Monotonic and fatigue properties of kenaf /glass hybrid composites under fully reversed cyclic loading

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Abstract. The aim of this work is to investigate the effect of hybridization of kenaf-glass fibers reinforced unsaturated polyester on fatigue life. Three types of composites were fabricated using hands lay-up method, namely, kenaf, glass, and hybrid composites with 30% of weight fraction, the hybrid was mixed with a ratio of kenaf: glass 10:20. Monotonic tests were achieved (Tensile and compression) to determine the fatigue stress levels. Fully reversed fatigue loading was conducted with a stress ratio of -1 and stress levels 55-85 % of the ultimate static stresses, all tests were conducted at 10 Hz of frequency. The results proof a positive hybrid composite; also agree with the rule of mixture that can predict the final composite properties. Moreover, it’s been observed an improvement in overall mechanical properties of hybrid compared to individual ones.

1. Introduction

Composites are an important category of materials for engineering applications. They form an essential part in the design process in many sectors, including the automotive, marine and aircraft industries. Over the past decade, there has been an increased demand for “green” or natural-fiber reinforced composites [1, 2].

Natural fiber reinforced plastics materials are low cost, light-weighted, have enhanced mechanical properties, free from health hazards, and thus have the potential for structural applications. Furthermore, studies were tried to extend the usage of natural fiber reinforced composites and improving their performance by using woven structure of natural fibers reinforced composites especially kenaf fiber [3, 4]. Despite the attractiveness of natural fiber reinforced polymer matrix composites, they suffer from lower modulus, lower strength, and relatively poor moisture resistance compared to synthetic fiber reinforced composites such as glass fiber reinforced plastics (GFRP) [5].

A combination of synthetic fiber with natural fibers in one resin to form a new hybrid laminated composites with an interesting balance to the material pros and cons of the individual ones is an
alternative way to discover new materials to consumers. Hybrid composites are extensively used in many engineering applications [6].

Several studies reported the fatigue behavior of natural fiber reinforced composites and reported a considerable fatigue resistance. Abdullah et al. [7] investigated the fatigue life and fiber loading effect of unidirectional kenaf reinforced epoxy under tension-tension fatigue loading, used a stress ratio of 0.5 at 5 stress levels and 5 Hz of frequency. It was found that kenaf fiber with higher volume fraction showed better fatigue life. Kalam et al. [8] studied the effect of oil palm fruit punch fiber loading on fatigue properties of oil palm reinforced epoxy composite. The uniaxial tension-tension fatigue loading was conducted with 0.1 and 0.5 of stress ratios and 20 Hz of frequency. They concluded that increasing the fiber content reduced the fatigue life of composites. Liang et al. [9] reported the fatigue behaviors of flax reinforced epoxy under uniaxial tension-tension loading under 0.1 stress ratio and 5 Hz frequency. Recently, Abdullah et al. [10] investigated the fatigue endurance of unidirectional Arenga Pinnata fiber reinforced epoxy under tension-tension mode with stress ratio of 0.1 and 10 Hz frequency and found that the fatigue life improving by reducing the stress level.

Despite of the considerable fatigue endurance of natural fibers based composites, it can be found that only exists in low cyclic fatigue regime which limited the applications of natural fibers composites. As a result, a new interested trend of using natural fibers by hybridizes them with synthetic fibers to improve their strength and extend the range of their applications. Regarding fatigue life of natural-synthetic hybrid composites, it can be noticed that a few studies reported a fatigue results of natural-synthetic hybrid composites. Thew et al. [11] used Bamboo-glass reinforced Polypropylene hybrid composites in sandwich sequence, compared to pure bamboo it was found that the hybrid has shown better fatigue life and more resistant to environmental aging. Bagheri et al. [12] has selected flax-carbon reinforced epoxy hybrid composite for biomedical application. Even though, there was no complete comparison with individual fibers in this study, the results showed improvement in fatigue strength compared with previous work on pure flax.

This work presents the mechanical properties of non-woven kenaf; woven roving glass and kenaf-glass hybrid reinforced composites were studied and characterize the fatigue performance of composites through S-N diagram, specifically the effect of hybridization on uniaxial tension-compression cyclic loading. The results were analyzed and a comparison was made among the three campsites. The tension – compression mode was selected in fatigue test at a stress level of (-1) under four stress levels from 55-85 % of ultimate stress of composite.

2. Experimental details
The materials selected for this study were non-woven kenaf randomly oriented, woven roving, E- glass EWR600 type which used as a reinforcement, and unsaturated polyester with 2% of catalyst as a matrix as shown in figure 1. Both fibers were used as received without any chemical or thermal treatment.

Figure 1. Kenaf and Glass fibers used to fabricate composites.
Composite laminates were fabricated using hands lay-up technique, two steel plates covered with transparent paper to ensure a good surface finishing. The reinforcements were used without any pretreatment. Three types of composites were fabricated (pure glass, kenaf-glass and pure kenaf) with an orthoparthetic unsaturated polyester mixed with 2 wt% Butanox M60 MEKP catalyst. A static weight of 15 kg was used for post curing for 24 hours before cutting the samples. The fiber weight fraction \( W_f \) of composites was calculated using the ratio of fiber weight to total composite weight, the weight fraction of glass/UP laminate was 45%, for kenaf/UP 20% and for hybrid composite 30% with a ratio of kenaf: glass 10:20% of fiber weight, the final samples that have been prepared from composite laminates as shown in figure 2.

