Evaluation of tensile, flexural and Impact strength of natural and glass fiber reinforced hybrid composites

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Abstract

The development of composite materials made up of natural fibers is improving in engineering applications such as Automotive, Marine and Aerospace, due to its properties such as high specific strength, renewable, non-abrasive, low cost, bio-degradable. Many researchers have identified different natural fibers used to substitute glass fiber, among them jute appears to be favorable material because of its low cost, high strength, high aspect ratio, good insulating and low thermal conductivity. Hence the objective of this research work was to evaluate the mechanical properties of hybrid composites such as tensile strength, flexural strength and impact strength using static test methods as per ASTM standards and Finite Element Analysis was done to evaluate the properties of the composite laminate and compared results of FEA with experimental results. The composite laminates used for the present investigation was fabricated using hand layup technique. Incorporation of natural and glass fiber in different stacking sequence used to prepare hybrid laminates. The outcome of the present investigation indicate that hybrid composite laminates improve strength and can be used as alternate material for automotive application and Finite Element Analysis results proved the experimental results.

Keywords: Hybrid composites, mechanical properties, natural fiber, finite element analysis

Introduction

The improvement of composite materials and their related outline and assembling innovations is a standout amongst the most imperative advances ever. Composites are the material utilized as a part of different fields having selective mechanical and physical properties and are created for specific variety of application. Composite materials having a scope of preferences over other routine materials, for example, elasticity, sway quality, flexural qualities, solidness and exhaustion attributes. As a result of their various preferences they are generally utilized as a part of the avionic business, business mechanical designing applications, similar to machine segments, vehicles, burning motors, mechanical segments like shafts, weight vessels and flywheels, warm control and electronic bundling, railroad mentors and air ship structures and so on. The interest in natural fiber reinforced composite materials is rapidly growing both in terms of engineering applications and research. These natural fibers are completely renewable, environmental friendly, low cost and bio-degradable, due to this characteristics natural fibers have recently become attractive to researchers and scientists as an alternative method for fibers reinforced composites. Among natural fibers jute fiber appears to be promising material because it is inexpensive, high strength, high aspect ratio, good insulating and completely bio-degradable and recyclable. Consistency of the composites were studied by Manuel Chiachio, et al., [1] studied the basic structure of composite material and they concluded that composite materials can be used in wide variety of application such as automotive, aerospace and construction applications. Michael Karus, et al., [2] has studied the demand for natural fibers in automotive sector and interest in natural fibers increasing day by day. Manufacturing of composite materials made by the natural fibers using compression moulding has studied and natural fibers used in the transport segment increasing in European market also explained. AninMemon, et al., [3] has carried out investigation on jute reinforced polymer composites. Composites fabricated using compression moulding, when temperature increased effect of dispersion of fiber from the mould increased. Furthermore tensile strength decreased due to dispersion of fibers. Hence, investigation concluded that temperature of mould effect the properties
of composite material. Md. RashnalHossain et al., [4] studied the properties of jute epoxy composite material because of its properties compared synthetic fibers. In the investigation composites were fabricated by using hand layup method and composites were subjected to mechanical tests such as tensile and flexural test, results concluded that tensile and flexural strength of the composite depends on volume of fiber in the composite material.Jansons et al., [5] evaluated the effect of moisture and temperature as well as fatigue properties of carbon fiber reinforced polymer composites. From the study reveals that moisture absorption depends on the thickness of the laminate and properties also depends on the thickness of the composite. Kutty and Nandoet al., [6] investigated the process parameters influences on the properties of Kevlar and aramide composite laminates, investigation explains the process parameters such as nip gap, friction ratio and mill roll temperature maximum influence on the fiber sequence and also influences the mechanical properties of composite. Yuan et al., [7] studied the effect of modified Kevlar fibers on the mechanical properties of wood-flour/polypropylene composites. Study reveals that the addition of reinforcement increases the properties of composites.Wang et al., [8] studied static properties of synthetic fibers such as glass and Kevlar reinforced composites from the investigation results shows strength of the composite depends on the type of reinforce- ment used in the composite laminate. After vast literature survey carried on natural fibers and its propertiesits concluded that lack of research progressed on jute fiber and its application. Hence objective of this research work is to Evaluate the Tensile, Flexural and Impact Strength of Natural and Glass Fiber Reinforced Hybrid Composites.

