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Effect of Fiber Size on Mechanical Properties of Sugarcane Bagasse Reinforced Epoxy Composite

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Abstract—*The requirement of light weight ecofriendly material with requisite mechanical properties plays a critical role in protecting the environment and also helps to reduce the energy requirement. Natural fiber reinforced polymer composites are low-cost, low-density material with low carbon emission which can be advantageously used in various engineering applications. The sugarcane bagasse fibers (SBF) possess high flexural strength at rupture, but due to high porosity it has poor mechanical properties. The length of the natural fiber used as reinforcement has a significant effect on the mechanical properties of the composites. Therefore, in this study effect three different fiber size (long fiber (4 cm), short fiber (2 cm) and particulate fiber) on the mechanical properties of the SBF reinforced epoxy composite has been investigated. Samples were fabricated using hand layup method by mixing epoxy (67%), hardener (18%) and reinforcement (15%). In all these samples the fibers sizes were changed at the same composition. Mechanical characterization i.e., tensile test, flexural test and impact test of the fabricated samples were conducted as per the ASTM standard. It was observed that composite with medium fiber size (2 cm) possesses highest flexural strength (37.995 MPa) whereas composite having particulate form yields minimum flexural strength of 20.441 MPa. But particulate reinforced composite has highest tensile strength (14.769 MPa) whereas long fiber yields lowest tensile strength of 11.333 MPa. Similarly, composite with long fiber (4 cm) has highest impact strength (1007 N) followed by particulate reinforcement (877 N) and short fiber (851 N).*

Keywords: *sugar bagasse, tensile stress, epoxy, flexural strength, impact strength, composites, aspect ratio.*

1. INTRODUCTION

A composite material is made up of two or more distinct materials with different physical or chemical properties so that final composition has the synergetic effect on the overall property of the developed materials. The individual material that makes up the composite are called "constituent materials" or "components". These constituent materials can be of various types such as fibers, particles, or matrices. In a composite material, the constituent materials work together to create a material that has improved properties such as increased strength, stiffness, or durability, as well as reduced weight or cost compared to traditional materials. Composite materials are used in a wide range of applications, including aerospace, automotive, construction, sports equipment etc. Natural fibers derived from plants, animals, or minerals can be used as reinforcement to produce bio composites. Examples of natural fibers include sugarcane bagasse, cotton, wool, silk, hemp, jute, flax, and sisal. These fibers have unique properties that make them suitable for different applications. Natural fiber like Jute and sisal are strong and durable, while hemp is both strong and lightweight. Natural fibers have several advantages over synthetic fibers, including sustainability, biodegradability, and low environmental impact. They are also renewable resources that can be grown and harvested on a regular basis. In recent years, there has been a growing interest in using natural fibers as reinforcement materials in composite materials. These materials, known as natural fiber composites, have the potential to replace traditional synthetic composites in many applications, particularly in the automotive and construction industries. Sugarcane bagasse is a natural fiber that is derived from the residue of sugarcane after the juice has been extracted. It is a byproduct of the sugar industry and is often used as a renewable source of energy through combustion or as a raw material for the production of pulp and paper. In recent years, there has been increasing interest in using sugarcane bagasse fibers as a natural reinforcement material in composite materials. The fibers are known to have excellent mechanical properties, including high strength and stiffness, and are also lightweight, low-cost, and biodegradable. Sugarcane bagasse fibers have been used as reinforcement in various polymer matrices such as polypropylene, polyester, and epoxy. Applications for sugarcane bagasse composite materials include automotive parts, construction materials, packaging, and consumer goods. The use of natural fibers such as sugarcane bagasse in composite materials is a growing trend in the field of sustainable materials, as they offer a viable alternative to traditional synthetic fibers. Overall, the versatility and sustainability of sugarcane bagasse fiber make it an attractive material for a wide range of applications.

