Fatigue Behaviour and Life Assessment of Jute-epoxy Composites under Tension-Tension Loading

Padmaraj N H¹, Chethan K N¹, Pavan¹, Onkar Anand¹
¹Department of Aeronautical and Automobile Engineering, Manipal Institute of Technology, Manipal University, Manipal, India- 576104

E-mail: padmaraj.nh@manipal.edu

Abstract. The present study involves fabrication and fatigue life assessment of multi-layered, woven jute fibres with epoxy matrix composites. Jute fabric were treated with 1N sodium hydroxide solution for a duration of 6 hours. Alkali treatment was done to modify internal structure as well as surface properties of fibre. Laminates were fabricated by laying up multi layered woven jute fabric at varying angle [0-90°/ (±45°)₂/0-90°]. Vacuum bagging method was used to reduce the void content and thus increase the quality of composites. Tension-Tension fatigue tests were performed with a constant fatigue stress ratio (R=0.1) and results obtained from the tests were used to plot S-N Curve. A model based on power law equation was used for curve fitting.

1. Introduction

Fibre reinforced polymer material have been used in large number of applications because of their inherent advantages such as low cost of production, easiness in fabrication and good load carrying properties as compared to neat polymer resins. Reinforcements in polymer can either be synthetic or natural. Synthetic fibres such as glass, carbon etc. have high specific strength but field of applications are limited due to higher cost of production. Recently there is an increased interest in natural composites due to their reinforcement with natural fibres. Since natural fibres give good property at lower cost of production, jute fibre was chosen for this study. With time, there has been increasing attempts to use natural fibre in place of their synthetic counterparts in fibre reinforced composites (FRC). Multiple studies have been conducted on natural fibres such as kenaf, hemp and sisal as alternatives for glass fibres [1]–[5]. Non-edible fibres present potentially limitless supply without compromising sustainability.

Hossain et al.[6] used bidirectional jute-epoxy composites with vacuum assisted resin infiltration methods taking jute fibre preform in different staking sequences. In all cases, the fibre volume fraction is kept as 25%. Fabricated aggregates were categorized by tensile and three-point bending tests and outcomes thus achieved were related to theoretical values. In case of unidirectional oriented and cross-ply laminate, longitudinal tensile strength came out to be greater compared to transverse way. Nevertheless, for bi-directional laminate, tensile strength in both ways were found to be precisely close to each kind. In case of all fabricated materials, author discovered experimental outcomes which indicated tensile characteristics of the established materials being strongly reliant on the tensile strength of jute fibre and tensile characteristics of jute fibre are much flaw sensitive.
Gassan[7] studied the tension–tension fatigue performance of different natural fibre reinforced plastics. The composites were reinforced by flax and jute yarns with epoxy, polyester & polypropylene matrix. It was found, that natural fibre reinforced plastics with developed fibre strength, stronger fibre–matrix linkage or greater fibre fractions have higher critical loadings for damage origination and greater failure loadings. Additionally, reduction of damage propagation rates was also observed. In addition, unidirectional composites were less sensitive to fatigue and fatigue induced damage.

Result have also showed the significant effect of fibre loading on the mechanical properties of the laminates. Also, the formation of voids in the composites is an influencing factor on the mechanical properties. The hardness, tensile characteristics and impact strength of material rises with fibre loading. Properties like flexural strength and inter-laminar shear strength are influenced by void content in the composites[8].

Surface modification of natural fibres such as treatment with alkali solutions results in optimization of properties. This optimization occurs mostly due to fibre shrinkage after treatment which in turn affect the fibre structure significantly. As a result, mechanical properties of fibres such as tensile strength, Young’s Modulus and hardness are improved[4], [9], [10].