**Experimental**

**Material selection**

In the present investigation jute fiber was procured from the Jute Pragnya, Bengaluru, India. Glass Fiber was supplied by Marchtech Solutions Bengaluru, India. The polyester resin used in the investigation was general purpose polyester resin fb-333 and the hardener used was Catalystmethyl ethyl ke- tone peroxide (MEKP) and accelerator was cobalt napthenate. Both resin and hardener procured from the commercial resin supplier, Bengaluru, India. Figure 1 shows the Bi-Directional jute and glass fiber mat.

**Fabrication of composite laminate**

Composite Laminate was fabricated by Hand layup technique. The bi-directional jute fibre and the E-glass fibres were used as reinforcement and Polyester was considered as matrix material. Four laminates were prepared with different fiber orientation as shown in Table 1. Bi woven fiber reinforce-ments used for the laminate because these fibers gives better strength compared to uni directional and chopped fibers Each laminate included three layers of reinforcement in 0°/90° Bi woven fiber direction. Laminate L1 contains three layers of jute fiber, laminate L2 contains three layers of glass fiber and laminate L3 contains two layers of jute fiber and one layer of glass fiber similarly laminate L4 contains two layers of glass fiber and one layer of jute fiber.

The sticking of polyester resin to the surface was avoided by spraying the release gel on the mould surface. In order to obtain better surface finish, at both ends of themould, thin plastic layer were placed for easy removing of laminate. As per the mould size, E-glass fibers and woven mat jute fabrics were cut for the reinforcement and positioned on the layer of the mould after plastic layer. After reinforcement, polyester resin taken in a liquid form was added carefully in appropri-ate amount with hardener in the ratio 1:0.2:0.2 and resin was poured onto the layer of reinforcement already positioned on the mould. The polyester resin was evenly applied using brush. The next layer of reinforcement was positioned on the polyester resin with the help of roller with slight pressure on the reinforcement-polyester layer to take out any air voids as well as theleftover polyester resin on the mould. The process was repeated for each layer of polyester and reinforcement, until the necessary layers were placed. On the surface of fiber and polyester resin plastic layer was placed, again for easy removal of mould release gel was sprayed on the above layer of the top mould and pressure was applied. After curing at the temperature of 80°C, the mould was removedand the ready composite laminate was obtained and it was machined for the required dimensions. Preparation of composite laminate using hand layup technique is shown in the Figure 2.

Densities of the laminate calculated using the relation weight of the laminate divided by area of the laminate. Densi-ties of Laminate represented in the Table 2.

![Figure 1. Bi-Directional jute and glass fiber mat.](image)

| Laminate | Composition                      |
|----------|---------------------------------|
| L1       | 100% Jute Fiber                 |
| L2       | 100% Glass Fiber                |
| L3       | 60% Jute and 40% Glass Fiber    |
| L4       | 60% Glass and 40% Jute Fiber    |

![Table 1. Laminates and its composition.](image)
Mechanical characterization

Tensile strength

Tensile test or tension test is a basic test in which a specimen is subjected to uniaxial tension until the material fractures. Uniaxial tension refers to the force acting on the opposite faces of the material in opposite direction with respect to each other along the same axis. The material is placed between two grips and is subjected to tensile or tension force. This force causes the gauge length of the material to elongate and finally material fractures. Thus, elongation, final cross sectional area and peak load of the material are obtained directly from tensile test. In the present investigation, the tensile test laminates were prepared as per ASTM: D3039 (Dimension is 250×25×3 mm) and the testing was carried out using universal testing machine Model: KIC-2-1000-C, it can withstand maximum load of 10 KN and machine was connected with a computer and results are obtained in graphs and values are recorded in the separate file. Figure 3 indicates the experimental set up for tensile strength test.

Flexural strength

In the present investigation, laminates prepared as per ASTM: D790 Standard (Dimension is 127×12.7×3 mm) Flexural test was carried in a three point flexural setup in universal testing machine. Test carried to all four different compositions of laminates. Figure 4 represent the loading setup of the laminates for flexural test.

