Fabrication and Property Evaluation of Banana-Hemp-Glass Fiber Reinforced Composites

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Abstract

The role of natural and manmade fibers reinforced hybrid composite materials are growing in a faster rate in the field of engineering and technology due to its favorable properties. In the present unsustainable environmental condition natural fibers are serving better material in terms of biodegradability, low cost, high strength and corrosion resistance when compared to conventional materials. The benefits of components and products designed and produced in hybrid composite materials instead of metals recognized by many industries. The main objective of this experimental study is to fabricate the banana-hemp-glass fibers reinforced hybrid composites and to evaluate the mechanical properties such as tensile strength, flexural strength and impact strength. There are three different types hybrid laminates are fabricated by hand lay-up method by using glass, banana and hemp fibers as reinforcing material with epoxy resin. The specimen is prepared according to ASTM standards and the experiment has been carried out by using universal testing machine (UTM). From the experimental results, it has been observed that the banana-hemp-glass fibers reinforced hybrid epoxy composites exhibited superior properties and used as an alternate material for synthetic fiber reinforced composite materials. Morphological examinations are carried out to analyze the interfacial characteristics, internal structures, fiber failure mode and fractured surfaces by using scanning electron microscopy (SEM) analysis.

Keywords: Mechanical properties, Hybrid composites, Scanning Electron Microscopy (SEM), Banana-Hemp-Glass fiber composites.

1. Introduction

Now-a-days, natural fibers reinforced composites exhibit the superior mechanical properties than synthetic fiber reinforced polymer composites due to its inherent properties. The mechanical properties such as tensile strength,
flexural and impact strengths of natural and synthetic fibers reinforced polymer composites with different fiber volume were evaluated by Ramesh et al. [1]. The result indicated that, there is the significant improvement in mechanical properties and the process of hybridization reduces the risks related to the environmental concern. Sapuan et al.[2] fabricated the composites by using banana fiber is a waste product of banana cultivation and which is easily available in tropical countries like malaysia and south india. This fiber has many advantages and holding high mechanical strength when compared to the synthetic fibers. They have prepared three samples with different geometries and evaluated the maximum stress value and young’s modulus along two directions and found the maximum deflection under the maximum load conditions. Ramesh et al. [3] carried out an experiment to evaluate the tensile and flexural properties of hybrid composites and the results are compared. Form the experiment, they found that the incorporation of natural fibers such as sisal/jute with glass fiber improve the tensile and flexural strength and these composites play a vital role in the field of engineering and technology. They suggested that these hybrid composites can be used for medium strength applications.

Venkateshwaran et al. [4] studied the mechanical properties such as tensile strength, flexural strength, impact strength and water absorption rate of sisal and banana fibers reinforced epoxy composite materials. They have observed that there is the significant improvement in mechanical strength and reduction in water absorption rate while hybridizing the sisal fiber up to 50% by weight with banana fiber reinforced epoxy composites. The banana and GFRP composites have good tensile property with minimum deflection when compared to the flax and GFRP composites [5]. Also the banana and flax fiber reinforced composites holds more flexural and impact strengths when compared to the flax and glass fiber reinforced polymer composites.

Natural fiber reinforced composites are renewable, biodegradable, environment friendly, light weight material when compared to the synthetic fiber reinforced composites [6,7]. The potential applications of these composites are growing rapidly in many engineering fields especially the cost of the material is main factor and to improve erosive environment [8, 9]. The mechanical properties of sodium hydroxide treated natural fiber composites under saturation pressure can be improved without any major changes in mechanical behavior [10]. Yuanjian and Isaac [11] have investigated the impact and fatigue behavior of non-woven hemp fiber composites which is reinforced with polyester and found that there is the remarkable improvement in such properties.