2. Methodology
2.1 Materials

Lapox L-12 Epoxy resin and K-6 Hardener were provided by Yuje Enterprises, Bangalore, India. Table 1 shows the technical details of epoxy resin system. Woven jute mat was procured from Canara Coir Depot, Mangalore. The procured jute fibres were cut into the size of 250x250 mm². The layup arrangement of [0-90⁰/ (±45⁰)²/0-90⁰] was used i.e. four ply per laminate. Sodium hydroxide (NaOH) solution was used for surface treatment of the jute fibres. The fibres were treated with 1N NaOH solution for 6 hours and later rinsed under running water. The treated fibres were dried at room temperature for a day. The GSM of treated fibres was found to be 245.7 g/m². Figure 1 shows the woven jute fabrics.

| Epoxy Resin | Lapox L-12 (ARL-12) |
|-------------|---------------------|
| Brand Name: | Liquid epoxy resin  |
| Conventional Name: | based on bisphenol-A |
| Viscosity at 25°C | Medium viscosity, 9000-12000mPa.s |
| Epoxy value | 5.2-5.5 eq./kg |
| Epoxide equivalent | 182-192 gm/eq |
| Colour | Colourless |
| Compressive strength of cured resin | 110-120 N/mm² |
| Flexure strength | 130-150 N/mm² |
| Tensile strength of cured resin | 50-60 N/mm² |
| Impact strength | 17-20 KJ/mm² |
| Modulus of Elasticity | 4400-4600 N/mm² |
2.2 Fabrication

The composites were prepared according to the above layup using hand layup process. Two mats of 0-90° orientation were kept on the face side and two mats of ±45° orientation were placed in between them. The layup was placed on a base plate and inside vacuum bagging setup for curing under 0.6 bar of vacuum and at room temperature of 27°C for 30 minutes. Laminates were removed after 24 hours. The specimens to be tested were individually cut from the laminate as per ASTM D 3039.

2.3 Tensile Tests

Tensile tests were conducted on specimens to find out the ultimate tensile strength to determine the static stress for fatigue testing. Tests was carried out according to ASTM standard D3039 and five samples were tested in BiSS make universal fatigue testing machine. The dimensions of the samples were 250x25x4mm. The specimens showed brittle kind of sudden failure as shown in figure 2.

Figure 1. Bidirectional woven jute fibers

Figure 2. Specimens after Tensile Test
2.4 Density and Percentage Void

Experimental density calculation of the specimen was done as per ASTM standard D792. Experimental density calculation was done by immersing a section of specimen (20x20 mm) in a graduated beaker which was hanged by a thread. Experimental density was found to 1.161 kg/cm³. Theoretical density was calculated by using rule of mixtures. % of voids calculated by using equation (1), where $\rho_{ct}$ denotes theoretical density and $\rho_{ce}$ denotes experimental density of the composite. The density of jute fibres ($\rho_f$) is 1.46 kg/cm³ and that of epoxy resin is 1.2 kg/cm³.

$$\% \, \text{void} = \frac{\rho_{ce} - \rho_{ct}}{\rho_{ct}} \times 100$$  \hspace{1cm} (1)

Calculations were repeated for 5 specimens and the average %void was found to be 6.96%.

2.5 Fatigue Tests

Fatigue test were conducted in accordance with ASTM standard D3479 in load mode and at a cycling frequency of 2 Hz. The fatigue stress ratio R was kept constant at 0.1. Fatigue tests conducted at different stress levels based on the ultimate strength of the specimens starting from 40% of ultimate strength with 10% increments. In each stress level 5 specimens were tested for obtaining fatigue life of the specimens.

3. Results and discussion

Tensile test results showed that maximum load carrying capacity of the jute-epoxy composites are found to be 3.1 kN. Average load capacity for 5 specimens was found to be 2.8 kN and maximum stress level was found to be 27.26 MPa. The maximum value of tensile test was used for designing fatigue test. Figure 3 shows the stress-strain curve of jute-epoxy laminates for different samples.

![Figure 3. Stress-Strain curve of jute-epoxy laminates](image-url)

Based on the tensile tests, fatigue tests were designed and at a stress ratio of R=0.1. The maximum stress applied on the specimens varied from 10.9 to 24.5 MPa corresponding to 40% to 90% of the ultimate tensile strength. Average life obtained and the fatigue test details shown in table 2.
Table 2. Average fatigue lives for tested specimens

| Stress level | Maximum Stress (in MPa) | Minimum Stress (in MPa) | Average life |
|--------------|-------------------------|-------------------------|--------------|
| 40%          | 10.9                    | 1.09                    | 100000       |
| 50%          | 13.625                  | 1.325                   | 19759        |
| 60%          | 16.35                   | 1.635                   | 5133         |
| 70%          | 19.075                  | 1.9075                  | 3329         |
| 80%          | 21.8                    | 2.18                    | 809          |
| 90%          | 24.525                  | 2.4525                  | 183          |

