Research Article

Fabrication and Experimental Testing of Hybrid Composite Material Having Biodegradable Bagasse Fiber in a Modified Epoxy Resin: Evaluation of Mechanical and Morphological Behavior

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Abstract
Natural fibers such as bagasse, jute, sisal and coir are biodegradable as well as non-toxic in nature, so the use of natural fiber is safe. Bagasse contains about 50% cellulose, 25% hemicellulose, and 25% lignin. The present work has been undertaken to develop a composite using bagasse fiber as reinforcement and to study its mechanical properties, morphology, water absorption capacity and performance. The composites were prepared with different weight percentage of bagasse fiber by hand lay-up method. In the present research work, it can be concluded that with increase in wt% of bagasse fiber in matrix material the rate of water absorption increases. Ultimate tensile strength, ultimate compressive and flexural strength of the composite are less than the pure epoxy while Young's modulus is higher for composite. Ultimate tensile, ultimate compressive strength and flexural strength of composite is decreasing at all cross head speed with increase in wt% of bagasse fiber while flexural strain is increasing. Scanning Electron Microscopy (SEM) showed that for 5 wt% of bagasse fiber the binding between epoxy and bagasse fiber is better than the 10 and 15 wt% of bagasse fiber configuration. This was because of the increase in wt% of bagasse fiber, which results in cavities and improper binding in the composite domain. Thus, as we increase the wt% of bagasse fiber, it causes the decrease in mechanical properties of composite.

Keywords: Composite, Bagasse fiber, Mechanical behavior, Epoxy resin, Microstructure

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1 Introduction

Superior environmental performances are an important part of increased future use of natural fiber composite [1]. There are different materials which can be used as reinforcement in epoxy composite such as glass, natural fibers like bagasse, coconut fiber, jute fiber etc. They have different effects on the properties of the composite. Girisha *et al.* [2] used coconut coir and sisal fibers in hybrid combination and the fiber weight fraction of 20, 30 and 40% were used for the fabrication of the composite. Several other research works have been conducted to explore the effects of natural fibers in the polymer matrix [3]–[32]. Verma *et al.* [4] have reviewed the human hair natural fiber for the composite purpose. Same research group explored the properties of starch and sisal fiber biocomposite [5]. Bharath *et al.* [6] developed biofiber based composites for the printed circuit board application. Verma *et al.* [7]–[10] have explored the mechanical properties of chicken feather and human hair fiber for the polymer composite application. Same research group have fabricated pyrolyzed oil rubber (from waste tires)-epoxy polymer blend composite to various applications [11]. Jain *et al.* [12] have reinforced basalt fiber inside a polyvinyl alcohol based cross-linked biocomposite. Verma *et al.* [13] have also developed a chitosan-coated sisal fiber–Phytagel modified soy protein-based green composite. His research group have successfully developed starch-jute fiber hybrid biocomposite and pyrolyzed carbon black (from waste tires) reinforced epoxy nanocomposites [14]–[16]. Chaurasia *et al.* [17] and Verma *et al.* [18] have developed h-BN and graphene nanocomposites, respectively reinforced in a polyethylene matrix. Recently in 2020, Rastogi *et al.* [19] developed a nonwoven waste cellulose fabric–reinforced epoxy composites for various engineering applications. In the same year, Verma *et al.* [20] reported various surface modification techniques for the preparation of novel biofibers for composites. But, as per the authors' knowledge, there has no such study where a hybrid composite material having biodegradable bagasse fiber in a modified epoxy resin has been fabricated and experimentally tested.

Figure 1: Bagasse fiber.

2 Experimental Section

In this section, selection of material, preparation of composite, mechanical testing, and morphology is discussed. All the experimental set up for different tests and analysis is also discussed.