Ramaraj [1] observed that mechanical property in terms of tensile strength and thermal properties of polypropylene/sugarcane bagasse composites get enhanced with an increase in filler loading from 5 to 20% in the PP matrix. It was also observed that the flexural strength improved from 23.66 to 26.84 MPa, the Izod impact strength increases from 10.499 to 13.23 Kg cm/cm, the Charpy impact strength improved from 10.096 to 13.98 Kg cm/cm, and the HDT increased from 45.5 to 66.58C. However, the elongation and tensile strength also fell from 164.4 to 11.20% and 32.22 MPa to 27.21 MPa, respectively. Rodrigues et al. [2] found that the tensile strength of esterified sugarcane bagasse fibers reinforced in polyester resin increases by 71.5% over pure polymers [2]. Cerqueira et al. [3] found that tensile, flexural, and impact strengths of SB reinforced polypropylene composite increases. Epoxy composites reinforced with sawdust, rice husk, and SB shows increase in tensile strength as the weight percentage of SB decreases. As the weight proportion of SB declines, the compressive strength increased briefly before declining [4]. Performance of geopolymers made of laterite and reinforced with SB fibers shows decrease in density and an increase in sonic rate which is beneficial for enhancing acoustic and thermal insulation [5]. Effect of SB fiber characteristics and interfacial adhesion on enhancing PLA's stiffness and giving the material a favorable mix of properties for structural applications was investigated by Bartos et al. [6]. Similarly, effects of interfacial adhesion, particle parameters, and fiber attrition on the characteristics of composites made of PP and SB fiber was investigated and it was found that breakage of the SB fibers uses energy, which boosts impact resistance [7]. Similarly, Prasad et al. [8] experimentally analyzed the effect of chemical treatment and fiber length and type on the physical and mechanical properties of sugar cane bagasse reinforced epoxy composites. The rice husk and SB reinforced polyester composites shows increase in tensile and flexural strength [9]. An investigation on the effect of SB fiber being incorporated into the cement bricks on the economy and environment was explored by Michael and Moussa [10]. Oil palm / SB fiber reinforced phenolic hybrid composites shows improvement in tensile, physical, and morphological characteristics because of their higher cellulosic content and it also reduce the water content and void in fiber composites [11]

2. MATERIAL AND METHOD

SB fiber were collected from juice shop, and it was separated mechanically. The fiber was dried for 2 days in the sunlight and after it was treated with 5% aqueous NaOH solution for 8-10 hours. The hand-layup technique was used to fabricate polymer composite using sugarcane bagasse fiber as a reinforcement and epoxy as matrix. Epoxy (LY556s) weighing 92 g was mixed with 20 g hardener (HY951). All the samples contain 15 (wt%) of SB fiber. In order to fabricate the composite a thin layer of silicon oil was used on a plastic sheet for easy removal of composite. After this, a mold made of wood or iron having dimension 200×100×4 mm^3 was kept on the plastic sheet. Since the basic objective of the study is to analyze the effect of fiber aspect ratio on the mechanical properties of the SB reinforced composite therefore fiber of different length as described in Table 1.

Table 1: Details of sugar cane bagasse fiber

Fiber type	Fiber length	Fiber diameter	Aspect ratio
Long fiber	4cm	0.4 mm	100
Short fiber	2 cm		50
Particulate	--		--

The mixture of epoxy, hardener and fibers was poured into the mold. Hand roller was used to remove the air bubbles formed during the fabrication of composite. The mixture was compressed under suitable load for 24 hours. Specimen is then finally cut into specific dimension depending as per the ASTM standard.

