

Research Article

Tensile and Compressive Properties of Woven Kenaf/Glass Sandwich Hybrid Composites

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Received 23 December 2015; Revised 26 February 2016; Accepted 1 March 2016

Academic Editor: Arthur J. Ragauskas

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Monotonic (tensile and compression) properties of woven kenaf/glass reinforced unsaturated polyester sandwich hybrid composites have been experimentally investigated. Five types of composites laminates were fabricated using a combination of hand lay-up and cold press techniques, postcured for two hours at 80°C and left for 48 hours at room temperature. The hybrid composites contained fixed six layers of glass as a shell, three on each side, whereas the number of core kenaf layers was changed in three stages to get S1, S2, and S3 hybrid composites. Composites specimens with pure glass and kenaf were also fabricated for comparison. It was found that one kenaf layer replaced about 20% of total fiber weight fraction of the composite; this leads to reducing the density of final hybrid composite by 13%. Besides, in mechanical properties perspective, there are less than 1% reduction in compression strength and 40% in tensile strength when compared to pure glass composite. Generally, the results revealed that the best performance was observed in S1, which showed a good balance of all mechanical properties determined in this work.

1. Introduction

Natural fibers can simply be defined as fibers that are not synthetic or manmade. They can be extracted from either plants or animals. Currently, industry reports identified the fact that natural fiber composites sector reached 2.1 billion U\$ in 2010, and only kenaf production reached one million tons annually [1, 2]. This highlights the increasing interest in kenaf fiber composites and ongoing researches to identify the optimal method [3, 4] or using different resin systems [5–7] to fabricate it for advanced applications. Polymer composites or hybrid composites are combinations, which are developed by putting reinforcing material in a combination of several matrices, when different types of reinforcing fibers are embedded in a single matrix or when there is a mix of both aforementioned approaches. How these hybrid composites behave is very dependent on the reinforcing fibers used in the matrix and will posses their advantages and disadvantages [8, 9]. One good thing with hybrid composites is that advantage of other fibers can overcome the disadvantage of one of the fibers used in the composite. This capability of hybrid composites makes it possible to find the best regarding quality, lightweight, and cost. The quality of underlying fiber, fibers strength, the aspect ratio of fiber, length, how easily can fiber intermingle, failure strain, orientation, and layering pattern of the fibers influence the strength of the hybrid composite [10, 11].



FIGURE 1: Kenaf and glass reinforcements.

Hybridization of natural fibers with glass reinforced unsaturated polyester has been studied by many researchers, using different fiber loading and structures under different loading conditions. In this literature, the studies on hybridization of natural/glass fibers hybrid reinforced unsaturated polyester are highlighted. Kapok/glass fibers tend to have better compressive property and strength as compared to hybrid composites made using sisal/glass fiber and kapok/sisal composites [12]. Effect of loading of glass fiber on the tensile strength and compressive properties of sisal/glass fiber hybrid composite were studied by John and Naidu [13] and they identified that hybrid composites show better tensile strength and lower flexural properties. Similarly, Ornaghi et al. [14] conducted a study in determining the variation in the mechanical strength of sisal/glass fiber hybrid composites which have different ratios of sisal and glass fibers and different fiber loadings. The tensile and flexural properties of sisal/glass fibers hybrid composites were concentrated on by Naidu et al. [15, 16]. Natural and engineered fibers are consolidated in the same matrix (unsaturated polyester) to make hybrid composites. A noteworthy change in general properties of sisal/glass fiber hybrid composites has been found. John and Naidu [17] studied the compressive properties of unsaturated polyester based sisal/glass hybrid composites with fiber stacking; in this study, chopped strand fibers were utilized to manufacture the composites. The outcomes demonstrated that 75/25% fiber volume ratio of glass/sisal had higher compressive quality contrasted with other hybrid composites.

Recently, Sharba et al. [18, 19] investigated the impact of kenaf fiber orientation on the mechanical and fatigue properties of kenaf/glass hybrid sandwich composites. In this study, three types of kenaf fibers were used, namely, nonwoven random mat, unidirectional twisted yarn, and plain-woven kenaf in asymmetric sandwich configuration with glass as the shell and kenaf as the core with a constant kenaf/glass weight ratio of 30/70% and a volume fraction of 35%. All composites were tested under tensile, compression, flexural, and fully reversed fatigue loading. Authors concluded that nonwoven kenaf hybrid composites displayed weak properties compared to other hybrid composites while woven kenaf hybrid composites have shown considerable properties through monotonic tests and high fatigue resistance when compared to other hybrid composites.