Li [12] have evaluated and correlated the compressive strength, flexural strength, toughness, specific gravity and water absorbing ratio and the linear specific gravity of the composites are gradually reduced by adding the hemp fiber with concrete matrix. They have observed that the fiber content by weight is the important factor which affects the compressive and flexural strength of HFRC. Hemp fiber has superior reinforcement property while increasing tensile property and strong toughness in an alkali environment [13, 14].

Kobayashi et al. [15] investigated the processing and characterization of hemp fiber textile composites with micro-braiding technique and found that the hemp fiber is suitable reinforcement for textile composites. Kabir et al. [16] studied the mechanical property of chemically treated hemp fiber reinforced composites. They found that due to the rapid climate changes in environment, the physical and geometrical characteristics of natural fiber and synthetic fiber components are affected and the fibers are undergoes some irregularities and lose the maximum load carrying capacity of the materials in engineering applications. For better surface finish of the hemp fiber composites the chemical treatment process like alkali, acetyl and silane treatments are carried out. From this study they have found that the tensile strength of untreated fiber composites is much greater than the chemically treated fiber composites.

The natural fiber reinforced composites were fabricated with hemp/paper/epoxy and flax/paper/epoxy by adding the paper on the both surfaces of hemp or flax unidirectional fibers and the composites are tested under tensile loading conditions [17]. These tensile properties are compared with unidirectional composites with absence of paper between layers of composites. They found that the unidirectional natural fiber composite with one or two layers of thin paper holds the minimum variability in tensile strength and elastic modulus. The tensile strength and delamination properties of laminated composites with paper were improved when compared to without paper unidirectional composites and the modulus are slightly reduced when compared to epoxy composites.

Banerjee et al. [18] have conducted the micromechanics analysis of hybrid composites by using FEA software (ABAQUS/CAE 6.9-2). The different hybrid laminates are prepared by using short carbon fibers and glass fibers which is reinforced with polypropylene. In this study, the elastic constant and strength properties have evaluated by using analytical formula and the results are compared with FEA results. They have observed that the negligible
variability in elastic constants and longitudinal strength properties. They also found that the significant variability in transverse strength properties. Many researchers have reviewed the experimental data about hybrid composites and they observed that rule of hybrid mixtures is the prime factor to predict the mechanical properties of unidirectional interplay hybrid composites [19-22].

In the present experimental study, the mechanical properties of banana–hemp–glass fiber reinforced composite materials are evaluated. The banana–hemp–glass fiber reinforced composite materials are fabricated by hand lay-up process. The properties such as tensile, flexural and impact strengths are studied and presented in detail. The results indicated that the addition of banana and hemp fibers in the glass fiber composite materials improve the mechanical properties.

2. Experimental

2.1. Materials

In this experimental investigation the hybrid composites are prepared by using banana fiber, hemp fiber and glass fiber. The raw banana fiber and hemp fiber are supplied by M/s. Coir goods fiber Ltd., Kerala, India. The glass fiber, epoxy resin (epoxy 758) and hardener (HY911) are purchased from M/s. Sakthi fiber glass Ltd., Chennai, India. The physical properties of banana and hemp fibers are presented in Table 1.

Table 1 Physical properties of banana and hemp fibers [5, 12, 23]

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Banana fiber</th>
<th>Hemp Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density(kg/cm³)</td>
<td>1350</td>
<td>300-1300</td>
</tr>
<tr>
<td>Tensile Strength(MPa)</td>
<td>54</td>
<td>90</td>
</tr>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>2-5</td>
<td>3-5</td>
</tr>
<tr>
<td>Young’s Modulus (GPa)</td>
<td>3.48</td>
<td>4.4</td>
</tr>
<tr>
<td>Moist Absorption(%)</td>
<td>10-11</td>
<td>10-12</td>
</tr>
</tbody>
</table>

