Sisal Fiber / Glass Fiber Hybrid Nano Composite: The Tensile and Compressive Properties


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Abstract

Natural fiber reinforced polymer composites became more attractive due to their high specific strength, light weight, and environmental concern. The incorporation of natural fibers such as sisal with glass fiber hybrid composites has also gained increasing industrial applications. In this study natural and synthetic fibers are combined in the same matrix (unsaturated polyester) to make Sisal/Glass fiber hybrid composites using polyurethane resin. The fabrication of hybrid composite has been performed using hand lay-up method. The fabricated hybrid composite has been tested and their mechanical properties are evaluated. Additionally sisal nano fiber/glass fiber hybrid composite is fabricated by hand lay-up method and tested for comparing the strength with sisal/glass fiber hybrid composite.

1. Introduction

Natural fiber composites combine plant-derived fibers with a plastic binder. The natural fiber components may be wood, sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, banana leaf fibers, bamboo, wheat straw or other fibrous material. The advantages of natural fiber composites include lightweight, low-energy production, and environmental friendly to name a few. The use of natural fibers reduces weight by 10% and lowers the energy needed for production by 80%, while the cost of the component is 5% lower than the comparable fiber glass-reinforced component [1]. In the past, composites of coconut fiber/natural rubber latex were extensively used by the automotive industry. However, during the seventies and eighties, newly developed synthetic fibers due to better performance gradually substituted cellulose fibers. For the past few years, there has been a renewed interest in using these fibers as reinforcement materials, to some extent in the plastic industry. This resurgence of interest may be attributed to the increasing cost of plastics and the environmental aspects associated with using renewable and biodegradable materials [2].

Mechanical properties of banana fiber were studied by Kulkarni et al. [3]. They observed that the failure of banana fiber in tension is due to pull-out of micro fibers accompanied by tearing of cell walls. The tendency for fiber pull-out decrease with increasing speed of testing. Nilza et al. [4] investigated the potentials of banana, coir and bagasse fibers in composites. In their work, fiber samples were subjected to standardized characterization tests such as ash and carbon content, water absorption, moisture content, tensile strength, elemental analysis and chemical analysis. Results revealed that the banana fiber exhibited the highest ash, carbon and cellulose content, hardness and tensile strength, while coconut the highest lignin content. Venkateshwaran and Elayaperumal [5] reviewed the various works carried out so far in the field of banana fiber polymer composites. They revealed the structure, physical and mechanical properties of banana fiber composite. Furthermore, they described that very few works on banana fiber reinforced with epoxy resin was carried out.

Sreekala et al. [6] investigated the performance of mechanical properties of oil palm fiber with glass fiber and used phenol formaldehyde as resin. The investigation revealed that maximum mechanical
performance occurs at 40 wt% loading. Kasama and Nitina [7] studied the effect of glass fiber hybridization on properties of sisal fiber–polypropylene composites. Incorporation of glass fiber increases the mechanical, thermal and water resistance properties.

Chen and Sun [8] investigated the impact responses of the composite laminates with and without initial stresses using the finite element method. The deflections produced are small for simple cases and simple material architecture. Whereas, the deflections produced are complicated when complex architectures are considered. Finite element analysis is an important tool which is used to assess the strength of a natural composite. The finite element model was used to simulate the performance of the woven composites under different loading conditions [9] and the failures under combined tension and bending loading were studied. It was found that the failure occurred near the fixture where the composite was subjected to maximum bending.

Many researchers have shown that the strength of the natural composites can be improved by treating the fiber suitably. Herrera-Franco and Valadez-Gonzalez [10] improved the tensile, flexural and shear properties of the short fiber laminates by using saline treatment and matrix-resin pre-impregnation process through which the tensile and flexural moduli remain unaffected. The mechanical properties of jute fiber-unsaturated polyester composites prepared by solution impregnation and hot curing methods were studied by Dash et al., bleached fibers were found to have better mechanical properties at 60% weight loading than unbleached fibers. Alwar [11] studied the properties of date palm fiber which was subjected to different types of treatment processes. 1% NaOH treatment resulted in increase in the mechanical properties whereas HCl treatment resulted in deterioration of its properties.

2. Materials and Method

2.1 Materials

2.1.1 Natural fibers

Natural fibers are materials that belong to a class of hair like materials which are in the form of continuous filaments. Natural fibers are classified into two types, as plant (vegetable) fibers and animal fibers. Plant fibers namely cotton, flax, hemp, abaca, sisal, jute, kenaf, bamboo and coconut are widely used. They are preferred mostly since they are eco-friendly, and also available in less cost.

