A Sustainable Natural Composite Material for Automotive Applications

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Abstract:-This project focuses on making an eco-friendly composite material using sugarcane bagasse fibers and epoxy resin. The main goal is to study how different fiber-to-resin ratios (8:1, 11:1, and 14:1) affect the strength and stiffness of the final material. The sugarcane bagasse fibers were cleaned, dried, and mixed with Araldite AW106IN epoxy resin and hardener HV953IN in the given proportions. The samples were made according to ASTM D790 standards and tested using a three-point bending test to measure their flexural strength. Theoretical strength values were calculated using the Rule of Mixtures, which predicts how strong the composite should be based on the amount of fiber and resin used. The 8:1 ratio sample showed the best performance, with a flexural strength of 38 MPa. When compared with the theoretical value obtained from the Rule of Mixtures, the experimental result was slightly lower but still close, confirming good accuracy and strong bonding between fiber and resin. The study proves that sugarcane bagasse can be used as a natural reinforcing material to make lightweight and sustainable composites, which can be applied in areas like automobile body parts, reducing waste and supporting environmentally friendly engineering solutions.

Keywords: Sustainable Bagasse-epoxy composite, Flexural strength, Rule of Mixtures.

1. Introduction

The growing concern for environmental protection has increased the need for sustainable materials that can replace conventional, non-biodegradable ones. Natural fiber-reinforced composites have gained importance because they are lightweight, renewable, and biodegradable. These composites help reduce

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pollution and energy use during production, making them a better choice for sustainable development. The performance of a composite depends on the proportion of fiber and matrix used. This relationship is explained by the rule of mixtures, which states that the overall properties of a composite are determined by the combined contribution of its components, the fiber and the matrix, based on their individual properties and volume fractions [1]. In simple terms, increasing the fiber content can improve stiffness and strength up to an optimal point, beyond which bonding may weaken and performance may drop.

Composites with fiber-to-matrix ratios of 8:1, 11:1, and 14:1 were tested to identify the most efficient and sustainable ratio balancing strength, stiffness, and durability. Their use in automobiles is shown in Fig. 1.

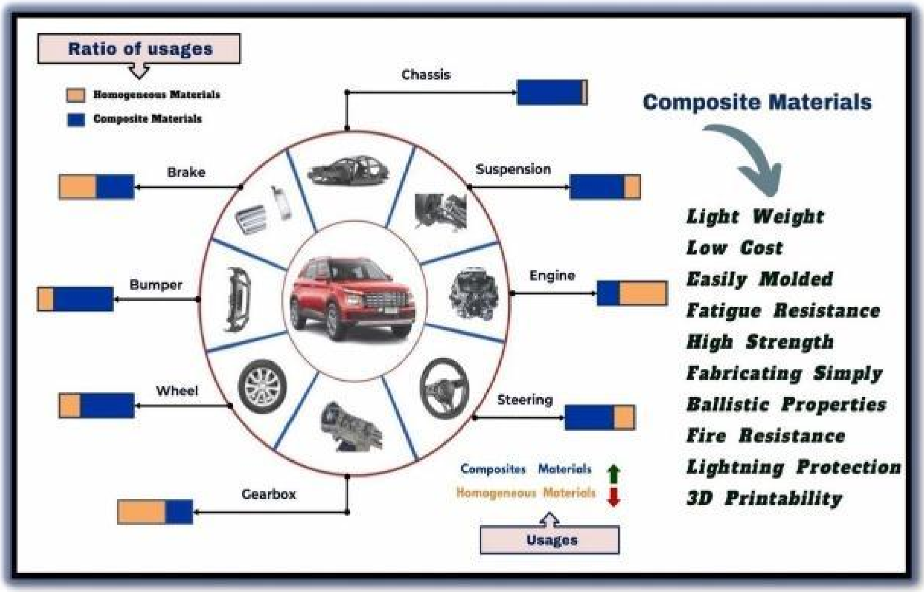

Fig.1.Representation of use of Composites in a Passenger car [1].

