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Development and Assessment of Mechanical Characteristics in Sisal-Glass Fiber Reinforced Epoxy Composites

G. Ashwin Prabhu[1,*], S. Karuppaswamy[2], J. M. Babu[3], Shekar K.[4], Vishnu S. Aher[5], S. Prathap Singh[6], R. Rangaraja[7], Antony Leo F.[8], Deepak K.[9], Aswin S[10]

Abstract

In many different fields, including tensile strength, reduced thermal expansion, and an amazing strength-to-weight ratio, fiber-reinforced polymer composites are gradually replacing conventional materials. This work mostly addresses the development and evaluation of the mechanical characteristics of epoxy composites improved with glass fibers and sisal. Among the benefits are biodegradability, lower weight, and more specific strength. Sisal polymer composites are included under natural fiber composites. Including sisal strands into glass fiber-reinforced polymers (GFRPs) strengthens them and provides a substitute for more traditional GFRPs. The possible improvement of mechanical characteristics in epoxy composites by means of glass fibers and sisal is investigated in this work. This work will discuss applications related to tensile characteristics, impact resistance, and flexural strength in the building and automotive domains. We fabricated the sisal-glass epoxy composites containing fibers using the hand lay-up technique. Layers of sisal fiber made up the inside; layers of glass fiber made up the outside. Testing the composite specimens' tensile strength, flexural strength, and impact resistance made it much easier to figure out their mechanical properties. When sisal fibers were added, the tensile strength went down compared to glass fiber-reinforced polymers (GFRPs), even though the flexural strength and impact resistance went up. While the maximum flexural stress attained over 200 N, the sisal-GFRP composites displayed an impact strength of 375.29 J/m. The results show that epoxy composites strengthened with glass fibers and sisal do a better job of resisting impacts and being strong when bent. This makes them a better material to use instead. Combining synthetic and natural fibers with composites can help you to achieve this. Future developments improving tensile performance could benefit more general uses.

***Author for Correspondence**
G. Ashwin Prabhu

[1,7]Assistant Professor, Department of Mechanical Engineering, St. Joseph's College of Engineering, Old Mahabalipuram Road, Chennai, Tamil Nadu, India
[2]Associate Professor, Department of Mechanical Engineering, Meenakshi College of Engineering, Vembuliammankovil Street, West K.K. Nagar, Chennai, Tamil Nadu, India
[3]Professor, Department of Mechanical Engineering, Vel Tech Rangarajan Dr Sagunthala R&D Institute of Science and Technology, Thiruvallur, Tamil Nadu, India
[4]Assistant Professor, Department of Mechanical Engineering, Ballari Institute of Technology and Management, Alipura, Ballari, Karnataka, India
[5]Associate Professor, Department of Mechanical Engineering, Amrutvahini College of Engineering, Near, Pune - Nashik Hwy, Sangamner, Ghulewadi, Ahmednagar, Maharashtra, India
[6]Assistant Professor, Department of Mechanical Engineering, St. Joseph's institue of technology, Old Mahabalipuram Road, Chennai, Tamil Nadu, India
[8,9,10]UG Student, Department of Mechanical Engineering, St. Joseph's College of Engineering, Old Mahabalipuram Road, Chennai, Tamil Nadu, India