2.2. Preparation of hybrid composites

The base plate was cleaned of rust by scrubbing with an abrasive paper. Then the surface was allowed to dry after cleaning it with a thinner solution. After drying, the surface was coated with silicon gel. The surface was given a few minutes to get it set for the mold lay-up. The epoxy resin and the hardener are mixed in the proportion of 10:1. The curing time or the pot life, which is how it is usually notified in the laboratory charts, was 20 minutes once mixed. The care must be taken so that the resin does not cure in the curing pot itself. A constant watch over the blend in the pot was made with the aid of a stop watch. Initially the natural fibers are dried with sunlight for 3 to 5 hours. The first laminate is fabricated by using banana and glass fibers with epoxy resin over the base plate. This laminate consists of three layers glass fiber and two layers banana fiber was fabricated by hand lay process. The size of the fabricated laminate is restricted to 300×300×4 mm. The top, middle and bottom layers of each laminate are consist of glass fiber and the second and fourth layers are filled with natural fibers. Similarly the hemp-glass fiber and banana-hemp-glass fibers with epoxy resin laminates are prepared by same hand lay method. Then the three sets hybrid laminate was cured under the loaded condition for 12 hours with the help of the weight press. The raw banana and hemp fibers used in for fabrication of composite laminates are presented in Fig.1 and Fig. 2. The fabricated composite laminates are given Fig.3 and Fig. 4.
2.3. Mechanical Properties of Composites

2.3.1. Tensile test

The tensile test specimens are prepared and testing of the composite laminates are carried out as per ASTM D638 standards and procedures. There are three specimen are used from each laminates for testing tensile behavior of hybrid laminates. The test has been carried out on the universal testing machine, by means of applying load on the specimen until its get failure and the results are observed. These methodologies are followed for remaining specimen in the same composite laminate and other laminate specimens to get the mean tensile strength and corresponding stresses for the comparison of results. The tensile test specimen before and after fracture of banana-hemp-glass fibers reinforced epoxy composites are presented in Fig. 5 and Fig. 6.
2.3.2. Flexural test

The flexural test specimens are prepared as per the standard methods of ASTM D790. The three test specimens of each laminate of banana, hemp, and glass fiber reinforced epoxy composites are prepared and tested by applying the 3 point flexural load with the help of the same universal testing machine (UTM). The results of flexural strength and displacement of each specimen are observed for result comparison. The flexural test specimen before and after fracture of banana-hemp-glass fibers reinforced epoxy composites are presented in Fig. 7 and Fig. 8.

2.3.3. Impact test

The three test specimens are prepared from each composite laminate of banana, hemp, and glass fiber reinforced composites for evaluating the impact load carrying capacity of the material. The test specimens are prepared from the laminate of hybrid composite as per the standard ASTM A370 and the edges of the specimens are neatly finished and small “v” notches are also provided by using hack saw blade. During the test the maximum energy that can be stored to break the specimens are noted for the entire specimen for analysis of results. The V notched impact test specimen before and after fracture of banana-hemp-glass fibers reinforced epoxy composites are presented in Fig. 9 and Fig. 10.

3. Results and discussion

The use of natural and manmade fibers reinforced hybrid composite materials are growing day by day due to its characteristics like eco-friendly, recyclable, bio-degradable and user friendly in nature. Many researchers are working in this field to make the composites hybrid and to replace metals and alloy materials in the field of engineering and technology without affecting the load carrying capabilities and cost aspects. In the present experimental study, the banana and hemp fibers are hybridized with glass fiber and prepared hybrid composite laminates. Then the test specimen are prepared from the composite laminates as per ASTM standards and testing of materials has been carried out under tensile, flexural and impact loading conditions by using universal testing.
machine and impact testing machine. The experimental results on mechanical properties of the tested composite specimen are observed and presented in Table. 2.