Epoxy resin is selected as the matrix material because of its easy processing, high mechanical properties and good adhesion to all types of fibers. The epoxy resin is made of diglycidyl ether of bisphenol A having yellow brown colour. Epoxy resin is mixed with hardener at the time of casting. Mixing of hardener helps in the hardening of epoxy resin (Araldite CY-230). In the present investigation, 9 wt% hardener (HY-951) has been used in all material developed. Sugarcane bagasse was selected as the reinforcing material. It has several advantages over other materials such as its biodegradable nature, low cost and acceptable mechanical strength (refer to the Figure 1 for the snapshot). It mainly has cellulose, hemi-cellulose and lignin as the chief constituents.

In this study, the bagasse material was chopped into fine fibers of random (almost similar) sizes. The epoxy resin was preheated to the temperature of amount 90 ± 10°C and then allowed to cool slowly to the temperature of 40°C. At this stage the finely chopped bagasse fiber were mixed with the epoxy resin at 40°C and the mixture was then stirred continuously for 5 to 10 min thus obtaining a homogeneous and uniform mixture of bagasse fiber and epoxy resin. Thereafter, wt of 10% of hardener was mixed with the bagasse and epoxy resin (solution).

The mixture thus obtained was then quickly poured in a pre-prepared mould and allowed to solidify in room temperature for approximately 48 h. Hand lay-up method of open casting was selected for casting of composite material. Composite materials are generally subjected to both mechanical loading and exposure to environmental conditions. Water absorption tests [using the Equation (1)] were conducted under water soaking conditions (pH 7.1). To determine water absorption rate the reading were taken at the difference of every 6 h for 78 h, their thickness and weight was measured by vernier callipers and electronic weighing machine. Before each reading specimen were wiped by a tissue paper.

Water absorption (WA) is calculated by the Equation (1):

$$WA(\%) = ((W_2 - W_1)/W_1)*100 \quad (1)$$

W_1 = initial weight of specimen, grams

W_2 = specimen weight after N hours of water soaking, grams

In the present investigation, scanning electron microscopy (SEM) was carried out for bagasse fibers in the epoxy resin matrix. The images at various magnifications were obtained through the microscopic investigation with LEO 435 V6. The composite material prepared by using bagasse fiber with epoxy resin and hardener is tested to check its strength and other necessary properties. Here in this study the tensile, compression and flexural tests have been performed.

3 Results and Discussion

In this section, the results obtained from water absorption, SEM and mechanical testing are presented and discussed. Appearances of bagasse fiber filled bio-composites are found to be opaque and yellowish in colour. Fibers of bagasse are clearly visible in the composite. For the water absorption test, the specimens filled with bagasse fiber were tested by dipping them under water for 78 h to study the effect of water absorption on dimensional stability. Water absorption test was done by dipping all the samples in water and water absorption rate was calculated by the Equation (1). Figure 2 shows that the water absorption increases rapidly for first 18 hours and after this water absorption rate slows down up to 48 h. After 48 h water absorption

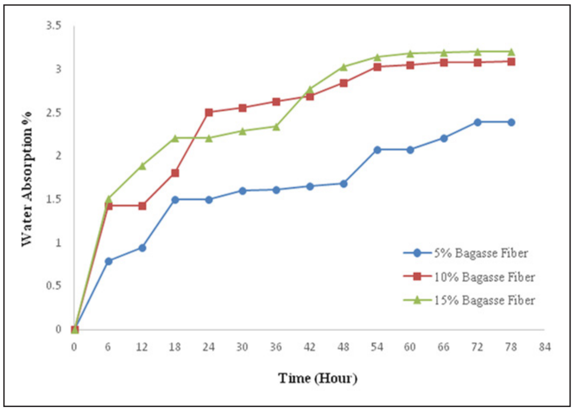

Figure 2: Effect of varying wt% of bagasse fiber on water absorption.

is not observed in case of 10 wt% and 15 wt% of bagasse fiber. But in case of 5 wt% slight increases in water absorption up to 72 h, after that it becomes constant. This can also be seen that with increasing wt% of bagasse fibers the water absorption has also increased, this may be because with the addition of bagasse fibers, voids and cavities in the materials are more which can be verified by Figure 2.