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INTRODUCTION

The composite materials have emerged as viable alternatives to traditional materials, owing to their superior properties and the potential for customization to meet specific requirements. These materials, composed of two or more distinct components, exhibit enhanced characteristics that surpass those of their individual constituents [1]. One especially intriguing class of materials with high demand is fiber-reinforced polymer composites. Their remarkable properties—that of outstanding tensile strength, low thermal expansion, and a useful strength-to-weight ratio [2-4] help to explain this. People working in the industry are constantly looking at creative combinations and layouts to get ideal performance qualities [5–7]. This is so because material science is always changing and producing notable advances in the field. Glass fiber-reinforced polymers (GFRPs) make up a considerable share of the larger class of fiber-reinforced polymer composites. By adding fine glass fibers to a polymer matrix, the composites make a material that is strong, light, and, most importantly, long-lasting [8–10]. Because of their strength, lightweight character, and rust resistance, Glass Fibre Reinforced Polymers (GFRPs) find great use in construction, aerospace, and automotive industries [11–13]. GFRPs have several advantages, but they can also fail in some ways, including delamination, which can compromise laminate performance and hasten failure [14–16]. Composites, including natural fibers, have attracted much interest recently as possible substitutes or extra materials for glass fiber-reinforced plastics (GFRPs). Natural fiber composites strengthened with hemp, jute, and sisal offer several benefits, including increased specific strength, lower weight, and biodegradability [17-19]. Among these, sisal fiber reinforced polymer composites have demonstrated promising properties and gained traction as a sustainable and cost-effective option [20-22]. The integration of natural fibers, such as sisal, into GFRPs has emerged as a promising approach to enhance the overall composite performance and address some of the limitations associated with traditional GFRPs [23-25]. Many studies have examined the possibilities of composites, including natural fibers, with a focus on their mechanical characteristics Glass fiber, jute, and sisal-reinforced polyester composites were mechanically examined by Ramesh et al. [26]. The results show that these composites have several possible uses. Fernandes and Correlo [27] investigated in their work how adding short natural coconut fibers affected cork-polymer composites. We showed how coupling agents and fiber loading affected the properties of the composite. Jarukumjorn and Suppakarn [28] investigated glass fiber hybridization for its impact on sisal fiber and polypropylene composites. Along with improved thermal qualities and water resistance, their results show gains in tensile, flexural, and impact strength. While previous research has made significant contributions to the field, our study presents a novel approach that has not been previously explored in the literature [29-31]. Unlike conventional studies that focused on either natural fibers or GFRPs independently [32-34], we have developed a specific layering configuration where glass fiber layers are strategically positioned at the top, middle, and bottom, with compressed sisal fiber layers in between [35-37]. This unique arrangement represents a significant advancement in hybrid composite design and fabrication. Our innovative methodology introduces several unique aspects to the field. First, we employ a technique of compressing sisal fibers before incorporation into the composite, a process that sets this study apart from traditional natural fiber composite fabrication methods [38-40]. The compressed sisal fiber sheets, prepared at a specific thickness of 1.2mm using compression molding at 10 bar pressure and 80°C, represent a significant advancement in natural fiber processing for composite applications [41-43]. Studies say that the best ratio for glass fiber to resin is 1:1; for natural fiber to resin, it is 1:2. Researchers find that the optimal ratio of epoxy to hardener is ten to one [44–46]. Researchers made hybrid composites [47] from crushed natural fibers by carefully changing the amounts of different ingredients, stacking the materials in different ways, and processing them in different ways. To find how the composite samples would respond to various loads, the study team conducted tensile, flexural, and impact testing as well as other mechanical tests. The tests find the composite's tensile strength, bending load capacity, and impact energy absorption [48]. The tensile strength was tested using the Universal Testing Machine (UTM) and ASTM D638 standards. Among the various parameters evaluated were area reduction, maximum elongation, ultimate tensile strength, and breaking strength [49]. Earlier GFRP composite versions were obviously defective. This ecologically beneficial method of making products solves problems and uses natural fibers, which also increases advantages and lowers issues [50]. The first thorough investigation of a hybrid configuration produced using this approach is presented in this paper. This presents a fresh angle on the development of reasonably priced, environmentally friendly, high-performance composite materials [51–53]. This work holistically investigates the mechanical properties of epoxy composites enhanced with glass fibers and sisal. The objective is to investigate all the numerous uses this hybrid composite can present as replacement material in great detail. The findings will clarify the interplay between synthetic and natural fibers and their combined effect on strengthening improvement. For upcoming applications, this will enable better fiber-reinforced polymer composites [54]. Epoxy composites strengthened with sisal-glass fiber find extensive use in many different kinds of industry. These composites are important in many different domains, including automotive, construction, aerospace, and maritime industries, because of their unusual mix of performance and sustainability. Combining synthetic and natural fibers allows one to create goods satisfying the increasing demand for eco-friendly solutions while nevertheless satisfying the required criteria for durability and strength.

