Study on Physical and Mechanical Behavior of Bauhinia Vahlii Fiber Filled Glass–Epoxy Hybrid Composites

Rashmi Ray, Sankar Narayan Das, and Abhipreet Mohapatra

Abstract Epoxy is well-suited for a number of industrial applications because of its versatility and its diversity. In many high-performance fields however, the overall use of epoxy limited its employment due to delamination, intrinsic fragility, low impact resistance and hardness to fractures. Epoxy's limitations can be overcome through inclusion and modification prior to industrial use. The present research describes the development of hybrid composites made of epoxy reinforced with glass fiber and filled with Bauhinia Vahlii fiber. Bauhinia Vahlii (BV) found to be most promising natural fiber for manufacturing composites for its superior mechanical as well as thermal properties. In this study, the incorporation of BV fiber on physical and mechanical behavior of glass–epoxy composites was investigated. Various composite compositions with three distinct natural BV fiber percentages (4, 8, 12%) were fabricated using a hand layup technique. The results showed that increasing the percentage of natural fiber concentration improves mechanical qualities, however at larger BV fiber loading, the strength reduces due to presence of more voids which signifies poor bonding.

Keywords Bauhinia Vahlii · Natural fiber · Glass fiber · Epoxy · Composite

1 Introduction

Composite materials have a number of advantages over traditional materials, including mechanical (tensile, flexural and impact) and tribological (wear resistance) advantages (wear, corrosion and fatigue). Composites found an outsized range of

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P. Pradhan et al. (eds.), *Recent Advances in Mechanical Engineering*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-16-9057-0_64

applications in the aerospace industry, applications in the field of mechanical engineering which includes machine components, automobiles, tanks, drive shafts, pressure vessels, electronic packaging and thermal management, aircraft structures and train coaches, etc. [1]. The genesis of the interest is that higher density fiber that is used in hybrid form is a more cost-effective utilization. A hybrid structure may also offer a more appealing combination of mechanical qualities, such as tensile, flexural and impact, than a single fiber reinforced composite [2]. Bio-composites are the combination of natural fibers with polymer matrices that may be thermosetting, thermoplastic or natural polymer. Thermoplastics polymers are recyclable, tough, easy to process [3]. Examples include polyvinyl alcohol, polyvinyl pyrrolidone, polyethylene, polypropylene, polystyrene, nylons and so on. Thermoset has low resin viscosity, good fiber wetting, excellent thermal stability and chemically resistant. But these are brittle and nonrecyclable [4]. Typical examples are epoxies, polyesters, phenolics, ureas, melamine, silicone and polyimides. A variety of thermoplastic or thermosetting polymers has been used with natural fibers to fabricate bio-composites for many applications [5–7]. Bio-composites are now used in a variety of industries, including automotive, medicinal, energy, toys, sports and so on. The advancement of new bio-composite materials with added functional properties in dynamic and smart packaging has made further scope for extension of materials innovation [8, 9]. In accordance with the current research, the objective of this project is to fabricate epoxy composite reinforced with laminated glass fibers and Bauhinia Vahlii fibers (chopped) randomly oriented to examine the influence of BV fiber percentage on physical and mechanical behavior of composites.

2 Materials and Methods

The BV stems used in this investigation were found in rural Odisha. The epoxy resin and hardener used was Araldite LY556 (320.816 g/mol) and HN951 (Molecular weight: 181.61), respectively. The laminated glass fibers and chemical sodium hydroxide is bought locally. Figures 1 and 2 illustrate laminated glass fiber and chopped BV fibers.

The BV stem fibers were made by removing the outer bark strips and cutting the inside bark into little bits of 3-4 mm long and 1 mm wide. 5% NaOH solution was used to treat the fibers for 1 h. The fibers were dried for 24 h at 60°C in an oven. Then, the fabrication of composite is done using the conventional hand layup method [10]. The epoxy resin is mixed with hardener at a 10:1 weight ratio. To make glass fiber reinforced epoxy composite sheets, the laminated glass fiber is inserted between layers of epoxy resin. This was followed by a middle layer of laminated glass fiber and a top layer of epoxy and BV fiber mixture. The composite cast is cured for 24 h under a 50 kg weight. Lastly, suitable dimensions specimens for characterization and testing are cut with a hack saw. The details of composite composition are shown in Table 1.