2.1.2 Sisal fibers

Sisal fiber is derived from the leaves of the plant. It is usually obtained by machine decortications in which the leaf is crushed between rollers and then mechanically scraped. The fiber is then washed and dried by mechanical or natural means. The dried fiber represents only 4% of the total weight of the leaf. Once it is dried the fiber is mechanically double brushed. The lustrous strands, usually creamy white, average from 80 to 120 cm in length and 0.2 to 0.4mm in diameter. Sisal fiber is fairly coarse and inflexible. It is valued for cordage use because of its strength, durability, ability to stretch, affinity for certain dyestuffs, and resistance to deterioration in saltwater.

![Figure 1 Flow chart showing Individualization Process](image)

The individualization process of nano fibers is a multi-step process as shown in Figure 1. Chemical treatments are applied onto the fibers to individualize nano fibers. The chemical treatments include pretreatment, acid hydrolysis and alkaline treatment.

2.1.3 Glass Fibers

Glass is the most common of all reinforcing fibers for polymeric (plastic) matrix composites (PMCs). The principal advantages of glass fiber are low cost, high tensile strength, high chemical resistance and excellent insulating properties. The two types of glass fibers commonly used in the fiber reinforced plastics industries are E-glass and S-glass.
2.1.4 Polyurethane Resin

Commercially available unsaturated polyurethane resin has been used for the investigation. Accelerator (methyl ethyl ketone peroxide) and the catalyst (cobalt naphthalene) are used to cure the resin. Thermoset polyurethane resin is one of the economical resin when compared to other resin due to its very low water absorbing capability and excellent bonding tendency as well as mechanical properties of polyurethane resin as shown in Table 1.

Table 1 Properties of polyurethane

<table>
<thead>
<tr>
<th>S. No</th>
<th>Properties</th>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td>-</td>
<td>1.1–1.46</td>
</tr>
<tr>
<td>2</td>
<td>Density</td>
<td>kg/m³</td>
<td>1125</td>
</tr>
<tr>
<td>3</td>
<td>Tensile strength</td>
<td>MPa</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>Tensile modulus</td>
<td>GPa</td>
<td>0.8–1.1</td>
</tr>
<tr>
<td>5</td>
<td>Compressive strength</td>
<td>MPa</td>
<td>90–250</td>
</tr>
<tr>
<td>6</td>
<td>Flexural strength</td>
<td>MPa</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>Flexural modulus</td>
<td>GPa</td>
<td>1.2–1.5</td>
</tr>
<tr>
<td>8</td>
<td>Shrinkage</td>
<td>%</td>
<td>0.004-0.008</td>
</tr>
</tbody>
</table>

2.2 Mould preparation

Mould used in this work is made up of well-seasoned teak wood of 300 mm x 300 mm x 3 mm dimension with eight beadings. The fabrication of the composite material was carried out through the hand lay-up technique. The top, bottom surfaces of the mould and the walls are coated with remover and allowed to dry. The functions of top and bottom plates are to cover, compress the fiber after the epoxy is applied, and also to avoid the debris from entering into the composite parts during the curing time.

2.3 Fabrication Procedure for Specimen

The composite material is fabricated by using hand layup method. GFRP layers are placed on top and bottom on the specimen and intermediate layers are filled with natural fibers. Resin and hardener mixture (10:1) is spilled for every layer. Initially the fibers are dried in sunlight to remove the moisture. The mould surface is cleaned and releasing agent (Poly Vinyl Alcohol) is applied. A thin layer of resin is also applied on the board. The woven roving (GFRP) are then completely filled with polyurethane resin, rolled to remove the entrapped air and to uniformly spread the mixture. In this way three layers of woven roving are placed one over the other to obtain top and bottom layers. A curing time of 3–4h is given for the top and bottom structures to obtain good strength. Then the GFRP laminates are removed from the mould surface. Now the sisal fibers are arranged alternatively with horizontal and vertical orientation (Fig. 3). For each layer, resin hardener mixture is applied and rolled. Within 15 to 20 min resin is dried. So, following layers need to be stacked up within the time period of 15 min to avoid drying of polyurethane resin. Finally the fibers are closed with three layered laminate of woven roving just like the base of the laminate. Now a load (8–10 kg) is applied for a curing period of 8–12 h on the mould. This gives us the required composite laminates which can be cut to required size. Similarly the Nano sisal – GFRP composite is prepared by replacing intermediate layers (Fig. 4). Similarly, the sisal/nano sisal – GFRP composite is prepared by replacing intermediate layers (Fig. 5).
3. Testing of composites