MATERIALS AND METHODS

This work demonstrates the construction of a hybrid composite material. Its matrix is epoxy resin; the reinforcement components are glass fiber and sisal fiber. Made up of direct roving spun into a cloth or tape, the glass fiber used was 900 WRM (Woven Roving Mat.). It gave constant filament strength (Figure 1) and reinforcement in both directions—0° and 90°. The inclusion of sisal fibers in the composite significantly enhances its biodegradability and overall environmental sustainability. In many different industries, sisal fibers—which come from plants, can be used over and over, and break down naturally—are a key component of reducing the environmental impact of composites and facilitating the change to more sustainable materials. Polymer composites extensively use glass fibers as reinforcement due to their remarkable properties and low cost. Figure 1 shows chopped sisal fibers, glass fiber, and sisal fiber.

The sisal plant provides an environmentally sustainable and reasonably priced alternative for reinforcing with exceptionally specific strength; hence, we obtained the sisal fibers from its leaves. The sisal fibers' density was 1.41 g/cm^3, their elongation at break ranged from 6 to 7 percent; their cellulose content fell between 60 and 65 percent; and their Young's modulus was 12.8 GPa. Figure 3 shows the 50 mm length of chopped sisal fibers used here. Figure 2 shows the latter elements: Epoxy Resin Ly556 (a) with HY51 Hardener b the manufacturing process produced five separate layers of composite specimens using the hand-laid method. Glass fibers made up the top, center, and lowest layers; chopped sisal fibers made up the second and fourth layers. The epoxy resin blend—used to coat and connect the fiber layers was created from a 10:1 mix of LY556 resin and HY951 hardener. After that, the composite laminates were cured at 80°C and under a pressure of 10 bar by means of compression modeling. The modern composite hybrids came out of this. The results revealed that the choice of the epoxy matrix was absolutely important. In tests, the tensile strength of sisal-glass hybrid composites was greatly affected by the type of epoxy matrix used. With both kinds of fibers, the adhesive showed amazing adherence, thereby enabling efficient load distribution over the material.

Figure 1. (a) Glass Fiber, (b) Sisal Fiber, (c) Chopped Sisal Fiber.

Figure 2. (a) Epoxy Resin (Ly556) (b) HY951 Hardener.

Figure 3. (a) Composite fabrication using Hand lay-up process (b) Mixing of Resin-Hardener-PU

We methodically evaluated the hybrid composite materials tensile strength, flexural strength, and impact energy. Figure 3 shows the following particular elements: Combining resin, hardener, and polyurethane using the manual lay-up procedure results in composites. The 260 x 24 x 5 mm tensile test specimens were then further tested in a Universal Testing Machine (UTM) following the final tensile strength determination. Stress-strain curve plotting helps one find the elastic modulus and ultimate tensile strength. Figure 4 shows the finer points: the designed compressor-molded machine. To evaluate their flexural strength and modulus, we bent the 119.5 x 12 x 5 mm flexural test specimens in three orientations. Charpy impact testing specimens let one evaluate composite impact strength. Figure 5 details the specifics: (a) the flexural testing equipment; (b) the impact testing equipment.

Figure 4. (a) Compression Molding Machine (left) (b) Developed composite (right).