Figures 3–5 show the SEM photograph of composite containing 0, 5, 10, and 15 (without treated) wt% of bagasse fibers respectively. Figures 3 and 4 are shown at 40X magnification, and Figure 5 is shown at 50X magnification. Figure 3 shows the micrograph of 5 wt% bagasse fibers filled in epoxy resin. In this figure, shear bands can be seen which leads to shear yielding of the material. Also, some crater can be seen which is due to blow holes, but at some places matrix cracking has taken place. Figure 4 shows the micrograph of 10 wt% of bagasse fibers filled in epoxy resin. In this micrograph the cavity which has occurred due to increase in wt% of bagasse fibers can be seen. Figure 5 shows the micrograph of 15 wt% of bagasse fibers filled in epoxy resin. In this micrograph there is a crack in the matrix at the interface due to which strength of the composite is decreased. It can be seen from the SEM results that homogeneity between the bagasse fibers and the matrix decreases with increase in the bagasse fibers content. It is reason for decrease in strength with increased in the bagasse fibers content within the matrix of the composite. With increased wt% of bagasse fiber cavities and cracks in the composite appears.

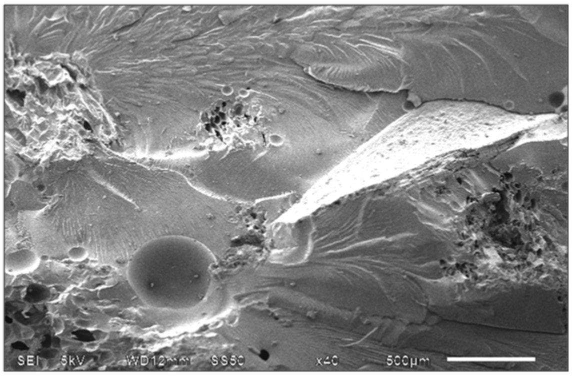

Figure 3: SEM for 5 wt% of bagasse fiber in epoxy resin at magnification 40X.

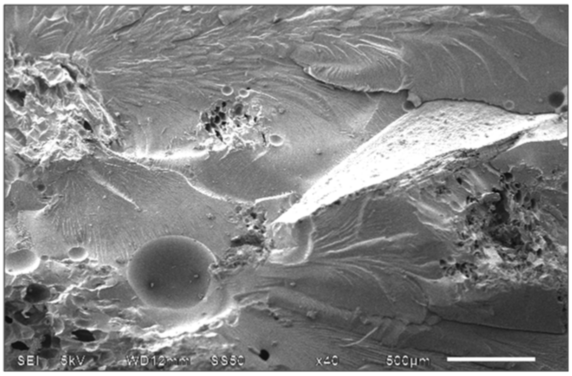

Figure 4: SEM for 10 wt% of bagasse fiber in epoxy at magnification 40X.

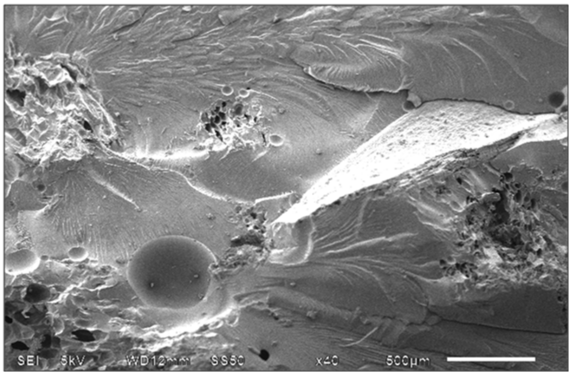

Figure 5: SEM for 15 wt% of bagasse fiber in epoxy at magnification 50X.