A graph was plotted to get S-N curve for the results obtained from fatigue test with Stress along Y-axis and number of cycles along X-axis. After plotting S-N Diagrams, model based on power law equations (Eq. 2) were determined. $S_{\text{max}}$ is the maximum absolute stress applied, $S_0$ is the Ultimate Tensile Strength and $N$ is the number of cycles to failure, and $b$ is the material fatigue strength coefficient. Eq. (2) gives a linear S–N curve on a semi–log plot.

$$S_{\text{max}} = S_0 N^b \quad (2)$$

There was gradual increase (negative gradient) in the slope of the curve as the number of cycles increased with decreasing stress levels as shown in figure 4. Curve was plotted using Curve Fitting Toolbox™ provided by MATLAB.

![Figure 4. Fatigue-life (S N) curve for Jute-Epoxy Composite](image_url)

4. Conclusion

It is a well-known fact that the measured strength of most materials is found to be much smaller (by orders of magnitude) than their theoretical strength. This is mostly due to imperfections and inherent flaws in the material. These flaws, especially in form of cracks that lie perpendicular to application of load are detrimental to the strength of material. This is however not the case in synthetic man-made materials such as glass fibres, where these fibres are almost defect free. Fibres due to their
minor cross-sections cannot be used straight in engineering aspects and are, therefore, embedded in matrix constituents to form fibrous composites.

A known shortcoming of natural fibre is their poor adhesion to matrix in their raw state. Hydrophilic nature of the fibres also leads to moisture absorption. In case of resin, its strength, fatigue life and other properties are not viable in its neat form for most applications. With increasing use of composites comes growing necessity to recognize their behaviour and design life. These applications include repetitive loading cycles, demanding the capability to understand and estimate fatigue in composites. An extensive study and analysis of fatigue behaviour of composite is needed before its use or application in any form. This project is taken up as an attempt to overcome some of the above problems and to fabricate a composite with desired properties.

5. References

[1] P. Wambua, J. Ivens, I. Verpoest, 2003, Natural fibres: can they replace glass in fibre reinforced plastics, *Composites Science and Technology*, vol. 63, no. 9, pp. 1259–1264.
[2] H. Katogi, Y. Shimamura, K. Tohgo, T. Fujii, 2012, Fatigue behavior of unidirectional jute spun yarn reinforced PLA, *Advanced Composite Materials*, vol. 21, no. 1, pp. 1–10.
[3] S. Liang, P. B. Gning, and L. Guillaumat, 2012, A comparative study of fatigue behaviour of flax/epoxy and glass/epoxy composites’, *Composites Science and Technology*, vol. 72, no. 5, pp. 535–543.
[4] M. Z. Rong, M. Q. Zhang, Y. Liu, G. C. Yang, H. M. Zeng, 2001, The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites, *Composites Science and Technology*, vol. 61, no. 10, pp. 1437–1447.
[5] T. Hojo, Z. Xu, Y. Yang, H. Hamada, 2014, Tensile Properties of Bamboo, Jute and Kenaf Mat-reinforced Composite, *Energy Procedia*, vol. 56, pp. 72–79.
[6] M. R. Hossain, M. A. Islam, A. Van Vuurea, I. Verpoest, 2013, Tensile Behavior of Environment Friendly Jute Epoxy Laminated Composite, *Procedia Engineering*, vol. 56, pp. 782–788.
[7] J. Gassan, 2002, A study of fibre and interface parameters affecting the fatigue behaviour of natural fibre composites’, *Composites Part A: Applied Science and Manufacturing*, vol. 33, no. 3, pp. 369–374.
[8] V. Mishra, S. Biswas, 2013, Physical and Mechanical Properties of Bi-directional Jute Fiber Epoxy Composites’, *Procedia Engineering*, vol. 51, pp. 561–566.
[9] J. Gassan, A. K. Bledzki, 1997, ‘The influence of fiber-surface treatment on the mechanical properties of jute-polypropylene composites’, *Composites Part A: Applied Science and Manufacturing*, vol. 28, no. 12, pp. 1001–1005.
[10] J. Gassan, A. K. Bledzki, 1999, ‘Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment of fibres’, *Composites Science and Technology*, vol. 59, no. 9, pp. 1303–1309.