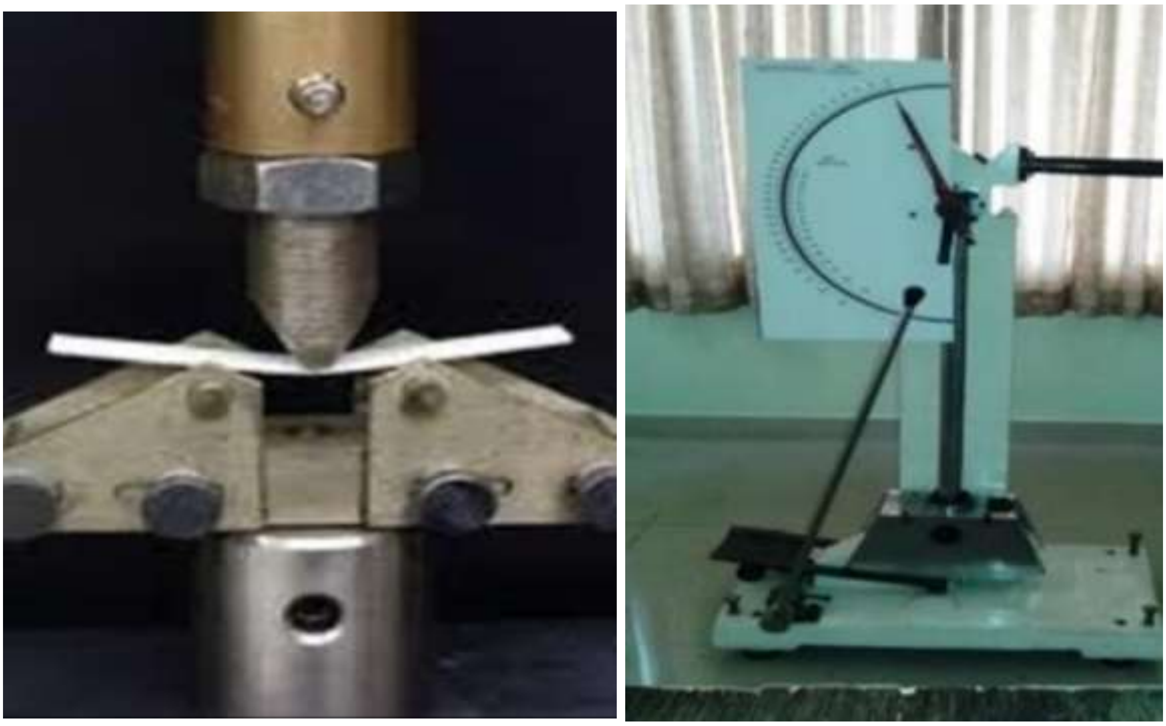

Figure 5. (a) Flexural Testing Machine (left) (b) Impact Testing Machine (right)

METHODOLOGY

The fabrication Composites reinforced with sisal-glass fibers (GFRP) involved several steps, utilizing materials such as glass fiber (900 WRM), and epoxy resin (LY556), hardener (HY951), and sisal fiber. Reputable for their low cost, ultimate tensile strength, chemical resistance, and insulating qualities, glass fibers were employed as a 900 WRM fabric with a bi-directional weave. Sisal fibers, extracted from sisal plant leaves through a hand extraction machine, were sun-dried and chopped into 50 mm lengths. The LY556 epoxy resin and HY951 Hardener was blended into a 10:1 ratio. Composite specimens consisted of five layers: glass fiber layers on the top, middle, and bottom, with chopped sisal fibers in the second and fourth layers, using a roller brush to apply the epoxy resin mixture. The manual hand lay-up process, an open molding method, was used for placing fiber reinforcements in a mold, followed by the application of the resin mixture. Post manual hand lay-up, compression molding was employed, involving the compression of the laminate between heated metal molds at 10 bar pressure and 80°C in a hydraulic press until curing. Tensile testing (ASTM D638) using a Universal Testing Machine to ascertain properties like ultimate tensile strength, Young's modulus, and elongation; flexural testing to evaluate flexural and impact testing using the Charpy method to measure impact strength through the energy absorbed during collision were mechanical tests on the manufactured sisal-GFRP composites. Table 1 lists sisal fiber's physical qualities. Tensile characteristics of the sisal-GFRP composite are shown in Figure 6.