It is noticeable that although natural fiber/synthetic hybrid composites principles were used to study their mechanical properties, major differences in reported results linked to natural fiber type and showed unexpected behavior for the final hybrid composites. As "the perspectives are to obtain new materials with improved properties at low cost by using easy and chemically sustainable technologies for the environment" [20], also, the effect of woven kenaf layer number in the core of hybrid sandwich composite is not studied yet.

Therefore, in this work, the mechanical (tensile and compression) properties of woven kenaf/glass reinforced unsaturated polyester sandwich hybrid composites have been experimentally investigated to address the potential possibilities of eco-friendly/manmade fibers hybrid composites for structural applications. Five types of composites laminates were fabricated using a combination of hand lay-up and cold press technique. The hybrid composites contained fixed six layers of glass as a shell, three on each side, whereas the number of core kenaf layers was changed in three stages to get S1, S2, and S3 hybrid composites. Composites specimens with pure glass and kenaf were also fabricated for comparison.

2. Experimental Setup

2.1. Materials. The materials used in the present study are as follows: woven kenaf fabric and plain-woven E-glass EWR 400 used as a hybrid reinforcement and unsaturated polyester as binding resin mixed with 1.5% wt. of butanox M50 as a catalyst. The materials were supplied from ZKK, SDN, and BHD. In this study, the fibers used as received without the addition of any chemical substances. Figure 1 shows kenaf and glass fabrics used.

2.2. Fabrication of Composites. Prior to fabricating the composite laminates, the kenaf fiber was placed in an oven at 105°C for 24 hours in order to remove the moisture contents of fibers; the oven is supplied with a fan to circulate the air inside the oven's chamber and ensure dry fiber. A combination of hand lay-up and cold press techniques was used to fabricate

Composite sequence	Fibers weight ratio (%)		Fiber fraction (%)				
	Glass	Kenaf	Weight	Volume	Density (g/cm ³)	Void contents (%)	Thickness (mm)
6 glass	100	0	50.1	31.3	1.53	1.6	3.25
3G-1K-3G (S1)	78	22	38.4	26.8	1.37	2.2	5.85
3G-2K-3G (S2)	66	34	36.8	26.3	1.32	2.5	7.75
3G-3K-3G (S3)	54	46	36.2	29.1	1.29	4.5	9.90
3 kenaf	0	100	25.2	24.4	1.18	1.4	6.95

TABLE 1: Designation and physical properties of hybrid composites.

the composites panel. Then, the composite was placed for 1 hour under cold press. Finally, postcuring is applied to place the composites inside the oven for 2 hours at 80°C and then they were left for 48 hours at room temperature before cutting them to required shapes for tests. In this study, three types of hybrid composites were fabricated in a sandwich configuration by placing 3 layers of glass on each side and changing the number of kenaf layers in the core; the change was made in three stages by placing 1, 2, and 3 layers of kenaf. For comparison purposes, six layers of glass and three layers of kenaf composites are fabricated as well.

The experimental density of composites was measured using Archimedes approach following the standard (ASTM D-792) with distilled water and sensitive digital balance with three significant numbers, five samples were measured, and the average value was recorded. The void contents of composites were determined using (1), while the fiber volume fractions of composites were calculated using (2). Table 1 shows the designation and physical properties of all the composites laminate fabricated:

Void content (%) =
$$1 - \rho_c \left[\frac{w_{f_1}}{\rho_{f_1}} + \frac{w_{f_2}}{\rho_{f_2}} + \frac{w_m}{\rho_m} \right]$$
 (1)
* 100%.

where w_f , w_m are the weight fractions of fibers and matrix. And ρ_c , ρ_f , and ρ_m are the densities of the composite, fiber, and matrix, respectively. Consider

$$v_f \% = \left[\frac{(w_k/\rho_k) + (w_g/\rho_g)}{(w_k/\rho_k) + (w_g/\rho_g) + (w_m/\rho_m)} \right] * 100\%, \quad (2)$$

where w_k , w_g , and w_m are the weight fractions of kenaf, glass, and matrix. And ρ_k , ρ_g , and ρ_m are the densities of kenaf, glass, and matrix.

2.3. Mechanical Tests. Tensile and compression tests were conducted for each group of hybrid composites; the tensile samples preparation and testing procedure was followed according to ASTM D-3039 with a crosshead speed of 2 mm/min, while compression samples and test follow ASTM D-3410 with a crosshead speed of 1 mm/min. Both tests were conducted using universal testing machine INSTRON 3382 equipped with 100 kN load cell.

