Tensile behavior of lotus natural fiber and e-glass fibers reinforced with epoxy composites

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Abstract. This paper is concerned with the study of tensile properties of lotus fiber reinforced with epoxy composites. Specimens of epoxy composites were made from natural fibers by arranging them in uniaxial, biaxial as well as in criss-cross manner with and without E-glass fiber. To enhance the mechanical properties, fibers were undergone alkaline treatment (NaOH) and later they were fabricated using hand lay-up technique. It is understood from the results that better tensile properties were shown by uniaxial and minimal by biaxial arrangement.

Keywords: Lotus, Composite, Tensile Strength, E-glass Fiber, Criss – cross, Uniaxial, Biaxial, Specimen

1. INTRODUCTION

Today, non-biodegradable materials became the major constituent in almost all products in the day-to-day human life. Increasing environmental awareness is forcing humans to seek more eco-friendly materials as a substitute such as natural fibers and other organic substances. The natural fibers include hemp, coir, jute, kapok, kenaf, flax, nettle, bamboo, sisal, ramie, etc. They show many advantages as compared to synthetic fibers such as biodegradability, recyclability and low density. They have similar specific tensile properties, and are also non-abrasive to the equipment causing minimal health risk [1]. Since they are cheaper and lighter, they have low mechanical properties as that of glass fiber. But this can be eased by hybridization of the natural fibers with glass fiber composites. Composites contain reinforcement (strong load carrying material) which is incorporated in matrix (weaker material). While reinforcement imparts strength, matrix sustains the orientation and position of reinforcement [2].

Academic and industrial areas have an increased interest in natural fibers as reinforcement in composites. They have many advantages over synthetic fibers. Even though moisture sensitivity stands out to be their major disadvantage, acceptable mechanical properties makes it consider them as a good choice in various domains. They have much wide range of applications in packing, building construction, cosmetics. Nowadays even the interior portions of Automotive and aircrafts are designed using natural fibers [3]. Car manufacturers across the globe have started accepting natural fiber composites for dashboards, door panels, headliners and interior parts [4].

Lotus (Nelumbo nucifera) is a flowering plant with high amount of fibrous content in stem and root. They come under the category of perennial aquatic herb which is mainly found in India and China [5]. The fibers used in this paper were extracted from the stems which were soaked in water for 2 nights and were washed with a piece of linen until all thorns were removed [6]. These stems contain large amount of cellulose which can be used in paper, textile and medical industries. Moreover lotus fibers are becoming popular in ayurvastra and also in making luxury garments, since they are eco-friendly and comfortable to use [7, 8]. Even though they contain 17 kinds of amino acids, they are insusceptible to skin and are healthy for human body [9]. Since these fibers have low density (1.18 gcm⁻³) they are suitable for making lightweight composites [10].

Glass fiber reinforcement is known to improve the mechanical properties of natural fiber composites. There are many types of glass fibers but in this paper e-glass fibers are used. Some of the merits of glass fibers are:

• Excellent chemical resistivity towards acids and solvents
Low dielectric constant, low moisture absorption and high strength to weight ratio. They are cheap and easy to trim even after curing. Effect of glass fiber inclusion was measured by making few composites using e – glass fibers. Lotus fiber orientation was also examined by arranging them in 3 different ways such as uniaxial, criss – cross and biaxial.

2. MATERIALS

Glass fibers used were of two types- uniaxial and biaxial. These glass fibers were of 5 – 10 µm diameter and had a surface density of 360 gram per square meter. Moderate adhesive epoxy resin (LY556) and polyamine hardener (HY951) which was cured under room temperature was used as the matrix. Natural fiber used here was lotus which is shown in figure 1.

![Figure 1. (a) Lotus fiber (b) Uniaxial glass fibers (c) Biaxial glass fibers.](image)

3. METHODOLOGY

3.1 Alkali treatment
About 250 grams of lotus fiber was soaked in 1 L of 0.5 % NaOH solution for 30 minutes. At 65 % humidity and at normal room temperature, fibers were allowed to dry for 3 days. Through alkalization, increase in quality of the composite was expected due to the improved adherence of fiber with the matrix. So the fiber will show better mechanical properties because of the removal of non-cellulosic content such as lignin and hemicellulose from the natural fiber which affects their tensile properties [11].

3.2 Preparation of mold
For making the composite specimens of desired shape, molding boxes were prepared which was made of wood. ASTM standards - D638 was followed to get the dimensions of the cavity (figure 2).
3.3 Preparation of composites
Since alkali treated fibers were in disordered manner, uniform threads were formed by twisting them. They were then cut into pieces of different length as per the 3 different arrangements (uniaxial, biaxial and criss-cross). Epoxy and hardener were mixed in 10:1 (v/v) ratio to make a solution for minimizing the fiber’s detachment. Three alternative layers of epoxy-hardener solution and lotus fiber were placed in the mold and this was done by hand lay-up technique followed by compression molding. Figure 3 shows the prepared specimens. Addition of epoxy increases adhesion effect which further leads to satisfactory reinforcement. This makes desirable fiber distribution and effective bridging of gaps in between those natural fibers [12].