3.1. Tensile test

The fabricated hybrid composite is cut using a saw cutter to get the dimension of the specimen for tensile testing as per ASTM: D638 standards. The test was carried out using a universal testing machine at a room temperature with 40% relative humidity. The tensile stress is recorded with respect to increase in strain. Three different types of specimens are prepared based on fibers used namely, sisal-GFRP, nano sisal–GFRP and sisal-nano sisal–GFRP (hybrid composites). The specimen was placed in the grip of the tensile testing machine and the test is performed by applying tension until it undergoes fracture. The corresponding load and strain obtained are plotted on the graphs.

3.2 Flexural test

The flexural test is performed on the same tensile testing machine as per the ASTM: D790 standards. It is performed at room temperature and close to 40% relative humidity for three different types of specimens. In this test, the specimen to be tested is subjected to a load at its midway between the supports and until it fractures and breaks. This test determines the behavior of the specimen when it is subjected to simple beam loading. Flexural test determines the maximum stress induced in the outer most fiber.

3.3 Double shear test

Double shear test is done as per ASTM standard (ASTM: D5379). Normally shear stress is negligible when compared to the bending stress when the beam is loaded. But sometimes, the shear stress becomes very important in certain design calculations. Universal testing machine is used for performing shear test with a special fixture for double shear testing.

3.4. Impact test

An impact testing machine with charpy arrangement is employed to perform the test. It is done as per the ASTM: D256 standards. The specimen is subjected to an impact blow by the pendulum until it fractures and the corresponding energy absorbed by the material is obtained. This test gives the maximum energy that a material can absorb which can be measured easily.

4. Results and Discussion

From Figure 6, the individualized sisal fiber and glass fiber hybrid composites, the mechanical properties also increase up to certain limit. Further, addition causes them to decrease due to poor interfacial bonding between fiber and matrix. The maximum mechanical properties, tensile strength, compressive strength and flexural strength are found out as 18.7 MPa, 45.5 MPa and 26.8 MPa respectively. These mechanical properties are for the fiber size are decreases the strength is to be increases due to the interfacial between fiber and matrix increases.

On further looking to the figure 7, the maximum impact strength properties are to be found in the individualized nano sisal fiber and glass fiber hybrid composites. The mechanical properties of the fibers are increases to reducing the fiber size and its length.
5. Conclusion

In this work, different fiber composites are fabricated with fibers like sisal, nano sized sisal and glass combining them as well. All the composites have the highest volume fraction of 0.40 along with GFRP. Their mechanical properties like tensile strength, compressive strength, impact strength and flexural strength are investigated and from the results obtained, the following conclusions were drawn. The tensile strength of Nano sisal composite is the relatively more than sisal/Nano sisal composite and much higher when compared with sisal composite. It has a value of 18.7 kN/mm².

The percentage elongation of single fiber in tensile testing is found to be less than that of the hybrid composite. Therefore, the hybrid composite withstands more strain before failure in tensile testing than the single fiber composite. The flexural strength of the composite is in decreasing order from sisal, sisal/Nano sisal and Nano sisal hybrid. Nano sisal has the highest flexural strength since its strength increases with increase in interfacial adhesion.

Compressive test results show that all the three manufactured composites have almost the same compressive strength in the range 19-46 kN. Impact strength of Nano sisal composite is 30 J which is quite high when compared with the sisal and hybrid composite whose impact values are 23 J and 20.4 J respectively.

From the above results, the Nano sisal-GFRP hybrid composite is found to be the best option for all general applications. This composite can be used in applications where high impact strength is necessary. Sisal fibers are abundantly available from agricultural resources; they are cheaper than the conventional natural fibers like bamboo, abaca, etc. Moreover they have high mechanical properties as discussed above and hence can be used for a variety of applications like housing, automobile and packaging industry, etc.

This work can be further extended to real time applications of automotive components such as Dash board, mudguard and engine cover. The composites mechanical characteristics can be analyzed under different working conditions and better design may be suggested which will provide a way for green environment concept.
References


