demand for timber product for craft and furniture industries. Natural fiber composites possessing comparable physical and mechanical properties to those of timber may be potential alternative for the substitute.

Sugar palm fiber has been selected as reinforcement for the composite due to its availability and durability. Sugar palm plantation in Indonesia approximately covers the area of 70.000 hectares [3]. Such plantation can be found in East Kalimantan (17.794 hectares), Central Kalimantan (17.000 hectares), West Java (13.878 hectares), and the other provinces. Ciamis Regency is the main palm fiber producer in West Java Province [4], and Temanggung Regency is the center for Central Java Province where the area of palm plantation covers an area of 573,93 hectares [5]. So far, palm fiber has been utilized for producing brooms, ropes and being used as filtering materials for sanitation and water infiltration installations [4][5]. Such fiber has not been utilized by making use of its mechanical characteristics for structural materials.

Unlike high strength synthetic fiber composite beams being failed in their compressive faces [6], natural fiber composite beams are commonly failed initiated in their tension faces [7]. Thus, substitution of high strength glass fiber for natural fiber in the tensile face may improve the flexural performance of natural fiber-reinforced polymer composites. Sapiai et al [8] reported that the increase of flexural strength by ~49% and flexural modulus by ~12.5% was obtained by hybridizing kenaf with glass fibers where glass fiber was placed at both outer layers of the beams, in comparison with those of kenaf fiber-reinforced epoxy composites.

This current paper deals with improving the composite beams performance, *i.e.* flexural strength and flexural strain to failure, by partial substitution of glass fiber for natural fiber at the outermost tension side.

2. RESEARCH METHOD

Four sugar palm/glass fiber hybrid and one reference sugar palm fiber-reinforced epoxy composite plate panels were fabricated. The sugar palm fiber was obtained from local sugar palm trees. Prior to being embedded into the matrix, the fiber underwent alkaline teatment by soaking it in sodium hydroxide solution containing 5 wt% of NaOH, neutrelazing by saoaking it in plain water for 8×6 hours, rinsing in flowing water, draining, slow drying for 2 days, and cutting to produce 2 cm-long chopped sugar palm fiber. The glass fiber and epoxy were obtained from local supplier.

Whilst the chopped sugar palm fiber were randomly oriented, the glass fiber was arranged unidirectional in longitudinal direction such that optimum harnessing of its tensile strength can be achieved. The total fiber volume fraction was kept constant at 0.3, while the hybrid ratio *i.e.* glass fiber-to-total fiber volume ratio, $r_h = V_{fg}/V_{fsp}$, was varied at 0.0, 0.1, 0.2, 0.3 and 0.4. Such that five different plate panels have been fabricated, by means of hand lay-up and press molding technique. The specimen were cut from the plates using a circular saw blade rorating at ~6000 rpm to produce specimens in accordance with the ASTM D790 [9] standard. Three different span-to-depth ratios, *i.e.* 16, 24 and 32, have also been ulitized. At least five specimens were tested for each variation as suggested by the sdopted standard.

Mechanical testing was carried out in the Material Laboratory of the Department of Mechanical Engineering of Universitas Sebelas Maret, Surakarta, using a Universal Testing Machine (UTM). The output of the test are load-deflection relation data. The magnitude of flexural strength and strain were calculated using the following equatoins [9].

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

$$\varepsilon_f = \frac{6Dd}{S^2} \quad (2)$$

where:

σ_f = the magnitude of flexural strength (MPa)
F = the magnitude of lateral force (N)
S = support span (mm)

w = specimen width (mm)
d = specimen depth (mm)
ε_f = the magnitude of flexural strain (mm/mm)
D = mid point deflection (mm)

3. RESULT AND DISCUSSION

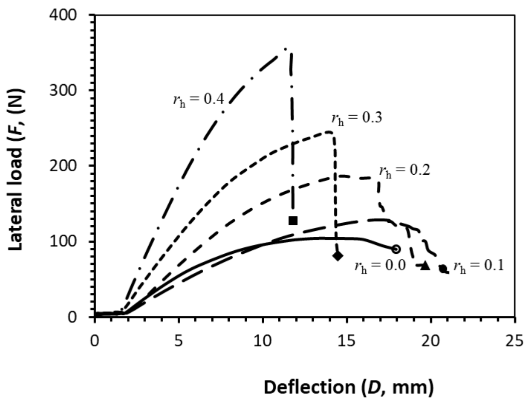
The lateral load-deflection relation data were ontained in the form of graph and numerical values. It should be noted that toe compensation must be done before the application of equations (1) and (2).