RESULTS

We evaluated the strength of the sisal-glass fiber-reinforced polymer (GFRP) composites using several tests. Tensile, flexural, and impact tests were among those done. We have compiled the results of these tests here.

Tensile Characteristics

We looked at how well the sisal-GFRP composites worked under tensile stress using a Universal Testing Machine (UTM) and the ASTM D638 standard for testing procedures. Measuring 260 x 24 x 5 mm, the specimen's dimensions were Table 2 lists the computed values for elongation at fracture, Young's modulus, and ultimate tensile strength. Table 2 shows the values from the tensile testing.

Table 1. Physical properties of sisal fiber.

Property	**Value (Units)**
Density	1.41 (g/cm³)
Diameter	205-230 (μm)
Cellulose Content	60-65 (%)
Elongation at Break	6-7 (%)
Young's Modulus	12.8 (GPa)

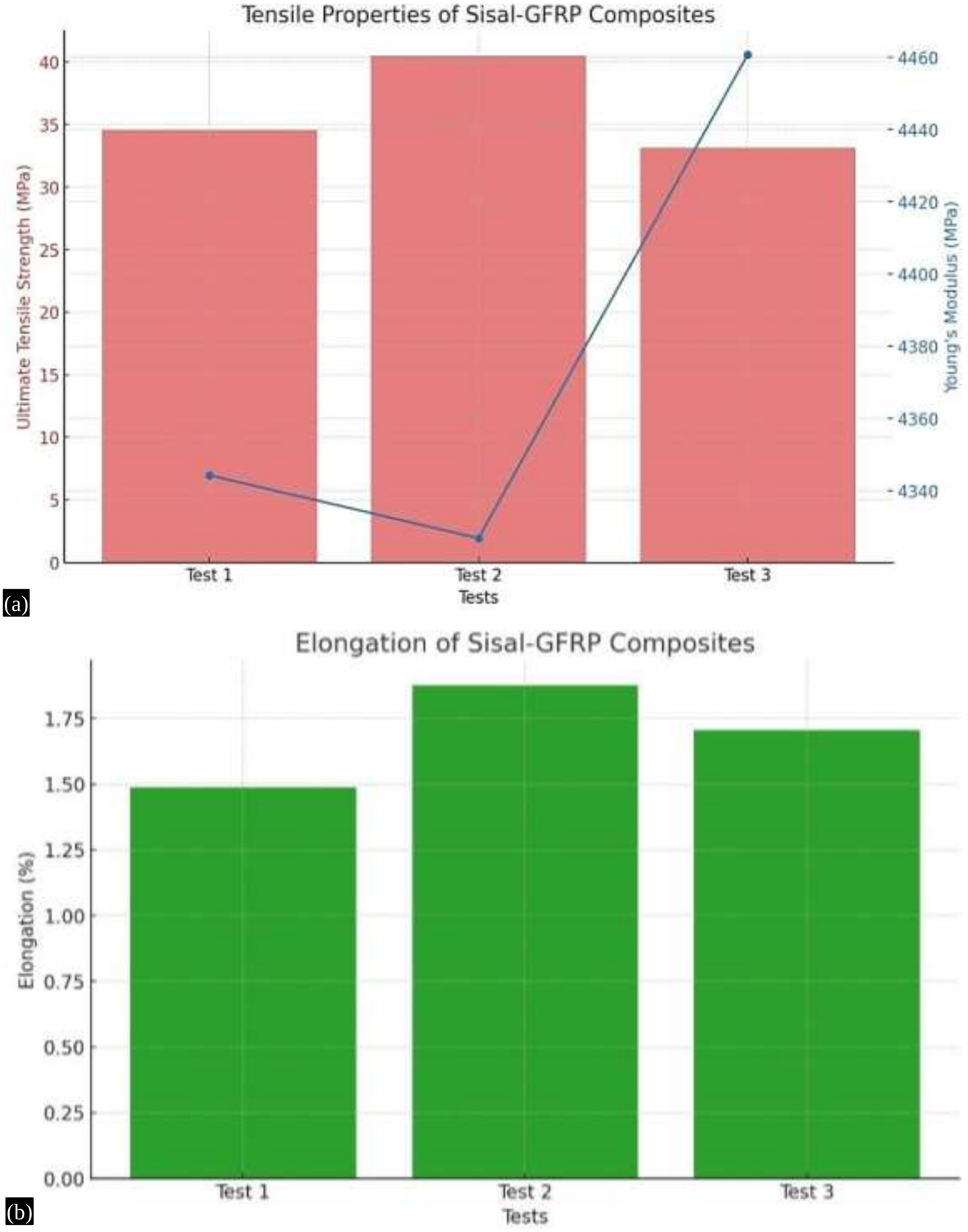

Figure 6. (a and b) Tensile properties of sisal-GFRP composite.

Table 2. Results of tensile tests for epoxy composites reinforced with sisal and glass fibers.

No of Tests	Ultimate Strength (MPa)	Young's Modulus (MPa)	Elongation (%)
1.	34.5835	4344.26	1.488
2.	40.4971	4326.85	1.8765
3.	33.1436	4460.73	1.7065

The findings showed that the sisal-GFRP specimen exhibited a maximum ultimate tensile strength of 40.4971 MPa. The Young's modulus values ranged from 4326.85 MPa to 4460.73 MPa, with elongation at break varying from 1.488% to 1.8765%. Tensile strength is a main feature of sisal-GFRP composites that regulates their tensile load carrying without breaking. Tensile strength, 40.4951 MPa, reveals that sisal fiber added to the GFRP composites generated higher strength. This value aligns with the tensile strength measured in past research for numerous natural fiber-reinforced polymer composites. Usually referred to as the elastic modulus, the Young's modulus measures a material's resistance to elastic deformation and its stiffness. The values obtained for the sisal-GFRP composites, ranging from 4326.85 MPa to 4460.73 MPa, are within the expected range for this type of composite material. The elongation at break, which represents the maximum strain a material can endure before fracturing, varied from 1.488% to 1.8765% for the sisal-GFRP composites.