The specimens were prepared from composite laminate using a wheel saw and then the edges were smoothed



FIGURE 2: Tensile strength and strain of composites.

using sand paper. The dimensions of tensile samples were 250 mm length and 25 mm wide with 170 mm-gauge length. The compression specimens size was 140 mm in length and 25 mm in width with a minimum gauge length of 13 mm to prevent the buckling effect during the compression test. In each test, five samples from each composite were tested, and the average value was determined and recorded as a result.

2.4. Morphological Test. The Scanning Electron Microscope (SEM) microimages were conducted using SEM model (Hitachi S-3400N VP-SEM). The tensile fracture surface of S1 hybrid composite was cut to suitable length and prepared for SEM test; the aim of the test is to get a closer view of the bonding between glass and kenaf and their failure mode.

3. Results and Discussion

3.1. Tensile Properties. Tensile tests for three sequences of kenaf/glass hybrid composites and for pure glass and pure kenaf reinforced unsaturated polyester were conducted. The tensile strength of hybrid composites is shown in Figure 2. From results, it can be found that glass reinforced composites possess the superior strength of 215 MPa compared to the poor strength of kenaf-based composites of 35 MPa. In between, it can be noticed that hybridization process of kenaf

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FIGURE 3: Tensile modulus of composites.

with glass significantly improves the overall mechanical properties of hybrid composites compared to kenaf composites.

From the other view, it can be noticed that adding more kenaf to composite tends to reduce the tensile strength of the hybrid composite due to kenaf low tensile strength but with a little effect on tensile modulus as shown in Figure 3, while there is no considered effect on tensile failure strain of hybrid composites.

In general, S1 hybrid composite shows the best performance among the other hybrid composites and offers an excellent balance of weight to strength ratio and also reduces the use of nonbiodegradable material to lower the impact of using synthetic fibers. A similar trend of results was reported by Almeida Júnior et al. [21].

The microimages also showed that SI hybrid composite possesses a good adhesion between glass and kenaf which leads to higher tensile strength. Also, the fiber failure mode gives an indication of good load transfer through fibers and matrix as shown in Figure 4.

3.2. Compressive Properties. Figure 5 shows compressive strength and strain of woven kenaf/glass hybrid composites and also glass and kenaf reinforced unsaturated polyester to get a full comparison of the effect of hybridization. It can be observed that addition of kenaf layer to the composites has little or no effect on compressive strength of hybrid composites; the strength values were ranging from 85 to 90 MPa. In Figure 6, compressive modulus has been affected by hybridization process, and S1 possesses a higher compressive modulus of 16 GPa compared to 15 GPa to glass composite; regarding compressive strain, the trend observed that the more the kenaf layers added, the higher the compressive strain of hybrid composites observed due to ductility behaviour of kenaf fiber when compared to glass fibers; this conclusion is also supported by Rao et al. [22]. Compression strength and modules are relevant design parameters because composites are frequently used in flexure, and the lower compressive strength will lead to high bending



FIGURE 4: Microimage of tensile failure surface of S1 hybrid composite, showing kenaf, glass fibers, and unsaturated polyester (UP) resin.



FIGURE 5: Compressive strength and strain of composites.

and instant failure [23, 24]. Finally, in order to generate an overall comparison of the main parameters that have been affected by changing the number of core kenaf layers in hybrid sandwich composites, Figure 7 illustrated the trend of these parameters through the hybrid composites studied in this work.

4. Conclusions

Briefly, the hybridization of woven kenaf/glass reinforced hybrid composite was successfully studied and evaluated. It was found that increasing kenaf fiber to composite results in reduction in tensile strength within acceptable range and a slight effect on tensile modulus, while there is no observed change in tensile strain of hybrid composites. In compressive



FIGURE 6: Compressive modulus of composites.



FIGURE 7: Trend of tensile strength, compressive strength, and density of composites with changing number of core kenaf layers.

loading condition, it was noticed that hybridization process has small or no effect on compressive strength of hybrid composites and S1 hybrid composites possess the best compressive modulus. However, the compressive strain of hybrid composite was found to be increased by adding kenaf layer to hybrid composites. Finally, SEM microimages showed a good adhesion between glass and woven kenaf and an excellent compatibility as hybrid reinforcements.

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

Acknowledgments

This work is supported by UPM under GP-IPS 9438714 and FRGS/5524499 Grants. The authors would like to express their gratitude and sincere appreciation to the Ministry of Higher Education & Scientific Research of Iraq for its scientific assistance and financial support.

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