3.3.1 Lotus fiber composite (no glass fiber).
- Base of cavity in mold was coated with epoxy-hardener solution. Alternative layer by layer arrangement finally formed three layers of fiber and four layers epoxy-hardener in the cavity.
- It lead to an overall fiber to epoxy-hardener volume by volume ratio of 60:40 which is shown in table 1.
- 5 threads of lotus fiber were placed along the length in each layer to form uniaxial arrangement of specimen.
- In biaxial arrangement, twisted threads were cut according to the width of the cavity, which were then placed along the length of the mold. Approximately 60-70 pieces were cut and placed accordingly.
For criss-cross arrangement of fiber, threads were cut into pieces in such a way that it can fit across the width at an angle of 45 degrees. Around 65-75 pieces of these cut fibers were placed in tilted manner along the length.

### 3.3.2 Lotus fiber composite containing glass fiber.

- Epoxy-hardener, lotus fibers, epoxy-hardener, glass fibers, epoxy-hardener layers were arranged in the cavity by starting with epoxy-hardener.
- So in total 2, 5, 2 layers of lotus fiber, epoxy-hardener, glass fiber were obtained respectively which lead to a volume by volume ratio of 45:45 for lotus and epoxy-hardener in mold cavity.
- In uniaxially arranged specimen, 165 mm long lotus fibers were measured and cut to arrange along the length. Each layer carried 5 threads and uniaxial e-glass fibers were attached accordingly.
- For biaxial arrangement, fibers were cut and arranged perpendicular to cavity’s length. Biaxial e-glass fibers were inserted and almost 60-70 pieces of fiber were required.
- Fibers were cut and arranged in the cavity at an angle of 45 degrees to the length. Criss-cross arrangement was done by using 65-75 pieces of lotus fiber and biaxial E-glass fiber.

| Sl. No. | Composite description                                      | Lotus fiber (% v/v) | Epoxy-hardener (% volume / volume) | E - glass fibers (% volume / volume) |
|---------|------------------------------------------------------------|---------------------|-----------------------------------|-------------------------------------|
| 1       | Lotus fiber composites with epoxy(no glass fibers)         | 60                  | 40                                | 0                                   |
| 2       | Lotus fiber composites with epoxy containing glass fibers  | 45                  | 45                                | 10                                  |

They were allowed to dry at atmospheric temperature for 13 days and were taken out from the mold to get the specimen for performing the mechanical test. Involved steps in the preparation of specimens are abbreviated in flow chart (figure 4).
4. EXPERIMENTAL PROCEDURE

1. Digital tensile testing machine in laboratory was used to perform tensile test of ASTM D638 standard specimens. Details of machine are provided in table 2.
2. Grips in the machine securely clamp 2 ends of the specimen as shown in figure 5.
3. The gauge length of the specimen was 115 mm.
4. Grips of the machine pull the specimen at a constant rate (1 mm min\(^{-1}\)).
5. Force applied and its elongation of the specimen were continuously recorded and a graph was drawn.
6. When the force applied in the specimen exceeded critical load, failure occurred and it got broke.

**Table 2. Specifications of machine used.**

| Equipment                  | Digital Tensile Testing Machine |
|----------------------------|----------------------------------|
| Model number               | 8801                             |
| Load cell                  | Dynacell load cell highlights compensation for inertial loads brought about by overwhelming fixtures and grips |
| Maximum working pressure   | 207 bar                          |
| Capacity of dynamic load   | Axial force up to ± 100 kN       |
| Computer software used     | Bluehill : Static test & Wavematrix : Dynamic test |
| Supplier                   | Instron                          |
5. RESULTS

Load-extension curve of lotus fiber composite, with and without E-glass fibers obtained from the digital tensile testing machine are given in figures 6-8. Largest value of tensile stress that a substance could withstand before failure occurs is known as tensile strength. Stress is directly proportional to the load applied. Hence maximum load corresponds to maximum tensile strength. It gives the tendency to elongate the material since force was acting along the length in opposite direction. Usually natural fiber composites show somewhat lesser mechanical properties due to decrease in stiffness and brittleness [1]. But incorporation of E-glass fiber showed greater improvement in it.