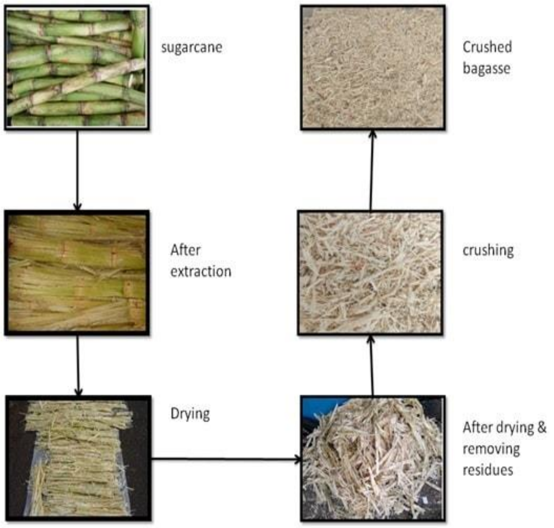


Figure 1: Steps for extraction of Sugarcane bagasse

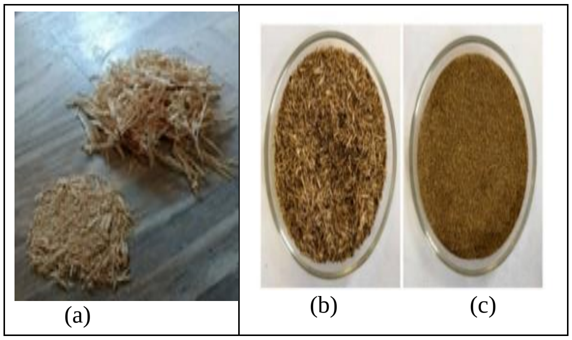


Figure 2: Extracted sugar cane bagasse fiber (a) long fiber (b) short fiber (c) particulate

Table 2: Details of testing standards and equipment

Testing	ASTM	Size (LxBxH) mm	Testing System	Speed rate
Tensile test	ASTM D 638	165× 19× 4 mm	INSTRON 1195 (retrofitted by BiSS, India	5 mm/ min
Flexural test	ASTM D 790	125 ×12.70 ×4 mm	INSTRON 1195 (retrofitted by BiSS, India	
Impact test	ASTM D 6110	63.5 ×12 × 4 mm	Zwick GmbH	

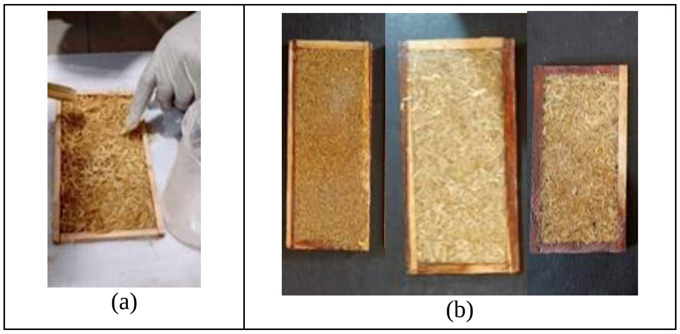

(a) (b)

Figure 3: (a) Composite fabrication (b) Fabricated samples

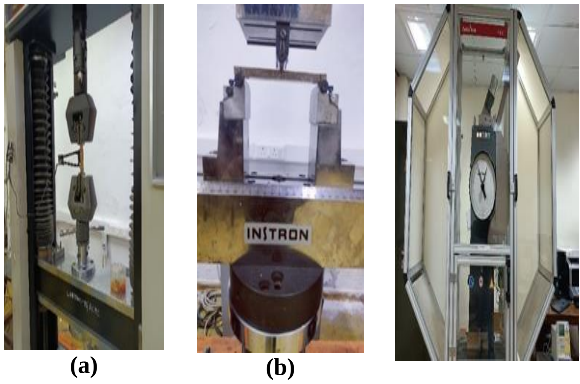
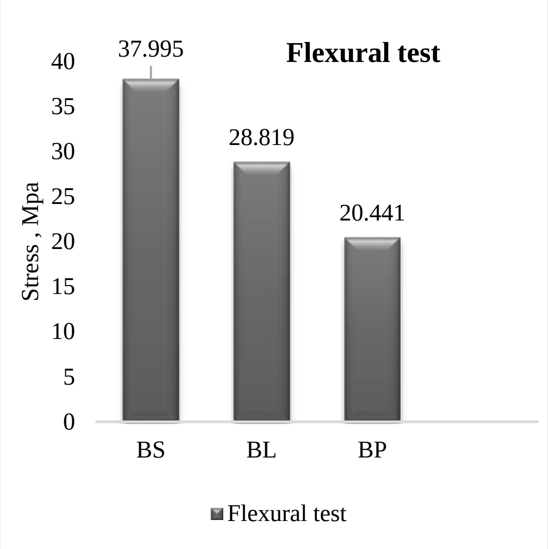

(a) **(b)** **(c)**

Figure 4: (a) Tensile test (b) flexural test (c) Impact test

3. RESULTS AND DISCUSSION

The effect of fiber size or aspect ratio on various mechanical properties like flexural, tensile and impact strength of SB reinforced epoxy composite has been elaborated in the following sections. All the composites were reinforced with 15 (wt%) of SB.



