Effect of fiber orientation on the tensile and flexural properties of vetiver fiber reinforced epoxy composites

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Abstract - Natural fibre composites find application in some areas of aerospace, automotive, marine, electrical and sports equipments. They replace traditional materials due to the advantage of bio-degradability and environmental durability. However, better understanding of the composite behavior is required to ascertain its durability in the field of applications. In this work, vetiver fibre composites are prepared and tested for tensile and flexural strength. Vetiver fibers of length 15-16cm were used as reinforcements and epoxy resin with hardener is used as the matrix. Three types of composites were prepared using three different arrangements of the Vetiver fibers. The orientation of the fibres include longitudinal, transverse and a third arrangement combining both the directions. The flexural and tensile tests of these three types of composites are carried out and the results are compared with each other and useful conclusions were drawn from them.

Keywords: Vetiver fiber, composite, epoxy, hand layup technique, tensile test, flexural test.

1. Introduction

Natural fibre composites are viable alternatives to synthetic fibre reinforced materials owing to the benefits of low weight, reduced cost, reasonable strength and modulus, environment friendly and easy to recycle. The fibres are generally used as reinforcements with the resin matrix. In some applications it is used in the form of fillers in plastic polymers [1]. The recent development in natural fibre processing and composite science provides good opportunity to explore new materials which can be recycled and are biodegradable. They are emerging as a good substitute for glass fibres mainly in the automotive industry where they are used in door panels, seat coverings and back rest, floor mats etc [2,3]. Several research works based on the reinforcement of natural fibres has been carried out in the recent decade. The behaviour of the polymer composites reinforced with fibres such as jute, kenaf, hemp, flax, sisal, oil palm fibre, coir, banana, bamboo has been studied [4]. Some of the composites with natural fibre reinforcement are found to be commercially viable due to their low market price. But still the market share of these composites is low due to their low thermal stability, low impact strength and high water absorption [5]. The strength of these composites depend on the chemical treatment of the fibers, fiber weight or volume fraction, piling of the layers of fiber and bonding between matrix and fiber [6,7]. To enhance their mechanical properties, composites of hybrid type are also being explored by conjoining two kinds of natural fiber or a natural fiber with glass fiber [8,9].

Vetiver with its biological name chrysopogon zizanioides, is a grass variety belonging to the family of Poaceae [10]. Its origin is reported to be from India. Its grass and thick aromatic roots are highly valued and mainly used for medicinal purposes [11]. The root extract is also used for textile finishing [12]. Vetiver fibers as strengthening agent in conventional concrete have been found to increase the compressive strength and flexural strength [13]. A study on vetiver-polypropylene composite revealed substantial increase in tensile strength and youngs modulus compared to neat polypropylene material
The vetiver was mixed with polypropylene in the form of grass and fiber in various percentages. The chemical treatment on vetiver grass was also found to enhance the mechanical properties of the composite. It was reported that the reinforcement of natural fibers with polypropylene has aided in higher rate of crystallization [15]. The characterization of alkaline treated vetiver fiber revealed modifications in its physical properties. It has resulted in higher decomposition temperature compared to untreated fiber. It has also resulted in enhancement in the crystalline structure of the fiber [16]. A hybrid composite of vetiver-jute-glass was developed and the analysis showed improvement in flexural and tensile behaviour of the composite in comparison with bifibered composites made of vetiver-glass or jute-glass [17].

The work on vetiver fiber as a natural fiber composite is limited. Nihal et al reported the tensile properties and impact strength of polymer plastic composite with varying weight percentage of vetiver fibre [18]. Although, many studies have been made into the mechanical behaviour of natural fibre composites with respect to their weight percentage, the variation in mechanical properties corresponding to the orientation of the fibre in the composite is not so well explored. V.G. Geethamma et al has used natural rubber with coir fibers to study the effects of fibre orientation [19]. The current effort deals with the study of tensile and flexural behaviour of vetiver fiber in different orientations.