3.1. Lateral Force-Deflection Relation

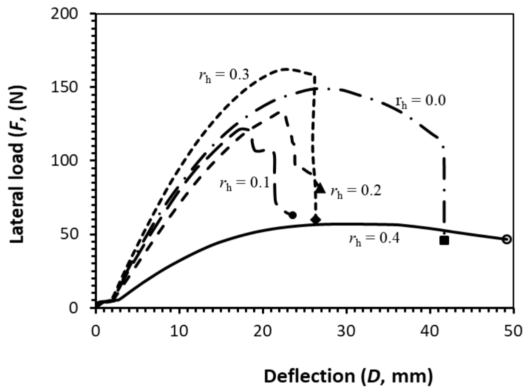
Figure 1 shows lateral force-deflection relations of representative samples of various cases. Irregular lateral force-deflection relation can be observed at the initial loading stages of figures 1(a), (b) and (c). These may be attributed to the aligning process of the specimen under loading and the support rollers of the test fixture due to imprefection of the specimen geometry inherited from the hand lay-up and manual process of plate panel fabrication.

Figures 1(a), 1(b) and 1(c) exhibit similar pattern where partial substitution of higher strength glass fiber in longitudinal direction for lower strength randomly oriented chopped sugar palm fiber at tension faces significantly increases the magnitude of load bearing capacity of the beams. The more layers being substituted the larger the increase of the magnitude of lateral load being able to support, similar to that previously reported for partial substitution of E-glass fiber for carbon fiber [10]. Although both types of fiber possess stress-strain response, due to relatively low fiber content, i.e. at maximum for r_h = 0.4, V_{fg} = 0.04 and V_{fsp} = 0.26, nonlinear stress-strain relation of the epoxy matrix dominantly affects that of the composites.

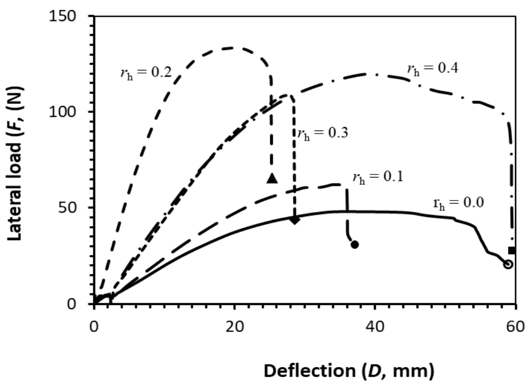
Comparing the three graphs shows that the S/d the lower the lateral maximum force although it is not fully obeying equation (1). According to equation (1a) for constant d and w, when the S increases by 50% from S/d = 16 to S/d = 24 the magnitude of F should decrease by ~33%, and when the S increases by 100% from S/d = 16 to S/d = 32 the magnitude of F should decrease by 50%. For the case of r_h = 0.0 samples, maximum lateral forces for S/d = 16, 24 and 32 are 104.2 N, 56.9 N and 48.1 N, respectively. These are slightly lower than those predicted using equation (1),



(a) *S/d* = 16



(b) *S/d* = 24



(c) *S/d* = 32

Figure 1. Lateral load-deflection relation of representative samples for various r_h and S/d

which may be attributed to the correction factor for longer beams as given in equation (1b). For r_h = 0.4 samples, these values are 356.9 N, 149.0 N and 119.7 N for *S*/*d* = 16, 24 and 32, respectively, which are significantly lower than those predicted using equation (1).

3.2. The Effect of r_h on Flexural Strength

The effect of hybrid ratio on flexural strength for various S/d has been presented in Figure 2.