Mechanical properties play an important role in engineering designing process. So at the time of manufacturing testing of mechanical properties is very necessary for material. In case of composites, mechanical properties hold an important role that is why the mechanical testing of composite is necessary. In the present work, tensile, compression and flexural tests are done that are described in the subsequent sections. The tensile properties of bagasse fibers at different weight percent in epoxy resin composite material were determined by 100 kN ADMET made servo controlled universal testing machine at different strain rates of 0.1 mm/min, 0.5 mm/min and 1 mm/min under displacement control mode. Tables 1–3 show that ultimate tensile strength is decreased with increase in wt% of bagasse fibers at various cross head speed. This decrement is due to imperfect inter-facial bonding between the bagasse fibers and epoxy resin matrix at higher weight percentage of bagasse fibers. From these tables, it can be seen that percentage elongation decreases with an increase in wt% of bagasse fibers content. This is due to the fact that the composite becomes harder with the increased in wt% of bagasse fibers. Therefore, the percentage elongation of materials decreases as filler reduce the ductility of matrix materials.

Table 1: Tensile properties with varying wt% of bagasse fibers in epoxy composite at cross head speed 0.1 mm/min

Bagasse Fibers (wt%)	Ultimate Tensile Strength (MPa)	% Elongation	Modulus of Elasticity (GPa)
0	39.00	5.72	1.1
5	29.00	3.38	1.6
10	15.00	2.42	1.3
15	4.00	1.99	0.89

Table 2: Tensile properties with varying wt% of bagasse fibers in epoxy composite at cross head speed 0.5 mm/min

Bagasse Fibers (wt%)	Ultimate Tensile Strength (MPa)	% Elongation	Modulus of Elasticity (GPa)
0	39.00	5.76	1.1
5	28.00	3.38	1.6
10	13.00	2.61	0.9
15	5.00	1.85	0.5

Table 3: Tensile properties with varying wt% of bagasse fibers in epoxy composite at cross head speed 1 mm/min

Bagasse Fibers (wt%)	Ultimate Tensile Strength (MPa)	% Elongation	Modulus of Elasticity (GPa)
0	39.00	5.77	1.2
5	19.00	3.77	1.4
10	13.00	3.77	1.2
15	5.00	1.28	0.5

The compression tests were carried out at fixed strain rate of 0.5 mm/min under displacement control mode. The result of ultimate compressive strength is shown in Table 4. From this table, it can be noticed that addition of bagasse fibers reduces the ultimate compressive strength of the composite materials.

Table 4: Ultimate compressive strength of bagasse fiber composite

Bagasse Fibers (wt%)	Ultimate Compressive Strength (MPa)
0	43.35
5	32.11
10	25.46
15	7.92

From Table 5, it is observed that flexural strength decrease with an increase in weight percentage of bagasse fibers. Flexural strength shows very rapid fall if wt% of bagasse fiber is increased beyond 10 wt%. It is observed that with increase in wt% of bagasse fiber flexural strain also increases.

Table 5: Flexural strength, strain and modulus of varying wt% of bagasse fibers

Bagasse Fibers (wt%)	Flexural Strength (MPa)	Flexural Strain	Flexural Modulus (GPa)
0	62.057	0.0509	1.740
5	22.041	0.0190	1.030
10	18.436	0.0286	0.880
15	4.623	0.0341	0.169

4 Conclusions

From the present experimental investigation following conclusions are drawn as follows. Successful fabrication of bagasse fiber filled epoxy composites by using hand lay-up technique followed by compression is possible. The results indicate that the tensile strength and tensile strain of the composite are less than the pure epoxy and tensile strength of composite is decreasing with the increase in wt% of bagasse fiber at all cross head speed. Modulus of elasticity is increasing of composites in comparison with pure epoxy and it is decreasing with increasing wt% of bagasse fiber. The compressive strength (43.35 to 7.92 MPa) also has the same trend as the case of tensile strength. Flexural strength is less in comparison with pure epoxy, with increasing wt% of bagasse fiber flexural strength is decreasing, but flexural strain is increasing with increasing wt% of bagasse fiber (0.0509 to 0.0341). SEM showed that for 5 wt% of bagasse fiber binding between epoxy and bagasse fiber is good. Further increase in wt% of bagasse fiber results in cavities and improper binding. This is the main cause of decrease in mechanical properties.

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