Tension Fatigue Behaviour of Woven Bamboo and Glass Fiber Reinforced Epoxy Hybrid Composites

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Abstract. The aim of this paper is to investigate the influence of stacking sequence of multi layered woven bamboo and glass fibers reinforced with epoxy matrix composites under static tensile and tension-tension fatigue loading. Six layers of bamboo fiber and seven layers of glass fiber has been used to prepare the samples by hand lay-up technique with [0°/90°] and [±45°]. Extensive fatigue tests (frequency 3 Hz and stress ratio 0.1) were performed in accordance with ASTM D3479. In constant amplitude and load-controlled tests, a percentage of the ultimate tensile strength (UTS) was applied to the composite specimens. Five stress levels were applied from 90% of UTS, and decreased in steps of 10% of UTS. The obtained results were used to draw S/N Curve and [0°/90°] lay-ups show better fatigue strength than [±45] laminate.

1. Introduction

Synthetic fibers are reinforced with epoxy composites provide the high strength benefits and stiffness to weight ratio as compared for conventional composite materials. In spite of there are benefits, the widespread use of synthetic fiber composites has a tendency to decrease because of their adverse effect on environmental issues and high initial costs [1]. Composites made of natural fibers provide many useful properties such as low-density & yielding relatively light-weight composite materials. Therefore, the increased interest in natural fiber based polymeric composites to substitute conventional synthetic fibers in some useful applications [2,3]. The disadvantage of natural fiber are absorbed more moisture. Therefore, the use of natural fibers alone in polymer matrix is not adequate in satisfactory needs of fiber reinforced polymeric composites. Due to this issue, natural fibers maybe combined with synthetic fibers with the same matrix materials provides the best benefits of the properties of both synthetic and natural fibers. This results in a hybrid type of composite materials and has improved mechanical properties than a natural fiber reinforced polymer materials [4–7]. Gassan investigated the effect of type of fiber, fiber architecture (woven and unidirectional), fiber & interphase properties and type of resin on fatigue properties [8]. It was suggested that natural fibers with unidirectional architecture as well as a higher strength and modulus had god fatigue life and better resistance to damage origination. Vasconcellos et al. [9] investigated the cyclic fatigue behaviour of a woven hemp epoxy based composites. Cyclic fatigue tests were conducted with a stress ratio (R=0.1), frequency of
1 Hz and different levels of maximum applied loading. The obtained results were allowed a complete description of damage mechanisms developed in hemp fiber reinforced epoxy composites and three stages damage mechanisms for fatigue tests. Asgarinia et al. investigated the hybridization of flax and glass fiber on their fatigue properties [10]. Authors concluded that better fatigue performance of flax fibers comparable to glass fibers had shown the beneficial in load-bearing applications. Aidy et al. investigated the fatigue and fracture properties of woven bamboo fiber reinforced composites. The fatigue strength of 30 MPa was obtained with highest 1*10⁶ cycles. The Research of study finding suggested that the bamboo strips on unsaturated polyester as provided relatively better fatigue and fracture properties and a good method of reinforcing fibers to fracture failures and fatigue [11]. Padmaraj et al.[12] evaluated the fatigue life evaluation of multi layered jute fiber/epoxy composites. Laminates were fabricated by woven jute fibers with different fiber stacking [0-90°, (±45°)], 0-90°]. Tension-Tension fatigue tests were conducted with a constant stress ratio of 0.1 and obtained results were used to draw S/N Curve with power law equation. Against this background, the current investigation has been undertaken to study the fatigue behaviour of woven bamboo/glass fiber reinforced epoxy hybrid composite laminates fabricated with a stacking sequence of [0°-90°] and [±45°]. An experimental study is performed at five stress levels use axial tension-tension fatigue loading mode at a stress ratio of 0.1 and frequency of 3 Hz.

2. Materials and Methods
The composition and properties of the bi-directional bamboo and glass fiber reinforced epoxy composites used in the current study.

2.1. Raw Materials
The present work uses woven bamboo fabrics and glass fabrics in the epoxy matrix to prepare a series of hybrid composites. Bamboo is an orthotropic material with high strength along longitudinal direction as shown in figure 1(a). Woven Bamboo fiber and E-Glass fiber mats are purchased by local supplier in Bengaluru, Karnataka. The E-glass plain with an areal weight of 210 g/m² and Bamboo with an areal weight of 230 g/m². Figure 1(b) shows the bi-directional E-Glass fiber mat used during fabrication of samples.