Finite element analysis

In the present investigation, static analysis of composites was studied with the help of ANSYS 15. The modeling of specimens was done in ANSYS considering element type as SHELL 181, throughout the study. The element has four nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y and z axes. Thus each element has 24 degrees of freedom in total. The element size of 2 was considered for meshing of specimen. Figure 5 represent the meshing used for the tensile and flexural test. Using the simple rule-of-mixtures [9], elastic constants of the

| Laminate | Weight W (in grams) | Density ρc (g/cm³) |
|----------|---------------------|--------------------|
| L1       | 699                 | 1.23               |
| L2       | 776                 | 1.81               |
| L3       | 727                 | 1.62               |
| L4       | 677                 | 1.35               |

Table 2. Laminates and its composition.
unidirectional composite were calculated.

\[ E_1 = E_f V_f + E_m V_m \]  
\[ E_2 = E_m \left( \frac{E_f + E_m + (E_f - E_m) V_f}{E_f + E_m - (E_f - E_m) V_f} \right) \]  
\[ \nu_{12} = \nu_f V_f + \nu_m V_m \]  
\[ \nu_{23} = \nu_f V_f + \nu_m V_m \left( \frac{1 + \nu_m - \nu_{12} E_m / E_1}{1 - \nu_m^2 - \nu_{12} \nu_m E_m / E_1} \right) \]  
\[ G_{12} = G_m \left( \frac{G_f + G_m + (G_f - G_m) V_f}{G_f + G_m - (G_f - G_m) V_f} \right) \]  
\[ G_{23} = \frac{E_2}{2(1 + \nu_{23})} \]  

For bi-woven fiber reinforced lamina

\[ \left[ \frac{1}{E_{11}} \right]^{WF} = \left[ \frac{1}{E_{11}} \right]^{UD} \]  
\[ \left[ \frac{1}{E_{22}} \right]^{WF} = \left[ \frac{2}{E_1} \left( \frac{E_1 + (1 - \nu_{12} E_{12}) E_{22}}{E_{12} (E_1 + 2 E_{12}) + (1 + 2 \nu_{12} E_{12}) E_{22}} \right) \right]^{UD} \]  
\[ \left[ \frac{\nu_{12}}{E_{11}} \right]^{WF} = \left[ \frac{4}{E_1} \left( \frac{\nu_{12} E_{12} (E_1 - \nu_{12} E_{12})}{E_{12} (E_1 + 2 E_{12}) + (1 + 2 \nu_{12} E_{12}) E_{22}} \right) \right]^{UD} \]  
\[ \left[ \frac{\nu_{13}}{E_{11}} \right]^{WF} = \left[ \frac{1}{E_1} \left( \frac{E_1 (\nu_{12} + \nu_{12} + \nu_{12} + \nu_{12} E_{12})}{E_{12} (E_1 + 2 E_{12}) + (1 + 2 \nu_{12} E_{12}) E_{22}} + \nu_{12} E_{12} \right) \right]^{UD} \]  
\[ \left[ \frac{1}{G_{12}} \right]^{WF} = \left[ \frac{1}{G_{12}} \right]^{UD} \]  
\[ \left[ \frac{1}{G_{23}} \right]^{WF} = \left[ \frac{1}{G_{23}} \right]^{UD} \]  

Where \( UD \) and \( WF \) denote unidirectional fiber and woven fiber respectively. After calculating the elastic properties of unidirectional lamina in the equation 1-6, bi-directional lamina elastic properties were calculated using equation 7-12 [11].

**Impact strength**

In the present investigation impact testing was carried out in a charpy impact setup. Composite laminate prepared for the test as per ASTM: D256 standard. The effect of strain rate on fracture and ductility of the material was analyzed. Figure 6 indicate the experimental set up and loading arrangement of the specimens for impact test.

Results and discussion

**Tensile properties**

In the investigation tensile test was carried out by put on tensile load on the composite laminate. Four different volume of fibers and resin were tested. In every test, three samples were tested to achieve average values of same composition of laminate and results were noted. The laminate was fixed in the fixture of the machine and load was applied and the corresponding change in length of the specimen was recorded. The load was applied on the laminate until it breaks and peak load, ultimate tensile strengths were recorded. After testing stress and strain curve obtained from the software it was recorded and load v/s displacement graphs were generated. Figure 7 represent the tensile test specimens.