![Figure 2](image-url)

**Figure 2.** The final samples prepared for testing (a) tensile and (b) compression.

### 3. Mechanical Tests

In order to achieve fatigue, stress levels, the ultimate tensile and compression stresses should be determined from monotonic tests. The ultimate tensile stress for composites was measured through tensile test and conducted according to ASTM D3039, on universal testing machine Instron 3366 equipped with 100kN load cell. Four specimens of (250 mm length and 25 mm wide) were tested with a crosshead speed of 2 mm/min and the average stress was taken.

The ultimate compressive stress for composites was calculated from the static compression test, which conducted according to ASTM D-3410, on universal instron 3366 of 100 kN the load cell. Four specimens (140mm length and 15 wide) were tested at a crosshead speed of 1 mm/min and the average compression stress was taken. A gauge length of 14 mm was used to minimize buckling effect, according to test standard recommendation.

Fatigue specimens were prepared and the fatigue test procedure was followed according to ISO 13003. Fully reversed loading condition (tension-compression) fatigue test was conducted by servo-hydraulic universal testing machine Instron 3374 equipped with 100 kN unit cell, the stress ratio of (-1) at 10 Hz of frequency. The test was performed at four stress levels started from 55-85% of the static ultimate stress of composite. Eight samples (120 mm length and 15 mm wide with minimum gauge length to prevent buckling) were prepared for each group of material in terms of two samples per stress level.

### 4. Result and Discussion

The stress-strain results show in figure 3, the effect of hybridization of kenaf-glass reinforced unsaturated polyester. Glass fiber composite presents superior tensile properties with ultimate tensile stress 148 MPa, and poor ultimate tensile stress for kenaf mat fiber composite of 12 MPa. In between
10% of kenaf and 20% of glass fiber of fiber weight gives a significant improvement compared to pure kenaf to reach for 48 MPa of UTS for hybrid composite as shown in figure 4. This called positive effect of hybridization when the main parameter improved compared to individual material [13]. It’s clear that the hybridization in this study follow the rule of mixture, especially for the tensile properties (UTS, elongation at break and the tensile modulus) and the range value of properties lie between the two individual ones, similar trend were reported in previous studies [14-17].

![Figure 3](image1.png)

**Figure 3.** Stress-Strain relations of glass, hybrid and kenaf reinforced UP.

![Figure 4](image2.png)

**Figure 4.** Comparison of mechanical properties of three types of composite.

On the other hand the compression results show the relatively lower value of the ultimate compression stress compared to tensile stress and it was just 38 MPa, the hybridization effect was
more noticeable in compression test and shows higher values of average 42 MPa as shown in figure 5. This can be explained due to the high compression stress of kenaf fiber. The failure modes of composites studied, matrix cracking and fiber breakage was the general mode for glass and kenaf fiber composites, while the hybrid showed some fiber pull out and delamination near to failure zone, the main reason of this is the difference in strain of the two fibers that can delay or speed the fiber breakage failure [18].

![Figure 5. Monotonic testing of composites (a) Tensile of hybrid; (b) Tensile of glass; (c) compression of glass.](image)

The fatigue S-N diagram as shown in figure 6 presents the results of three types of composites tested in this work under the most aggressive mode, fully reversed cyclic loading. The results display a normal scattering in their values, especially in hybrid and kenaf composites due to a variety of natural fiber behavior. The inconsistency in data scatter could be due to the presence of void in the specimen tested. Other data were scattered in a reasonable range [8]. It is been observed that the number of cycle to fail increases when maximum stress reduced.

The failure modes of the specimens under cyclic loading was monitored during its fatigue life and found there was a matrix cracking in the early stage of fatigue test. The final failure mode was observed in static tensile and tension-compression fatigue is similar, in brittle manner with a serrate fracture surface and showed small delamination area with fiber splitting for hybrid composite as shown in figure 7. Similar observations were also made by [19].
The figure 8 compared the stiffness degradation at the same duration of fatigue life for the three types of composites and it’s surprising that stiffness degradation of kenaf composite slower than glass fiber composite, this can be explained due to the ability of natural fiber continuously transfer loads onto adjacent fibers, this is also supported by the observation reported by [20].
5. Conclusion

In conclusion, the main point of this study is to identify the hybridization effect on the fatigue life of natural-synthetic fibers reinforced unsaturated polyester. The results proof a positive hybrid composite; also agree with the rule of mixture that can predict the final composite properties. Kenaf-glass hybrid composite shows good tensile properties compared to pure kenaf and better compression stress compared to pure glass, which gives an overall improvement in mechanical properties. The kenaf fiber composite can be used for structural and aerospace applications due to cost-effective properties.

Acknowledgement

This work is supported by UPM under GP-IPS 9438714 grant. 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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