Matrix Material: The epoxy resin used in the investigation is general purpose quick curing, medium viscosity epoxy resin HSC 7600 and the hardener used is HSC 8210. Both resin and hardener procured from the Hindusthan Urban Infrastructure Ltd., Kolkata, West Bengal (India).
2.2. Sample preparation

Composite laminates were fabricated by usual hand lay-up technique followed by light compression molding technique. The mould was prepared with mild steel of size 350 * 350 mm. It contains of two mild steel plates, lower die with rectangular slot and upper die with flat surface. Initially the mould was thoroughly cleaned by thinner solution and then coated with release agent used to facilitate easy removal of the composite laminate. The mold was allowed to dry for 20 minutes. The composite laminate consists of seven layers of glass (0°-90°) fibers and six layers of bamboo (0°-90°) fibers were placed alternately until the desired thickness might achieved. The laminates were prepared from bamboo and glass fabrics of dimension 300*300*5 mm. The epoxy resin was mixed with hardener in the proportion of 10:1 as per manufacturer recommendations and then poured onto each layer of woven fabric and remove entrapped air bubbles if present. As soon as the curing process was completed, mould was opened and the laminate was taken out carefully. Then further curing was done in hot oven at temperature of 45 °C for around 3 hours. The same procedure was repeatedly adopted to make other composite laminate with ±45°.

2.3. Density and void fraction measurement

The experimental density of the different composite samples with polymeric matrix can be determined using the liquid displacement method based on the Archimedes principle according to the standard ASTM D 792. Experimental was measured by immersed a specimen of dimension 20 mm*20 mm in a beaker. By this method, the volume of the sample is estimate by the mass of the volume that is displaced when the sample is submerged in a liquid. The experimental density of composite samples are determined from the equation 1.

$$\rho_{exp} = \frac{W_a}{W_a - W_L} \times \rho_s$$  \hspace{1cm} (1)

Where \( W_a \) & \( W_L \) represents weight of the sample in air and weight of the sample in liquid respectively. \( \rho_s \) stands the density of solvent used.

The theoretical density of the hybrid composite materials can be obtained from equation 2.

$$\rho_t = \frac{1}{\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}}$$  \hspace{1cm} (2)

Where, the suffix ‘f’, ‘m’ and ‘t’ stand for the fiber, matrix and theoretical density of composite materials respectively.

The void content of composite sample has been evaluated as per ASTM D-2734-70. Volume fraction of voids \( V_v \) in the hybrid composite specimens are obtained from equation 3.

$$V_v = \frac{\rho_t - \rho_{exp}}{\rho_t}$$  \hspace{1cm} (3)

Where \( \rho_t \) and \( \rho_{exp} \) stands for the theoretical and actual density of the composite materials. The densities of epoxy resin, glass fiber, and bamboo fiber obtained from the supplier’s data sheet are 1.2, 2.54, and 1.2 g/cm³ respectively.

2.4. Tensile Tests

The tensile test is conducted in the universal testing machine of servo-hydraulic test systems with 50 kN capacity in load cells. A flat rectangular shaped specimen of 250 mm length and 25 mm width has been tested as per ASTM D3039. Specimens were placed in the grips and pulled at a constant strain rate of 5mm/min until failure occurred. A complete tensile profile will be obtained as it is continued to stretch until it breaks. Total five number of specimens are tested for each specimen and mean values
are reported on UTM used for tensile testing. Then, the ultimate tensile strength (UTS) is obtained from equation 4.

\[ UTS = \frac{P}{b \times d} \]

Where ‘P’ is Maximum load (kN), ‘b’ is width (mm), and ‘d’ is the thickness of specimen (mm).

2.5. Fatigue Tests
The tension fatigue behaviour of developed composite laminate was analysed with ASTM D3479. Samples were fabricated into rectangular cross-sections (250*25*5mm³) with a gage length of 150 mm and 25 mm end tabs as shown in figure 2(a). The tabs (50mm*25mm*3mm) were made from aluminium and were bonded by the epoxy resin to both ends in order to avoid premature failure and slippage. Fatigue tests were performed in constant amplitude load mode and loading pattern controlled using sinusoidal waveform at a stress ratio of 0.1. For each of the five stress levels ranging from 0.5 to 0.9 UTS, by increments of 0.1 UTS. The material of fatigue life is impact by frequency; higher frequency results in self-heating occurs in laminates [13]. To minimise the impact of self-heating tests were performed at a frequency of 3 Hz. From BISS make, UTM equipped with fatigue setup as shown in figure 2(b), specimens to failure and stress v/s number of cycles (S/N Diagram) will be recorded by computer data acquisition system.