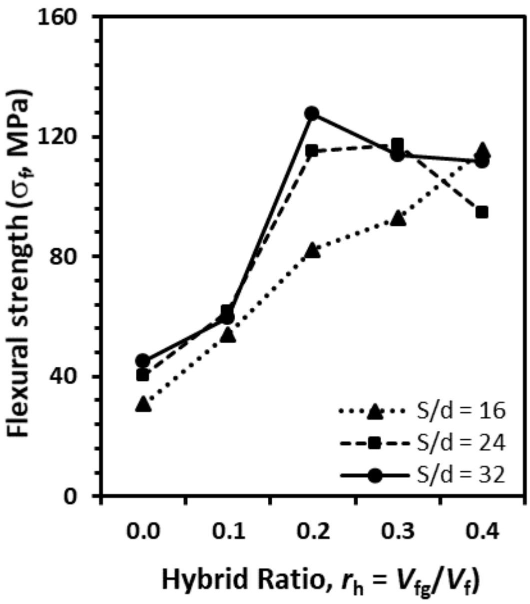


Figure 2. The effect of hybrid ratio on flexural strength for various *S*/*d*

Figure 2 shows that the larger the *S*/*d* the higher flexural strength.The decrease of shear-to-normal stress ratio may be respinsible for the increase of flexural strength as has been pointed out by the current author in previously published paper [11]. Generally speaking, the larger the *S*/*d* the fewer the sugar palm fiber that can be substituted with glass fiber to achive optimum flexural strength. The shortest beam, *S*/*d* = 16, demonstrates the increase of flexural strength with the increase of glass fiber content up to r_h = 0.4. Whilst at *S*/*d* = 24, the optimum flexural strength was achieved at r_h = 0.3 then followed by a significant decrease for further increase of r_h up to 0.4, at *S*/*d* = 32, the optimum flexural strength was achieved at r_h = 0.2 then followed by a noticable decrease for further increase of r_h up to 0.3 and 0.4.

Most noticable increase in flexural strength was obtained at ferwer subtitution of glass fiber, up to r_h = 0.2, because the high strength glass fiber placed at the outermost layer of tension side will withstand the highest normal stress created over the cross-sectional area due to bending load. The highest flexural strength (~128 MPa) was obtained at r_h = 0.2 and *S*/*d* = 32, followed by that of r_h = 0.3 and *S*/*d* = 24 (~117 MPa), and that of r_h = 0.2 and *S*/*d* = 16 (~116 MPa).

3.3. The Effect of r_h on Flexural Strain

Figure 3 shows the effect of hybrid ratio on flexural strain for the three different span-to-depth ratios.

In can be seen in the figure that, apart from those of single fiber-type composite samples, strain-to-failure increases with the increase of hybrid ratio. Considering the failure strain of the fibers being used, although that of glass fiber (3 %) is much lower than that of sugar palm fiber (22.3 %) [12], the increase of strain-to-failure for *S*/*d* = 24

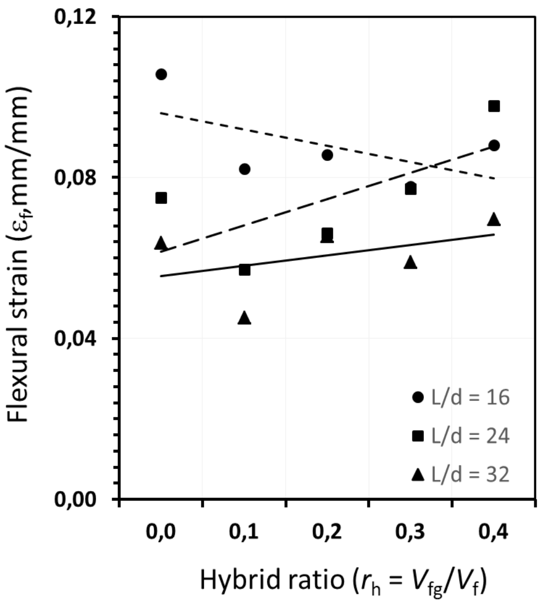


Figure 3. The effect of hybrid ratio on flexural strain for various *S*/*d*

and *S*/*d* =32 may be caused by glass fiber-epoxy matrix interfacial bonding is commonly stronger than that of sugar palm fiber-epoxy matrix. In addition, randomly oriented fiber composites commonly demonstrate more dominant matrix properties in comparison with fiber properties do. The decrease of strain-to-failure with the increase of glass fiber content for shorter beams, *S*/*d* = 16, may be attributed to its following the rule of mixtures.

4. CONCLUSION

Hybrid sugar palm/glass fiber-reinforced epoxy composite plates of five different hybrid ratios have been fabricated and flexural tests of three different span-to-depth ratios have been carried out in accordance with the ASTM D790 tetst standard. It is revealed that (i) longer beams exhibited higher flexural but lower strain-to-failure, (ii) flexural strength increses with the increase of glass fiber content, (iii) shorter beams, *S*/*d* = 16, demosntrate a decrease in flexural strain to the contrary of longer beams, *S*/*d* = 24 and *S*/*d* = 32, with the increse of glass fiber content.

ACKNOWLEDGMENT

The authors would like to thank Mr. Bambang Surono for his assistance in supervising the composite plate fabrication process.

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