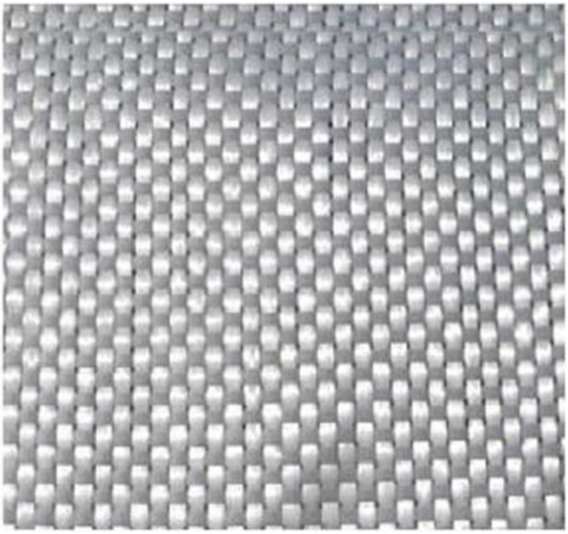

Fig. 1 Laminated glass fiber

Fig. 2 Chopped BV fibers

2.1 Morphological Analysis of BV Fiber

A Leo Supra 35VP scanning electron microscope (SEM) was used to capture the surface of BV fiber. The surfaces of alkali treated and untreated BV fibers were examined using a 20 kV microscope. A 10 nm coating of gold was applied to the sample surfaces.

Table 1 Details of composite composition

Composite designation	Composition
Composite 1 (C1)	Epoxy (80%) + Glass fiber (20%) + BV fiber (0%)
Composite 2 (C2)	Epoxy (76%) + Glass fiber (20%) + BV fiber (4%)
Composite 3 (C3)	Epoxy (72%) + Glass fiber (20%) + BV fiber (8%)
Composite 4 (C4)	Epoxy (68%) + Glass fiber (20%) + BV fiber (12%)

2.2 *Physical Characterization of Composite*

The formula for calculating the theoretical density (ρ_{ct}) of composite material is [10]

$$\rho_{ct} = \frac{1}{\left[\frac{W_{bvf}}{\rho_{bvf}} + \frac{W_{gf}}{\rho_{gf}} + \frac{W_{m}}{\rho_{m}}\right]} \tag{1}$$

where the weight fraction and density are represented by w and ρ, respectively. BV fiber, glass fiber, matrix and composite material are denoted by the suffix bvf, gf, m and ct, respectively. Using a simple water immersion procedure, the actual density (ρ_{ca}) can be estimated experimentally. The following equation is used to compute the volume fraction of the voids (V_v) in the composite

$$V_v = \frac{(\rho_{ct} - \rho_{ca})}{\rho_{ct}} \tag{2}$$

2.3 *Mechanical Characterization of Composite*

A Universal Testing Machine (UTM) was used to measure the composite's tensile properties (INSTRON 3382) at10 mm/min crosshead speed [10]. The ASTM D638 test standard is used to conduct tensile tests on composite samples. Again, the three-point bending method was used to test the composite's flexural strength and flexural modulus in a Universal Testing Machine at a crosshead speed of 10 mm/min. Similarly, using a pendulum type Izod Impact testing machine, the ASTM D 256 standard was applied to determine the impact strengths of composites. Like a cantilever beam, specimens were vertically fastened and struck by a single pendulum swing released at a specified distance from the clamp. 3.45 m/s and 0.905 kg, respectively, were the hammer velocity and weight. The hardness of the composites sample was measured according to ASTM D785-98 standard in a Rockwell Hardness Testing Machine.

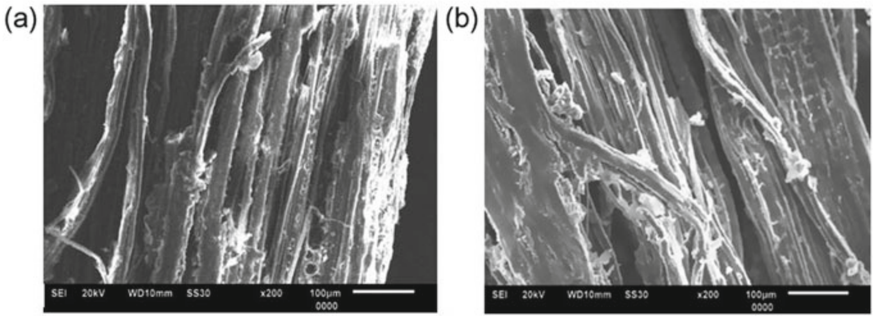

Fig. 3 Scanning electron microscope of **a** untreated BV fiber, **b** NaOH treated BV fiber