3.1 Flexural test

Figure 5: Variation of fexural strength with size of reinforcement

Table 3: Flexural strength for various composites

Type of reinforcement	Symbol	Length of reinforcement	Flexural strength (MPa)	Flexural peak load (kN)	Flexural Displacement (mm)
Bagasse Long fiber	BL	4cm	28.819	0.084	3.231
Bagasse short fiber	BS	2cm	37.995	0.162	3.918
Bagasse Particulate	BP	--	20.441	0.110	2.820

Fig. 5 reveals that highest flexural strength of 37.995 MPa is obtained in composite with short fiber (cm) due to combined effect of lignin content, fiber orientation, inter-fiber bonding. Short fibers are more easily aligned in the direction of the applied force, which allows them to bear more of the force and resist bending. In contrast, long fibers can become entangled and less aligned, which reduces their ability to resist bending. Furthermore, short fibers have a greater surface area per unit volume than long fibers, which provides high interfacial bonding with the surrounding matrix. This interfacial bonding can enhance the transfer of stress from the matrix to the fibers, thereby increasing the flexural strength of the composite material. Table 3 illustrates that composite with particulate reinforcement has lowest flexural strength (20.441 MPa) compared to short fiber and long fiber.

3.2 Tensile test

Fig 6 depicts that the long fiber SB composite has lowest tensile strength. The addition of particulate reinforcement increases the tensile strength by 30.8 % compared to long fiber. Sugarcane bagasse fibers have a high degree of crystallinity, which contributes to their high tensile strength. short fibers have a greater surface area per unit mass, which can result in stronger inter-fiber bonding and higher tensile strength. Short fibers are more easily aligned in the direction of force, whereas long fibers can become entangled and less aligned. This alignment allows the fibers to bear more of the applied force, resulting in higher tensile strength. Short fibers have a greater surface area per unit volume than long fibers, which provides more opportunities for interfacial bonding between the fibers and the surrounding matrix. This interfacial bonding can enhance the transfer of stress from the matrix to the fibers, thereby increasing the tensile strength of the composite material (Table 4). Furthermore, both particulate and short fibers have uniform in length and shape, whereas long fibers can have variations in length and shape that can create weak points in the material. These weak points can reduce the tensile strength of the composite material. Overall, while long fibers can provide other benefits to composite materials such as improved stiffness, short fibers tend to have higher tensile strength due to their alignment, interfacial bonding, and uniformity

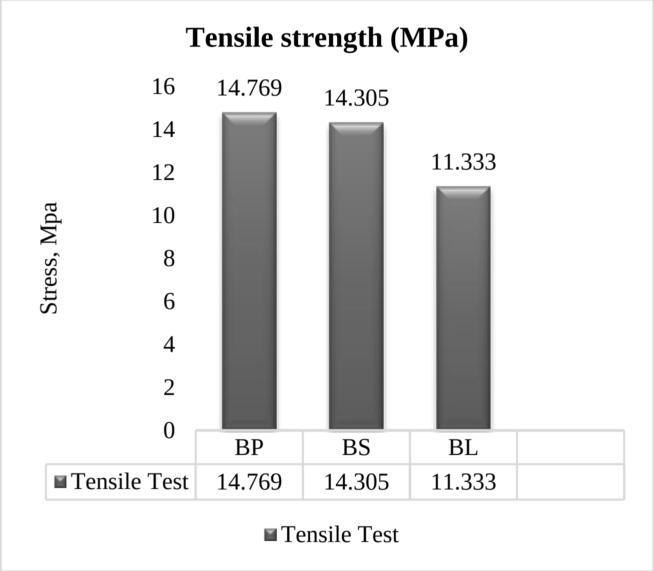


Figure 6: Effect of fiber size on tensile strength

Table 4: Result of material obtained by tensile & flexural test

Sample (size)	Tensile strength (MPa)	Tensile modulus (GPa)	Tensile peak load (kN)	Tensile Displacement (mm)
BL 4cm	11.333	2.294	1.587	0.31
BS 2cm	14.305	2.929	2.003	0.253
BP	14.769	2.576	2.068	0.36