![Figure 2](image_url)

Figure 2. (a) Geometry of the fatigue specimens; (b) Loading set-up in BISS make UTM

3. Results and Discussion
Density of a composite material would depend on the relative proportion of the reinforcing and matrix materials. The measured and the theoretical density values of a composite material are not same due to the presence of micro voids and pores. These micro voids and pores are significantly influence the mechanical properties and even the accomplishment of composites. In the current work, the theoretical and measured densities of bamboo-glass fiber reinforced epoxy composites are presented in table 1. Five specimens of each laminate were measured for accuracy and then mean value of the experimental density was reported. It is observed that the theoretical densities evaluated from weight fractions are not same as the experimental densities. It is evident from table 1 that both theoretical and experimental density values are found maximum for [±45°] fiber stacking sequence.
Table 1. Density and void content of bamboo-glass fiber reinforced hybrid epoxy composites

| Stacking Sequence | Theoretical density (g/cm$^3$) | Measured density (g/cm$^3$) | Volume fraction of voids (%) |
|-------------------|---------------------------------|-----------------------------|-----------------------------|
| 0°/90°            | 1.344                           | 1.3220                      | 1.64                        |
| ±45°              | 1.357                           | 1.3390                      | 1.33                        |

Laminate with [0°/90°] and [±45°] stacking sequence lay-ups are tested in the universal testing machine to find the tensile properties. Figure 3 describes the load v/s elongation curve obtained during a tensile test. The load can increase linearly with respect to elongation for both the composite laminates in the beginning and then later varies with non-linear relationship. Laminate with [0°/90°] fiber stacking sequence withstands a maximum load of 12.75 kN and [±45°] composite laminate shows a maximum load of 11.89 kN. For [0°/90°] laminates, the measured average tensile strength is 93.5 MPa for an elongation of around 4.7% and for [±45°] specimens, the average tensile strength is 88.25 MPa with an elongation of around 4.3% which agrees with the published literatures.

The maximum value of tensile strength obtained from the tensile test was used for designing a fatigue test. Fatigue tests were conducted on three specimens for five stress levels, each prepare composite laminates: [0°/90°] and [±45°]. The S/N curves obtained from fatigue tests results are presented in figure 4: the maximum stress is drawn versus the logarithm of the number of failure fatigue cycles. The comparison of experimental S/N curves obtained for [0°/90°] and [±45°] composites shows that both laminates exhibit a gradual decreasing in fatigue cycles with increasing in stress levels of fatigue, with some dispersion in fatigue life for a given $\sigma_{\text{max}}$ level. Experimental results obtained from fatigue test were presented a linear fit based on the semi log linear relationship between stress level and the equation 5 model based linear regression analysis [14,15]

$$\frac{\sigma_{\text{max}}}{\sigma_{\text{UTS}}} = m \cdot \log(N_f) + b$$

(5)
Where, $\sigma_{\text{max}}$ is the maximum absolute stress applied (MPa), $\sigma_{\text{UTS}}$ is the ultimate tensile strength (MPa), $m$ is the slope of S/N curve, $N_f$ is the number of cycles to failure, and $b$ is the material fatigue strength co-efficient.

The values are agreeing to the published results. The accuracy of the result represented by $R^2 = 0.9767$ and these values with limit [14,16]

4. Conclusions
Based on fatigue properties of woven bamboo and composites glass hybrid epoxy, the following conclusions are made:

- The successful fabrication of woven bamboo and glass fiber epoxy hybrid composites were possible by usual hand lay-up technique.
- The tensile strength of the composites is governed by the type of fiber stacking sequence. Composite laminate with $0^\circ/90^\circ$ fiber orientation yielded a tensile strength of 93.50 N/mm$^2$, which was higher when compared with $\pm45^\circ$ laminate.
- Fatigue characterisation of woven bamboo and glass fiber reinforced epoxy composites laminates on tension fatigue test at a stress ratio of 0.1 and frequency of 3 Hz was presented.

Finally, it is concluded that the hybrid polymer composite with woven bamboo and glass fiber could be used in the industrial applications of automotive sector where the structures are under the operation of cyclic loadings.

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