These values indicate the ductility of the material and its ability to undergo plastic deformation before failure. This work highlights the great opportunities of sisal-GFRP composites as strong materials with improved tensile properties. The integration of sisal fibers not only enhances the tensile strength but also contributes to desirable stiffness and ductility characteristics. These attributes make sisal-GFRP composites an attractive option for diverse engineering applications that require a balanced combination of strength, stiffness, and flexibility. About sisal-GFRP composites to improve the adhesion between the fibers and the matrix, refine processing methods, and ascertain their lifetime under different environmental conditions, more research is required. Additionally, further studies could focus on the economic and environmental benefits of using natural fibers in composite materials, promoting sustainable engineering solutions.

Flexural Properties

The maximum flexural load sustained by the specimen's was 181.38792 N and a flexural strength of 201.29053 MPa. The orientation of a material determines its flexural strength mostly; this is a crucial determinant of its capacity to resist bending loads without failing. We use this material in structural or load-bearing components that require flexibility. The sisal-GFRP composites can handle bending forces of up to 201.29053 MPa. The most force the specimen can withstand before bending or breaking is the flexural load. The material's composite characteristics recorded a maximum flexural load of 181.38492 N. Examining the gradient and curve arrangement helps one assess how the material responds to bending loads. This helps to define variables, which cover the strain at failure and the flexural modulus. Table 3 shows the sisal-GFRP composite flexural test vales.

