Mechanical and Thermo-Mechanical Behaviors of Snake Grass Fiber-Reinforced Epoxy Composite

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Snake grass fiber was used as a supporting material in an epoxy matrix. The goal was to develop a lightweight structural material. To enhance the interfacial bonding between the snake grass (*Sansevieria ehrenbergii*) fiber and polymer matrices, the fiber underwent chemical treatment with NaOH. Samples were prepared with both neat and treated fibers mixed with epoxy at various volume percentages. The mechanical properties of snake grass fiber exhibited improvement with increasing fiber length and fixation, reaching optimal values at 20 mm length and 20% v/v fixation. Dynamic mechanical analysis (DMA) demonstrated superior energy absorption by the composite up to 140 °C, irrespective of repetition. Thermogravimetric analysis (TGA) indicated rapid degradation of untreated fiber with a residue level of 0.2%, while the snake grass composite (25% v/v) exhibited stable residue content at 11%. Microscopic evaluation using a scanning electron microscope provided insights into the morphology of the fiber surface.

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INTRODUCTION

Scientists globally are exploring normal fiber-supported polymer composites as an eco-friendly alternative to traditional polymer composites due to increasing environmental concerns. Regular fiber-based composites, containing fibers from banana, *Casuarina*, bamboo, sisal, jute, coir, and certain types of grass, offer advantages such as greater strength-to-weight ratio, cost-effectiveness, use of natural resources, and a reduced carbon footprint (Xue *et al.* 2007; Zabihzadeh 2009; Xie *et al.* 2010; Sobczak *et al.* 2013; Tajvidi and Ebrahimi 2003; Saba *et al.* 2014; Shafigh *et al.* 2022).

Various researchers have explored the potential of these natural fibers as support materials for polymer matrix composites, emphasizing the crucial role of the fiber-matrix interaction in determining the mechanical properties of such composites (Gonzalez *et al.* 1999; Saheb and Jog 1999; Demir *et al.* 2006; Parthasarathy *et al.* 2022). Studies have investigated the impact of chemical treatments, such as acetylation and alkalization, on sisal fiber composites, revealing significant improvements in fiber-matrix adhesion and mechanical characteristics (Rong *et al.* 2001).

Hybrid composites, combining fibers such as banana and sisal, have demonstrated enhanced ductile properties, as reported by Venkateshwaran *et al.* (2012). Sreekumar *et al.* (2009) examined the mechanical properties of sisal fiber-polyester composites, highlighting the positive effects of surface modification treatments including silanization and permanganate treatment on rigidity and flexural strength (Manickaraj *et al.* 2023). The study explored sustainable plant-based fibers, specifically African teff and snake grass, in hybrid composites with bio castor seed shell, glass fiber, and SiC fillers. SC10SG20AT was found to exhibit superior mechanical properties, making it a recommended choice for lightweight applications. The incorporation of nano-fillers, such as calcium carbonate nanoparticles and montmorillonite nanoclay, has been studied to enhance mechanical properties in composites made with coconut sheath/polyester and groundnut shell particles, respectively (Rajini *et al.* 2013; Chen *et al.* 2015). Additionally, the use of *Shorea robusta* in polyester composites demonstrated improved mechanical qualities compared to pure polyester resin (Vimalanathan *et al.* 2016).

A study by Manickaraj *et al.* (2022) aimed to create epoxy composites using African teff and snake grass fibers reinforced with bio-based castor seed shell powder. Mechanical properties improved with up to 20 wt% of African teff fiber, showcasing the combined influence of bio castor seed shell powder and natural fibers. Ashok *et al.* (2022) explored the impact of nano-aluminum oxide (Al_2O_3) loading on Kevlar/snake grass fiber hybrid epoxy composites, revealing enhanced mechanical properties and improved ballistic impact resistance, particularly with 8 wt% Al_2O_3, suggesting potential applications in impact-resistant materials for bulletproof vests. Furthermore, a study by Nusyirwan *et al.* (2019) analyzed husk fiber/starch reinforced epoxy polymer composites, focusing on the impact of fiber and filler volume percentage on mechanical and thermal behavior. Mekonnen and Mamo (2020) explored the mechanical characteristics of a hybrid bamboo/jute/polyester composite with various blending ratios, reporting improved tensile properties. Ashok *et al.* (2023) found that adding 2 wt.% lignite fly ash nanofiller to *Calotropis gigantea* fiber/epoxy composite significantly enhances tensile, interlaminar shear, impact, and flexural strength, making it a promising material for sustainable brake applications with superior mechanical and tribological properties.

Jenish *et al.* (2021) utilized hand lay-up to create polyester composites reinforced with chemically treated snake grass fiber, emphasizing enhanced interfacial bonding. Similarly, Premkumar *et al.* (2022) demonstrated outstanding mechanical strength in composites containing equal proportions of kenaf and snake grass fiber. Modifying snake grass fiber using NaOH, as studied by Rokbi *et al.* (2011), was found to reinforce the link between the fiber and matrix, making the fiber more frangible. The research by Premkumar *et al.* (2022) specifically investigated the mechanical properties of epoxy resin influenced by both untreated and treated snake grass fiber.