2. Materials and Methods

The materials used in the fabrication of the composites are vetiver natural fiber, epoxy resin of specification LY556, hardener of specification HY951[20] and wood for making the mould. Vetiver fibers used in the preparation of the composite were first cleaned thoroughly with distilled water and then treated with 0.5M NaOH solution to remove dust, cellulose, lignin, hemicelluloses from the outer surface of the fibers. Chemical treatment of natural fibers using NaOH is known to raise the strength of natural fiber composite [17, 21]. After 2 hours of treatment, the fibers are cleaned in distilled water to eradicate surplus NaOH and ayup procedure was used for preparing the natural composites [22, 23]. Epoxy resin and hardener were mixed in the ratio of 10:1 to prepare the matrix for the samples.

2.1 Preparation of Mould

The moulds required for tensile and flexural tests were fabricated conforming to ASTM D638 and ASTM D790 standards respectively using low density fiber board. The dimensional model was prepared as per the standards shown in figure 1 and figure 2 using solidworks software and CNC lathe machine was used to get the required shape of the mould from the wooden base structure. The mould was then cleaned thoroughly to remove chips and dusts over the surface. These moulds are used for preparing the composites using hand lay-up process. For breaking the mould upon completion of the hand layup process, a cutting machine was utilized to cut away the wooden mould. During the cutting process, extra care was taken so as not to damage the samples.

2.2 Preparation of Composites

Three types of composites were prepared using three different arrangements of the Vetiver fibers as shown in figure 3.

**Composite Type Longitudinal:** Long Vetiver fibers of length 15-16cm were placed longitudinally throughout the length of the sample.

**Composite Type Transverse:** Short Vetiver fibers of length 1-1.2cm were placed transversely throughout the length of the sample.

**Composite Type Bi-directional:** This sample was prepared using both short and long fibers. The short fibers were placed transversely and the long fibers were placed longitudinally.

The fibers with uniform shape and size were selected and cut to the required length. The epoxy-hardener solution is formulated in the ratio of 10:1 [24]. The composites were prepared using hand layup technique and then subjected to soft compression moulding method. For preparing the composite type longitudinal, the epoxy solution was laid first, followed by the layer with longitudinal fibers. This alternate arrangement of epoxy solution and vetiver fibers were carried out till 4 layers of epoxy and 3 layers of fibers were obtained. For the longitudinal arrangement, 5 threads of fibers were placed in each layer.

For preparing the composite type transverse, similar procedure was followed by placing the fibers in the transverse direction. The fibers were cut to fit in the width of the mould. Around 35 cut fibers were used in each layer of preparation. The composite type bi-directional was prepared by placing the fibers in both longitudinal and transverse directions alternatively. After the first epoxy layer, the fibers are placed in
longitudinal direction with 5 threads in the layer. This was followed by second epoxy layer and the fiber layer in transverse direction. This procedure was continued till two layers of longitudinal fiber and one layer of transverse fibers were obtained. The epoxy and fiber ratio were maintained at 40:60.

Figure. 1 Specifications of tensile test mould

Figure. 2 Specifications of the flexural test mould

Figure. 3 Orientation of the vetiver fibres used for testing

3. Experimentation

To understand the tensile behaviour of the vetiver fibre composites, tensile test was done in Instron 8801 machine shown in figure 4. Samples were prepared according to the tensile test standard for natural composites. The tensile test was completed at a rate of 1mm/min at room temperature to find out the ultimate tensile strength of the specimen. According to the standard, the gauge length used for the specimen is 50mm. The three point bending test was also performed in the Instron 8801 machine. The samples were prepared according to the test standard for natural composites. The testing was done at a strain rate of 2mm/min by applying the load in the center of the span of the specimen.

Figure. 4 Tensile test performed in Instron universal testing machine
4. Results and Discussion

4.1 Tensile test results

The load-displacement behaviour of the vetiver fibre composite in tensile testing with three different orientations are shown in figure 5. A portion of the testing samples are shown in figure 6.