In sustainable vehicle design, flexural strength is an important property that shows how well a material can resist bending or deformation under load. Automotive parts like hoods, panels, and bumpers often face bending forces during use or impact. Therefore, materials need to be both strong and light. This study focuses on developing and testing green composites made from sugarcane bagasse with epoxy resin to check their flexural strength through experiments and verify using rule of Mixtures [2, 3].

Sugarcane bagasse, which is the leftover fiber from sugar production, is being widely studied as a natural material to make eco-friendly composites. It is cheap, easy to find, and biodegradable, making it a good alternative to synthetic fibers for automotive and industrial use.

Mahamod et al. developed sugarcane bagasse–epoxy composites for vehicle fenders and found that using about 20% bagasse fiber improved the strength and impact resistance of the part. This shows that such composites can be used in car body components [4]. In Similar way Tripathi et al. tested different fiber contents in bagasse–epoxy composites and noticed that tensile, flexural, and hardness values improved up to 20% fiber but started decreasing afterward because the fibers did not bond well when too much was added [5]. Zafeer et al. reviewed many studies on bagasse fiber composites and explained that chemical treatments like alkali or acid washing help improve bonding between the fiber and resin. This leads to better strength and durability [6]. Abedom et al. created a hybrid composite using sugarcane bagasse and bamboo charcoal with polyurethane resin and found that a mix of 30% bagasse and 70% bamboo charcoal gave the best results for strength and thermal insulation, making it suitable for car interiors [7]. Hiranobe et al. discussed how sugarcane bagasse can be reused in many ways, such as making biofuels, biochar, and composites, reducing industrial waste [8]. Ajala et al. also highlighted that bagasse is a renewable biomass that can help meet energy needs and protect the environment [9]. Ungureanu et al. mentioned that the by-products from sugarcane can be turned into valuable materials through sustainable processes [10]. Amaresh et al. showed that bagasse can be converted into renewable and compostable materials that are useful for making eco-friendly products [11]. All these studies suggest that sugarcane bagasse can be successfully used to make lightweight, strong, and sustainable composites. With the right fiber treatment and mixing ratio, it can replace traditional materials in automotive and industrial application

2. Methodology

This study develops sugarcane bagasse–reinforced epoxy composites by selecting materials, preparing molds, fabricating samples with varying fiber-to-resin ratios, and curing them under controlled conditions for consistent mechanical testing.

2.1 Material Selection and Preparation

Unwashed sugarcane bagasse was collected from local sugar mills, washed, sun-dried, and cut into 10–56 mm fibers for uniform resin dispersion. Araldite AW106IN epoxy and HV953IN hardener were used for their strong adhesion, high strength, and room-temperature curing, making them suitable for composite fabrication.

2.2 Mold Fabrication:

Custom molds were prepared using metal and silicone sheets to maintain uniform sample dimensions of 255 mm × 50 mm × 6 mm, following ASTM D790 standards for flexural testing. These molds ensured consistency in shape, thickness, and surface finish of the composite specimens.

2.3 Composite Sample Preparation – Stepwise Procedure

Weighing and Mixing: The required proportions of sugarcane bagasse fibers and epoxy resin were measured accurately. The epoxy resin and hardener were mixed in a 1:1 ratio, after which fibers were gradually added to the mixture to ensure even distribution. The compositions were based on different fiber-to-matrix ratios as follows and as shown in Fig.2:

a) 8:1 → 15 g bagasse + 140 g epoxy resin
b) 11:1 → 12 g bagasse + epoxy resin
c) 14:1 → 10 g bagasse + epoxy resin