Impact Characteristics

The strength of impact sisal-GFRP composites was assessed through Charpy impact testing. Table 4: presents the tested values for impact reading and impact strength. The highest impact strength achieved with sisal-GFRP composites was 375.29 J/m. Elements such as matrix bond strength, distribution, and fiber orientation cause the noted variations. When sisal fiber is mixed with GFRP composites, they become stronger against tensile, flexural, and impact forces. This invention also improved their environmental sustainability and cut expenses relative to other fiber composites. These improved properties make sisal-GFRP composites suitable for various engineering and industrial applications, including automotive parts, construction materials, and sports equipment.

Table 3. Tested flexural values of sisal-GFRP composites.

Test Numbers	SPECIMEN ALIGNMENTS FOR FLEXURAL	
	Flexural load N	*Flexural strength MPa*
1	151.11143	175.99742
2	172.30566	129.58275
3	181.38792	201.29053

Table 4. Evaluated measurements of Impact test.

No of Tests	**ALIGNMENTS OF SPECIMENS FOR IMPACT**	
	Impact Reading (J)	***Impact Strength (J/m)***
1	0.8706	375.29
2	0.8655	366.76
3	0.723	283.531

RESULTS AND DISCUSSION

The findings indicated that sisal-GFRP composite specimens had a relatively low tensile strength, with a maximum value of 40.4971 MPa (Table 2). The composite Young's modulus, indicating stiffness, ranged from 4326.85 MPa to 4460.73 MPa, and the maximum elongation at break was about 1.8765%. In terms of flexural properties, the flexural strength varied between 129.58 MPa and 201.29 MPa, with the maximum flexural load sustained being approximately 181.38 N. The impact characteristics of the composites ranged from 283.531 J/m to 375.29 J/m; 375.29 J/m was the maximum reported impact strength. This implies their ability to compile momentum upon impact. The tests showed that adding sisal fibers to the GFRP matrix made it much stronger than both pure GFRP and sisal fiber composites when it came to bending and impact. Sisal-GFRP hybrid composites show enormous promise in fields including construction and automotive that call for enhanced resistance to bending and impact. One big problem with hybrid composites is that the synthetic glass fibers and natural sisal fibers stick together very well. The hydrophobic character of glass and the hydrophilic character of sisal could influence the adhesion between two materials. Alkaline treatment, among other techniques, altered the surface of the sisal fibers. By considerably improving mechanical performance, the increase in fiber-matrix contact helped solve the issue as well. Coupling agents enhanced the interfacial bonding across the fibers and resin.

CONCLUSION

The study investigated, production and assessment of sisal-GFRP composite materials, leveraging sisal plant fibers as reinforcement within a polymer matrix. Results indicated significant enhancements in mechanical properties, specifically tensile and flexural strength, due to the integration of sisal fibers. This underscores the potential of utilizing natural fibers in enhancing composite performance across diverse applications. Moreover, the research underscores the feasibility of natural fibers in composite manufacturing, aligning with green technology and sustainable practices. The findings suggest that sisal fibers' inherent strength contributes substantially to the improved mechanical attributes observed. This validates the feasibility of utilizing renewable resources for composite production, promoting environmental sustainability. Furthermore, the study emphasizes the significance of exploring agro-waste products as valuable resources in a circular economy framework. This approach supports responsible manufacturing practices, contributing to resource efficiency and reducing environmental impact. In conclusion, the investigation provides critical insights into optimizing composite materials through natural fiber reinforcement. It highlights their role in fostering eco-friendly manufacturing solutions and advancing sustainable practices. The study's outcomes suggest a promising future for utilizing sisal and similar natural fibers in composite applications, paving the way for innovative developments in green technology and materials science.

Declaration of interest

The Author(s) report no conflicts of interest.

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Not Applicable

Data Availability Statement

This study does not develop nor examines any new data

Ethics Statement

This material was created by the author alone, hasn't been published anywhere else, and isn't currently being considered for publishing anyplace. It fully and properly reflects the study and analysis of author or authors.

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