3.3 Impact Charpy test

Long fiber composites show better Charpy impact strength as shown in the Fig. 7. It is observed from Table 5 that impact strength of long fiber composite have 18.4% more value than short fiber. Impact strength time increased 4.5546 to 5.3246 ms. In general, fibers with longer lengths tend to have higher impact strength than fibers with shorter lengths. This is because longer fibers are better able to distribute and absorb impact forces, whereas shorter fibers are more prone to breakage under stress. And the intended application. Long fibers have higher aspect ratio therefore energy transfer between the matrix (epoxy) and fiber takes place more efficiently thereby increasing the toughness. The tangled network of long fiber helps in dissipating the impact forces throughout the composite instead of concentrating the forces in one particular area.

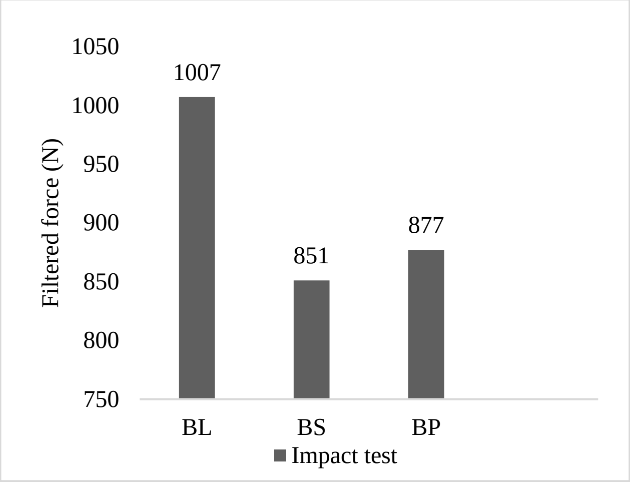


Figure 7: Impact test filtered force (N)

Table 5: Result of material obtained by impact (Charpy) test

Sample size	Impact strength Force (N)	Impact strength Time (ms)
BL (4cm)	1007	4.5546
BS (2cm)	851	4.7891
BP	877	5.3246

4. CONCLUSIONS

Effect of aspect ratios of sugar cane bagasse reinforced epoxy based natural composite has been investigated in this study. Composites having 15 wt% of reinforcement were produced with hand layup method. SB fiber of 0.4 mm diameter having length of 4 cm and 2 cm with aspect ratio of 100 and 50 were used as a reinforcement for the fabrication of composites. In order to investigate the effect of reinforcement size composite containing particulate reinforcement was also fabricated. The mechanical characterization of the fabricated composites was conducted in terms of tensile, flexural and impact strength.

Following are the conclusions based on the findings of this study.

a) Composite reinforced with short fiber (aspect ratio 50) yields highest flexural strength of 37.995 MPa. The flexural strength short fiber reinforced composite increases by 85.37% and 31.8 % compared to particulate reinforced and long fiber reinforced fiber composites.

b) The tensile stress of particulate reinforced composite is more compared to short fiber and long fiber reinforced composites. Addition of long fiber SB reinforcement decreases the tensile stress by 30.3% compared to particulate reinforced composites.

c) Short fiber yields highest tensile modulus (2.929 GPa) whereas long fiber has lowest tensile modulus of 2.294 GPa.

d) Long fibers are better able to distribute and absorb impact forces; therefore, composites with long fiber yields highest impact strength of 1007 N. Reinforcement with short fiber and particulate reinforcement decreases the impact strength of composites by 15.5 % and 13% respectively.

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