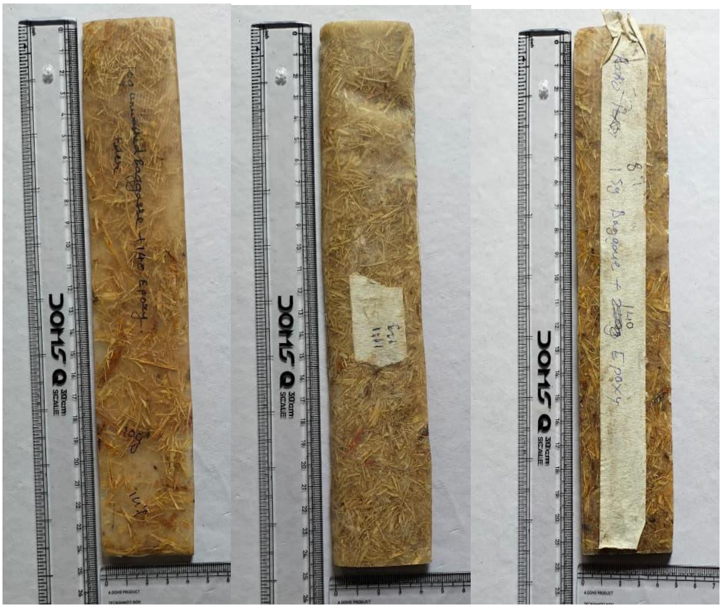

Fig.2. Samples with ratio 14:1, 11:1, 8:1

Mixing:

The mixture was stirred thoroughly to achieve a uniform blend and prevent fiber agglomeration.

Casting:

The prepared mixture was carefully poured into the molds, ensuring that no air bubbles were trapped.

Curing:

The filled molds were kept at room temperature for 24 to 48 hours to allow complete curing and hardening.

Demolding:

After curing, the composite samples were gently removed from the molds to prevent damage or cracking.

Finishing:

The cured samples were trimmed and polished to obtain smooth and uniform dimensions, making them ready for mechanical testing.

2.4. Property Estimation Using Rule of Mixtures

Before performing experimental tests, the mechanical behavior of the sugarcane bagasse fiber–epoxy composite was estimated theoretically using the Rule of Mixtures. This analytical method helps predict the overall composite properties based on the known properties and volume fractions of its constituents, the fiber and the resin. The mechanical properties of sugarcane bagasse fiber and Araldite AW106IN epoxy resin with HV953IN hardener were collected from published literature and are listed in Table 1.

Table 1. Mechanical properties of sugarcane bagasse fiber and epoxy resin

Property	Sugarcane Bagasse Fiber	Epoxy Resin
Density (ρ) (g/cm³)	1.25	1.2
Young's Modulus (E) (GPa)	6	3
Flexural Modulus (GPa)	5	3
Compressive Strength (MPa)	40	80
Poisson's Ratio (ν)	0.3	0.35
Shear Modulus (G) (GPa)	2.1	1.1
Impact Toughness (kJ/m²)	10	5

The overall composite property (Pc) was calculated using the standard Rule of Mixtures expression:

$$Pc = Vf\,Pf + Vm\,Pm \qquad (1)$$

where:

Pc = property of the composite

Vf = volume fraction of fiber

Vm = volume fraction of matrix (Vm = 1 – Vf)

Pf = property of the fiber

Pm = property of the matrix

Using this relationship, the estimated values for density, modulus, compressive strength, and other properties were calculated for different fiber-to-resin ratios (8:1, 11:1, and 14:1). The results are presented in Table 2.

Table 2. Estimated properties of sugarcane bagasse–epoxy composites

Property	Formula	8:01	11:01	14:01
Density (g/cm^3)	ρ_a = V_fρ_f + V_mρ_m	1.204	1.203	1.202
Young's Modulus (GPa)	E_a = V_fE_f + V_mE_m	3.28	3.25	3.2
Flexural Modulus (GPa)	E_a(flex) = V_fE_f(flex) + V_mE_m(flex)	3.19	3.16	3.13
Compressive Strength (MPa)	σ_a = V_fσ_f + V_mσ_m	76.3	76.7	77.3
Shear Modulus (GPa)	G_a = V_fG_f + V_mG_m	1.19	1.18	1.17
Impact Toughness (kJ/m^2)	I_a = V_fI_f + V_mI_m	5.46	5.41	5.33

The calculated results show only small differences in properties between the three composite ratios. Because epoxy resin makes up most of the material, it has a greater effect on the overall strength and stiffness than the fiber. A slight decrease in modulus was seen as the amount of epoxy increased, while compressive strength and impact toughness showed a small improvement. These estimated values act as a reference for comparing with experimental test results to check the accuracy of the fabrication process and the performance of the composite.