Plotted graphs showed a linear relationship until the breaking point where it showed a sudden depression. To get more precise result, load was applied at a very small rate of 1mm per minute. Graphs obtained clearly implied that the largest value of tensile strength (18.91 MPa) was shown by the composite in uniaxial natural fiber arrangement (in presence of glass fibers). On the other hand, criss-cross and biaxial arrangement showed a lesser value of 18.38 MPa and 11.92 MPa respectively. In case of Lotus - epoxy composites, uniaxial, criss-cross and biaxial structure show values of 17.15, 13.73 and 9.14 MPa.
Figure 6. (a) Lotus and epoxy composite (Lotus fiber arrangement in uniaxial manner); (b) Lotus and epoxy composites with glass fiber (Lotus fiber arrangement in uniaxial manner)

Figure 7. (a) Lotus - epoxy reinforced fiber composite (Lotus fiber arrangement in biaxial manner); (b) Lotus-epoxy-glass fiber reinforced composite (Lotus fiber arrangement in biaxial manner)
Orientation of fibers and glass fiber inclusion were the key factors for the variations seen in the graphs obtained.

5.1 Comparison based on presence of glass fiber in composites

Hybridization with glass fiber showed significant increase in composite mechanical properties. 6 Specimens were made with a fixed volume percentage of 60 and 40 of lotus and epoxy-hardener respectively. Similarly another 6 specimens containing lotus, epoxy-hardener, E-glass fiber in 45, 45, 10 volume % were prepared respectively. Addition of glass fibers in the composite always played a vital role in slightly increasing the tensile strength of the natural fiber [13].

It was evident from the graph that uniaxial arrangement without glass fiber can withstand a tensile strength of 17.15 MPa as compared to a specimen having the same arrangement incorporating glass fiber whose strength was 18.91 MPa. When criss-cross arrangement showed a tensile strength of 13.73 MPa, presence of glass fiber increased it to 18.38 MPa, whereas in case of biaxial arrangement, it went up to 11.92 MPa from 9.14 MPa. It concludes a drop of 9.3%, 25.3% and 23.32% breaking stress in uniaxial, criss-cross and biaxial arrangement respectively. These values are summarized in Figure 9.
Among all these specimens, it was well-defined that specimens with E-glass fiber had higher tensile strength.

5.2 Comparison based on orientation of fibers
For all composites, with and without E-glass fiber, highest tensile strength was shown for uniaxial, followed by criss-cross and least was for biaxial arrangement. When the fibers were in uniaxial orientation, fiber matrix interface were bonded with appreciable compatibility as compared to biaxial and criss-cross arrangement. Experimental values of breaking load and stress are listed in the table 3 for all specimens.

Table 3. Experimental results of tensile test.

| Sl No. | Specimen Composite components (fiber orientation) | Breaking load (N) | Breaking tensile stress (MPa) |
|-------|--------------------------------------------------|-------------------|-------------------------------|
| 1     | Lotus and epoxy (uniaxial)                       | 1337.72           | 17.15024                      |
| 2     | Lotus and epoxy (biaxial)                        | 713.12            | 9.14259                       |
| 3     | Lotus and epoxy (criss-cross)                    | 1071.25           | 13.73398                      |
| 4     | Lotus, epoxy and glass fiber (uniaxial)          | 1474.74           | 18.9069                       |
| 5     | Lotus, epoxy and glass fiber (biaxial)           | 930.11            | 11.92444                      |
| 6     | Lotus, epoxy and glass fiber (criss-cross)       | 1433.61           | 18.37963                      |
| Mean  |                                                  | 1160.09           | 14.87                         |

Uniaxially oriented lotus-epoxy-glass fiber reinforced composite failed at a tensile stress of 18.91 MPa. Criss-cross and biaxial specimens having E-glass fiber, showed 2.79% and 36.93% drop in breaking strength compared to this. Whereas uniaxially oriented lotus –epoxy reinforced composite showed 17.15 MPa and in case of criss-cross and biaxial orientation it decreased to 19.92% and 46.69% respectively.
6. CONCLUSION

ASTM D638 standard was followed to make specimens of lotus fiber in uniaxial, criss-cross and biaxial orientation with and without E-glass fiber. Lotus fibers were treated with NaOH solution before the mold was prepared to enhance bonding at the fiber-matrix interface. When glass fiber was added 45:45 volume/volume ratio of lotus fiber and epoxy-hardener was followed. They were arranged in 60:40 volume / volume ratio in the absence of E-glass fiber. The fibers which were cut according to the required dimensions were arranged in layer by layer manner to fill the cavity. Results obtained from the tensile test performed in digital tensile testing machine showed that uniaxial orientation of fibers withstood greater tensile stress. Moreover it was enhanced by the addition of E-glass fiber. Tensile strength of the specimens in uniaxial, criss-cross and biaxial were increased by 10.24 %, 33.82% and 30.43 % by the addition of glass fiber. These composites have a huge number of applications such as in medical field and in textile industry. Since the load it can withstand was limited, it can be used for the production of soft carry bags.

7. ACKNOWLEDGEMENT

The authors are extremely thankful for the support from the management of VIT Vellore in helping for accomplishing this research. They are also thank Vibration lab, VIT Vellore for providing required epoxy, hardener and E-glass fibers. The authors are grateful for the assistance in providing the tensile testing machine in advanced materials testing lab, VIT Vellore. All other cooperation from lab technicians and faculties are sincerely acknowledged.

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