![Figure 5 Load-Extension variation for the three orientations of the tensile samples](image1)

The tensile test data are tabulated in table 1. The tensile strength of the fibre composite is found to be in the range of 7MPa to 9MPa. Nihar et al has reported a tensile strength of 25.4MPa to 26.9MPa with the use of polypropene as the matrix with 35% of fibre. The investigations on different orientations with epoxy resin as matrix has not been carried out. The fibre orientation with longitudinal direction is found to give the highest tensile strength of 9.624MPa [18]. Saravanna et al performed the tensile strength of Vetiver fibre composite with matrix of epoxy polymer Lapox-L12 and Lapox K-6 and found to be 11.9MPa [23].

![Figure 6 Tensile test samples](image2)

Table 1. Tensile test data

| Type of composite          | Maximum Load (N) | Ultimate Tensile Strength (MPa) | Young’s Modulus (MPa) | Tensile strain at break (%) |
|----------------------------|------------------|---------------------------------|-----------------------|---------------------------|
| Composite Type             |                  |                                 |                       |                           |
| Longitudinal               | 719.48767        | 9.624                           | 1792.234              | 1.162                     |
| Transverse                 | 630.40257        | 8.932                           | 2447.313              | 2.638                     |
| Bi-directional             | 638.56840        | 7.867                           | 2538.860              | 0.786                     |
4.2 Bending test results

Flexural strength is an important aspect to gauge stiffness of a given composite and is determined using the slope acquired from the load–displacement curve. Such flexural behaviour is generally analysed by means of a three-point bending test. During this test, the layers are subjected to different stresses, the mid layer experiences shear, the top layer compression and the bottom layer to tension. The resulting failure of composite is thus attributed to both bending and shear. Various important material properties such as modulus of elasticity in bending, flexural stress and strain, stress–strain response of the specimen can be calculated from three-point bending test. In this work, the flexural test of three-point bending test was performed on a universal testing machine. The variations in flexural stress as a function of flexural strain of the vetiver fibre reinforced epoxy composites for the three specimens of different orientations are shown in figure 7. The tested samples are shown in figure 8.

The results in figure 7 shows that the flexural strength attains a maximum value of 45.74247 MPa for composite specimen with longitudinal configuration but it exhibits a minimum value of 17.43875 MPa in the transverse configuration. The sample with transverse lay of fibres show better flexural strength than the other two samples. The highest strain to failure, shows a ductile behaviour. However, the use of resin also plays a critical role in maintaining the fibers as straight structure and to prevent from bending.

![Figure 7 Flexural stress and flexural strain diagram for the three orientations of bending samples](image)

![Figure 8 Samples tested for flexural strength](image)

The data acquired from the flexural test is tabulated in table 2. The flexural modulus is found to vary between 2.1-3.1GPa. Flexural modulus helps to determine the degree of deformation of a material under bending stress and provides a measure of ductility of the material. Saravana Bavan et al carried out flexural tests on vetiver fibre composite after chemically treating the fibre using alkali method and preparing the composite with epoxy resin and hardener. The flexural modulus was reported to be 1.1-1.2GPa [23]. Composite type with longitudinal fibres has the highest value of flexural modulus of 3111.089 MPa and thus, has the highest stiffness of all the samples. While composite type with bi-directional fibres has the lowest flexural modulus.
value of all the samples of 2118.366 MPa.

Table 2. Flexural test data

| Type of composite | Maximum Load (N) | Maximum Flexure extension (mm) | Modulus (Automatic) (MPa) | Maximum Flexure stress (MPa) | Flexure strain (mm/mm) |
|-------------------|------------------|--------------------------------|--------------------------|-----------------------------|------------------------|
| Composite Type Longitudinal | 103.69 | 2.746 | 3111.08984 | 45.74247 | 0.01676 |
| Composite Type Transverse | 27.64 | 1.100 | 2318.03887 | 17.43895 | 0.00611 |
| Composite Type Bi-directional | 58.37 | 2.069 | 2118.36602 | 25.74904 | 0.01262 |

5. Conclusions

The tensile tests of the vetiver fiber epoxy composites showed a higher value of tensile strength for the composite with longitudinal fibers. The composites can be further tested for different proportions of fiber and epoxy. The flexural strength of the longitudinal fiber composite is found to be 62% more than the composite with transverse fibers and 44% more than the bi-directional fiber composites.

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