3 Results and Discussion

3.1 Scanning Electron Microscope (SEM)

Figure 3a displays scanning electron micrograph of untreated fiber that reveals porosity and non-uniform cellular features. The fiber surface is bounded by lignin and hemicellulose. Whereas, the alkali treated BV fibers in Fig. 3b shows more uniform and compressed cellular structures. The NaOH treatment re-energizes the hydroxyl groups present in cellulose and lignin. When natural fibers are exposed to NaOH solution, the hydroxyl group ionizes to alkoxide as follows:

$$\text{Fiber} - \text{OH} + \text{NaOH} \rightarrow \text{Fiber} - \text{O}^{-}\text{Na}^{+} + \text{H}_2\text{O} \tag{3}$$

3.2 Void Fraction

The inclusion of voids in the composite accounts for the difference between theoretical and experimental densities as obtained from Eq. (1) and presented in Table 2. As the fiber loading increases from 0 to 12 wt% BV fiber, the void percentage in the composites increases. Maximum void found in 12% BV fiber loaded composites 4 obtained from Eq. (2). The presence of voids has a substantial impact on several mechanical properties, as well as the performance of composites in the workplace. An excellent composite should, without a doubt, have fewer voids.

Table 2 Void fraction of composite

Composites	Theoretical data (g/cc)	Experimental data (g/cc)	Volume fraction of voids (%)
Composite 1 (C1)	1.776	1.750	1.46
Composite 2 (C2)	1.571	1.520	3.24
Composite 3 (C3)	1.493	1.400	6.22
Composite 4 (C4)	1.385	1.276	7.87

3.3 Mechanical Characterization

Tensile properties

Figure 4a depicts the tensile strength of the composite sample. The tensile strength of the composites increases when the natural fiber loading is increased to a certain percentage. In comparison to 0 and 4 wt% BV fiber, the composite sample with 8 wt% BV fiber reinforced composite had the maximum tensile strength. However, due to fiber agglomerations, epoxy and BV fiber bonding are weak at 12 wt% fiber loading. Consequently, the strength is decreasing. Also, formation of void between fiber and matrix is greatly affecting the mechanical properties [11]. This suggests that the increased tensile strength of the BV fiber reinforced composite up to 8 wt% could be attributable to improved adhesion between natural fiber and epoxy resin. The tensile modulus of composites, on the other hand, increased as the BV fiber loading increased, as seen in Fig. 4b. This could be attributed to higher brittleness of the composite as well as the degree of resistance, due to higher BV fiber weight percent and eventually resulting in greater stiffness of the composite.

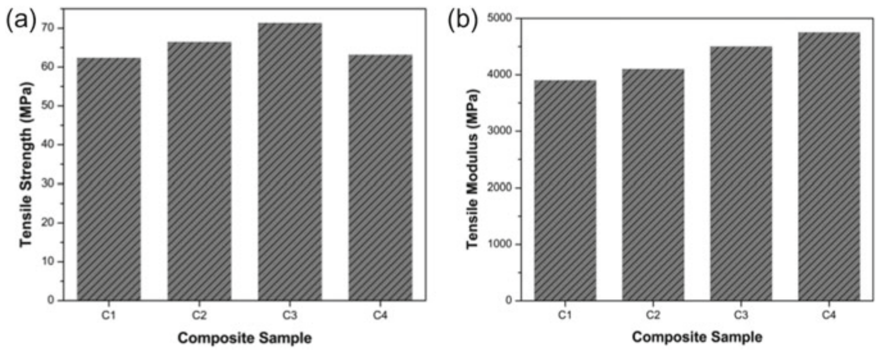

Fig. 4 **a** Tensile strength and **b** tensile modulus of composite sample

Flexural properties

When it comes to flexural characteristics, Fig. 5(a) shows that BV fiber loading raises the composite's flexural strength and modulus by up to 8%. This is due to a good stress distribution between the epoxy and the BV fiber. However, at higher BV fiber loading (12 wt%), fiber–fiber contact is discouraged, and the fibers are poorly distributed within the matrices. Figure 5b shows the same behavior in the case of flexural modulus. With the inclusion of natural fiber, the flexural modulus increases by up to 8% by weight, then drops as more fiber is added.