2.5 Experimental Testing

The experimental testing was carried out to determine the flexural strength of unwashed sugarcane bagasse–epoxy composites prepared with different fiber-to-resin ratios (8:1, 11:1, and 14:1). Each sample was tested using a three-point bending setup as per ASTM D790 standards. The specimens were placed on two supports, and a load was applied gradually at the center until failure or noticeable deflection occurred as shown in Fig.3. The applied load and corresponding deflection were recorded to calculate flexural strength using the formula $3PL/2BD^2$, where P is the applied load, L is the span length, B is the specimen width, and D is the thickness. This method helped in understanding how varying fiber content influences the material’s load-bearing capacity, stiffness, and resistance to bending.

Fig.3. Flexural Strength Testing Set Up

3. Results for Experimental Testing

Experimental testing was carried out to study the flexural performance of unwashed sugarcane bagasse–epoxy composites with varying fiber-to-resin ratios. The tests aimed to identify how fiber content affects the material’s strength and load-bearing ability. Each sample was evaluated using a three-point bending test to determine its flexural strength. Table 3 shows the results of flexural test.

Table 3. Flexural Test Results for Bagasse–Epoxy Composites

Unwashed Fiber	Sample No.	Breaking Point (mm)	Force (KN)	Calculations: 3PL/2BD^2	Best results(MPa)
8:01	1	112	0.1	19 MPa	
8:01	2	115	0.2	38 MPa	38
8:01	3	113	0.1	19 MPa	
11:01	1	101	0.12	22 MPa	
11:01	2	106	0.15	28 MPa	28
11:01	3	102	0.15	28 MPa	
14:01	1	No Break	0.1	19 MPa	
14:01	2	No Break	0.1	19 MPa	19
14:01	3	No Break	0.1	19 MPa	

The flexural tests on unwashed sugarcane bagasse–epoxy composites with ratios 8:1, 11:1 and 14:1 showed differences in strength. The best recorded flexural strength for the 8:1 sample was 38 MPa, for the 11:1 sample it was 28 MPa, and for the 14:1 sample the best value was 19 MPa (no specimens fractured during testing). These results indicate that the 8:1 composition gave the highest load-bearing capacity, while the higher epoxy content in the 14:1 composition produced lower strength and greater flexibility.

4. Conclusion

The experimental flexural test results followed the same pattern as the values predicted using the Rule of Mixtures for all fiber-to-resin ratios (8:1, 11:1, and 14:1). The theoretical calculations gave a good estimate of how the composites would behave. However, the experimental flexural strength values were slightly lower than the calculated ones, which are normal in practical testing due to factors like uneven fiber mixing, small air voids, and less-than-perfect bonding between the fiber and resin during fabrication.

Among all the compositions, the 8:1 ratio showed the closest match between experimental and theoretical results. This confirms that stress was transferred more effectively between the sugarcane bagasse fibers and the epoxy resin in this composition. The 11:1 and 14:1 samples showed lower experimental strength compared to their calculated values, suggesting that the reinforcement effect reduced as the fiber content decreased. Overall, the good agreement between experimental results and Rule of Mixtures calculations confirms that the fabrication process was reliable and that the Rule of Mixtures is a useful method for predicting the mechanical behavior of sugarcane bagasse–epoxy composites.

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Disclosure of Interests

The authors have no competing interests to declare that are relevant to the content of this article.

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