Figure 8 shows the tensile strength of four different laminates with different percentage of fiber and resin content. It can be observed from Figure 8 that tensile strength of the
laminate 2 which include 100% of glass fiber shows higher tensile strength compared all other laminates. Laminate with higher volume of glass fiber in the laminate 4 shows better strength compared to laminate 1 and laminate 2 with higher volume of jute fiber. Hence, from the volume fraction of glass fiber higher in the laminates gives higher tensile strength.

**Flexural properties**

Flexural test was carried in the same universal testing machine by put on load in between the test length of the composite. Test carried on the four different laminate and the various parameters of flexural testing was determined, peak load was recorded and load v/s displacement graphs were generated. Figure 9 shows the fractured flexural specimens.

Finite element analysis result

Finite element analysis carried using ANSYS to validate the experimental tensile and flexural results [10]. It can be observed that experimental results shows good agreement with the ANSYS values. It was concluded that by assuming uniform mixture and properties of the fibers in the entire laminate, the tensile strength of L2 laminate (279MPa) was 17.9% higher than L4 laminate (229MPa), 44.6% higher than L3 (154.5MPa) laminate and 72% higher than L1 laminate. In case of flexural testing, flexural strength of L2 laminate (373MPa) was 19.3% higher than L4 laminate (301MPa), 42.09% higher than L3 (216MPa) laminate and 68.36% higher than L1 laminate (118MPa). The results of tensile and flexural test, both experimental and ANSYS are tabulated in Tables 3 and 4.

The Figure 11 shows the contour plots of von Mises stress.

**Figure 7.** Tensile testing specimen of jute/glass fibre.

**Figure 8.** Variation of tensile strength for different fiber percentage of laminates.

**Figure 9.** Fractured Flexural tested specimen.

**Figure 10.** Variation of flexural strength for different fiber percentage of laminates.

**Figure 11.** Fractured Flexural tested specimen.

![Figure 7](image7.png)

![Figure 8](image8.png)

![Figure 9](image9.png)

![Figure 10](image10.png)

![Figure 11](image11.png)
of L1, L2, L3 and L4 laminates for Tensile and flexural test analysis respectively.

**Impact strength**

Charpy Impact Test was used to determine the impact properties of the material. The effect of strain rate on fracture and ductility of the material was analyzed. From the Figure 12 it can be observed that laminate 2 with 100% of glass fiber absorbed more energy compared to other laminates because of high volume of glass fiber in the laminates. Figure 13 shows the energy absorbed in the impact testing of the laminates.

**Conclusions**

The Finite Element Analysis and experimental studies on the mechanical properties of natural and synthetic fiber was investigated. Effect of fiber loading and orientation on mechanical properties of jute and glass fiber reinforced polymer based hybrid composites led to the following conclusions:

In tensile test, laminate L1 with 100% of jute fiber shows decrease in strength when compared with laminate L2 with 100% of Glass fiber.

In flexural test, composite laminate L3 & L4 with Jute and Glass fiber orientation concludes improved strength than laminate L1. In the same way Laminate L4 shows improved strength than laminate L3, because volume of glass fiber was higher in the laminate.

The combination of reinforcement such as glass fiber and jute fiber in composite laminates improves the mechanical strength and this makes way to the increase of the utilization of natural fibers in various applications.

Experimental results validated using Finite Element Analysis, results from the analysis proved the experimental results.

From the present investigation it has been observed that the composites with natural fiber and synthetic fiber increases mechanical strength such as tensile strength, flexural strength, impact strength of the composites with the increase in fiber and also strength significantly varied by the fiber composition.

**Competing interests**

The authors declare that they have no competing interests.

**Authors’ contributions**

| Authors’ contributions          | AKP | RSS | SP |
|---------------------------------|-----|-----|----|
| Research concept and design     | --  | ✓   | -- |
| Collection and/or assembly of data | ✓  | --  | -- |
| Data analysis and interpretation | --  | ✓   | -- |
| Writing the article             | ✓   | --  | -- |
| Critical revision of the article | --  | ✓   | -- |
| Final approval of article       | --  | ✓   | -- |
| Statistical analysis            | --  | --  | ✓ |

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