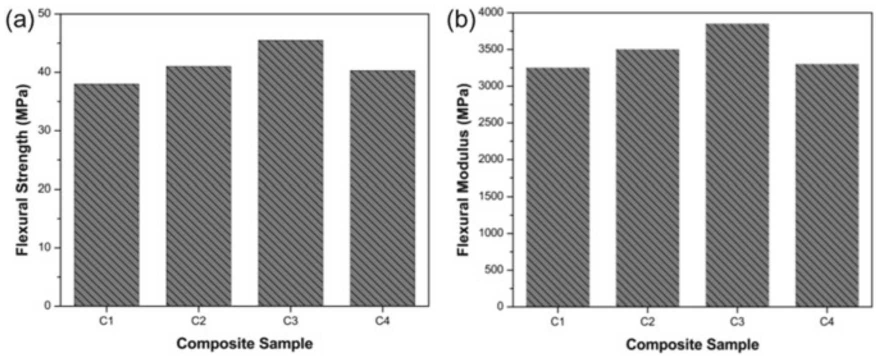

Fig. 5 **a** Flexural strength and **b** flexural modulus of composite sample

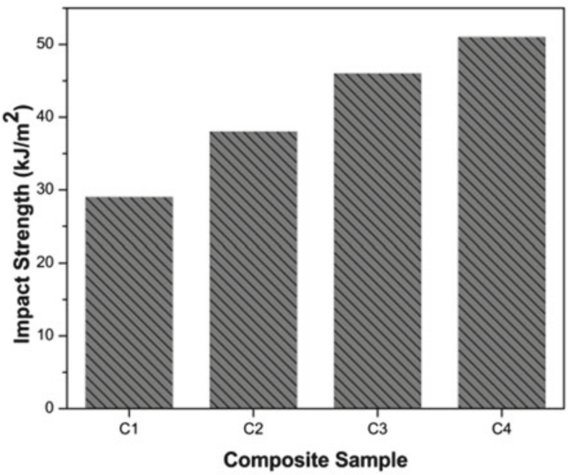

Fig. 6 Impact strength of composite sample

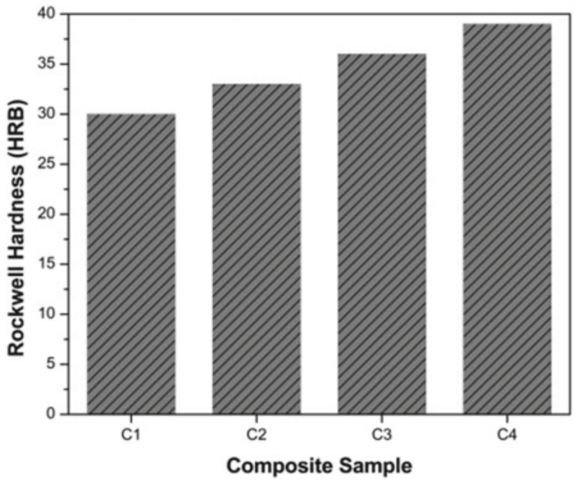

Fig. 7 Hardness of composite sample

Impact strength

The impact strength of composite samples is shown in Fig. 6. In contrast to tensile and flexural strength, the impact strength increases with increased BV fiber weight percentage. This implies that due to addition of BV fiber loading, the energy absorbing capability of the composite increases and makes the composite material more ductile.

Hardness

It has been discovered that when fiber loading increases, the Rockwell hardness values increase dramatically as shown in Fig. 7. The presence of BV fiber in epoxy causes the composites' stiffness to improve. As rigidity depends on fiber volume and modulus, this is the case. The outcomes show that the hardness value of the composites improves progressively as the BV fiber content increases, maximum at 12 wt%.

4 Conclusion

The present paper addresses a potential opportunity to build epoxy-based Bauhinia Vahlii/glass fiber hybrid composites that are made with varying percentages of BV fiber keeping a constant weight of glass fiber. The composite's tensile and flexural qualities were enhanced by the addition of appropriate quantities of BV fiber. However, the tensile and flexural strength decreases at 12 wt% Bauhinia Vahlii fiber, because to the larger volume fraction of voids. The addition of natural fiber leads to an improvement in impact strength and hardness of the composite material.

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