Table. 2 Experimental results of the hybrid composite samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tensile strength (MPa)</th>
<th>Flexural strength (KN)</th>
<th>Impact strength (Joules)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana-glass fiber composites</td>
<td>39.5</td>
<td>0.50</td>
<td>5.33</td>
</tr>
<tr>
<td>Hemp-glass fiber composites</td>
<td>37.5</td>
<td>0.29</td>
<td>5.33</td>
</tr>
<tr>
<td>Banana-hemp-glass fiber composites</td>
<td>28</td>
<td>0.51</td>
<td>8.66</td>
</tr>
</tbody>
</table>

3.1. Tensile strength analysis

The composite samples are tested in the universal testing machine (UTM) and the typical force vs. stroke curve generated directly from the machine during tensile loading for the hybrid composites is presented in Fig. 11. The tensile strength comparison of different hybrid composites is presented in Fig. 12. From the figure it can be observed that the banana-glass fiber reinforced composites are performing better than the other composites tested which can withstand the tensile strength of 39.5MPa followed by hemp-glass fiber reinforced composites can hold the strength of 37.5MPa.

![Fig. 11 Typical force vs. stroke curve generated directly from the machine during tensile loading](image1)

![Fig. 12 Tensile strength comparison of different hybrid composite samples](image2)
3.2. Flexural Strength analysis

The flexural properties of the hybrid composite samples are tested and the experimental values are presented in Table. 2. The force vs. stroke curve generated directly from the machine during flexural loading for the hybrid composites is presented in Fig. 13. The flexural strength comparison of different hybrid composites is presented in Fig. 14. From the figure, it is asserted that the flexural load carrying capacity of banana-hemp-glass fiber reinforced composites is better than banana-glass fiber reinforced composites and hemp-glass fiber reinforced composites.

![Fig. 13 Typical force vs. stroke curve generated directly from the machine during flexural loading](image1)

![Fig. 14 Flexural strength comparison of different hybrid composite samples](image2)

3.3. Impact strength analysis

The impact test is carried out for evaluating the impact load carrying capability of the different hybrid composite specimens and the charpy impact test is used in the present investigation. The loss of energy is found out on the reading obtained from the impact testing machine. The impact strength comparison of different hybrid composite samples is presented in Fig. 15. The results indicated that the maximum impact strength is obtained for banana-hemp-glass fibers reinforced hybrid composites which hold the impact strength of 8.66Joules. The banana-glass fiber reinforced composites and hemp-glass fiber reinforces composites are performing in the same level can withstand the impact strength of 5.33Joules.
3.4. Scanning electron microscopy (SEM) analysis

The failure morphology of the hybrid composite samples tested in the present experiment is examined through scanning electron microscopy analysis. The SEM micrographs of the hybrid composite samples subjected to tensile loading are presented in Fig. 16. From the images, it can be seen that the fracture of the fiber and matrix due to the applied tensile load. The SEM micrographs of the hybrid composite samples subjected to flexural loading are presented in Fig. 17 and the samples subjected to the impact loading are presented in Fig. 18. The fiber breakage and fiber pull out due to flexural loading are clearly observed in Fig. 17. Fig. 18 indicated that the fractured edges of the fibers in the specimen and also the dislocation of fibers due to impact loading.
The banana-glass fiber, hemp-glass fiber and banana-hemp-glass fiber reinforced hybrid composites are fabricated and the mechanical properties such as tensile strength, flexural strength and impact strength of these composites are evaluated. The following conclusions have been derived from the experimental investigations.

- The banana-glass fiber hybrid composites have more tensile strength than other composites can withstand the tensile strength of 39.5MPa followed by the hemp-glass fiber reinforced composites which holds the value of 37.5MPa.
- The maximum flexural strength of 0.51kN hold by the banana-hemp-glass fiber reinforced composites followed by banana-glass fiber reinforced composites which is having the value of 0.50kN.
- The impact strength of the hybrid composites varies from the 5.33Joules to 8.66Joules.
- From the morphological observations the interfacial characteristics, internal structures of the fractured surfaces, fiber failure mode, fiber pull out and fiber dislocation are clearly observed.
- It is suggested that these banana-hemp-glass fibers reinforced hybrid epoxy composites can be used as an alternate material for synthetic fiber reinforced composite materials.

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