Glass fiber is extensively utilized as reinforcement in composites owing to its light weight, cost-effectiveness, and resistance to degradation. However, a significant drawback lies in the health risks associated with the production of glass fiber and its composites.

In this study, snake grass fiber material embedded in an epoxy matrix was chosen as a fiber material to investigate its impact on the mechanical, dynamic mechanical, tribological, vibration, thermal, and electrical properties of epoxy composites. The focus was on assessing its suitability for small and medium-scale applications. While many researchers typically have prepared composites using snake grass fiber, epoxy, and various fillers, the innovation in this research is the formulation of a composite using only sanke grass and epoxy. This novel approach involves utilizing both treated and untreated snake grass fiber in conjunction with epoxy, resulting in optimized outcomes.

EXPERIMENTAL

Sansevieria ehrenbergii Fiber

Snake grass, sourced from the Thanjavur region of Tamil Nadu, India, possesses favorable physical properties such as length, strength, and uniformity, making it particularly suitable for producing finer counts of fibers. The extraction of snake grass fibers (SGFs) involved manual processes from the leaves of *Sansevieria ehrenbergii*.

The physical properties of snake grass fiber, as reported by Prabhu *et al.* (2020), include a density of 0.8 g/cm^3, diameter ranging from 45 to 250 µm, tensile strength between 287 and 545 MPa, and a modulus of 9.7 GPa.

Hardener and Epoxy Resins

A composite was created using hardener HY 917 and epoxy resin LY 556. This resin, known for its ease of fabrication, exhibits commendable thermal and mechanical properties when combined with fibers and fillers. Moreover, it demonstrates resistance to chemicals. Both the hardeners and resins, weighing 6 kg each, were procured from Royal Scientific suppliers in Trichy, offering affordability and wide availability.

Alkali Therapy

A 5% NaOH solution was employed for alkali treatment of the SGFs, with an application duration of 3 hours. Following treatment, the fibers underwent rinsing with distilled water to remove excess chemicals and lignin. Subsequently, the fibers were dried in an oven at 70 °C for 3 hours, adhering to procedures outlined by by Jenish *et al.* (2021) and Mansour *et al.* (2011).

The various surface treatment processes have been explored in the development of fiber-reinforced composites. The relevance of alkaline treatment lies in its unique ability to address specific challenges and enhance the overall performance of the composite through improved adhesion, surface modification, and mechanical properties.

Specimen composition

Table 1 provides a breakdown of the components used in the preparation of the specimens.

Table 1. Specimen Composition

Sample No.	Snake Grass Fiber (%)	Epoxy Resin (%)
1	00	100
2	05	95
3	10	90
4	15	85
5	20	80
6	25	75
7	30	70

Hand lay-up method

The sample was fabricated employing the hand lay-up method shown in Fig. 1, utilizing a mold measuring 300 mm in length, 300 mm in width, and 3 mm in thickness. Within the mold, a polyester strip was positioned. The hardening agent and resin were meticulously blended in a glass container at a ratio of 1:10. Subsequently, the mold was sealed, and the resultant composite material was uniformly distributed and weighed, reaching a total of 45 kg after an approximate curing period of 32 hours at ambient temperature. Once thoroughly dried, the composite was extracted from the mold.

Fig. 1. Fabrication process

Tensile test

The tensile properties of the composite were evaluated through a series of tensile tests, with dimensions conforming to the ASTM D3039 (2017) standard. A Universal Testing Machine (Model: TFCU-600, Fine Instruments, Maharashtra, India) was employed for the tests. Fourteen samples, featuring various compositions, underwent testing. The specimens were subjected to constant tension until fracture occurred, with measurements of tensile force and elongation recorded as the load increased.

Flexural test

The flexural properties of the composite were determined using the ASTM D790 (2017) standard for specimen dimensions. The testing was conducted with a Universal Testing Machine (Model: TFCU-600, Fine Instruments, Maharashtra, India). A macroscopic testing device supported the specimen, which was loaded until failure at its center. Measurements of load and flexural force were recorded.

Impact test

The impact resistance of the polymer composite was assessed in accordance with ASTM D256 (2023). Fourteen specimens with diverse compositions underwent testing, utilizing an impact tester (Model: TFIT-300, Fine Instruments, Maharashtra, India) with a capability of 250 joules. The specimen, vertically suspended, was struck, and the impact energy was revealed upon the hammer's release.

Dynamic mechanical analysis

An epoxy hybrid polymer derived from snake grass was examined using the SEIKODMAI-DMSC 6100 (Seiko Instruments Inc., Japan) device under high and dynamic loading conditions. Dynamic Mechanical Analysis (DMA) was conducted in the tensile mode, with temperatures ranging from 30 to 200 °C. The testing involved an advancement frequency of 10 Hz at an average rate of 5 °C/min.

Thermogravimetric analysis

The thermal stability of the composite specimen was assessed using a TG/DTA 6200 (Seiko Instruments Inc., Japan) SEIKO Thermogravimetric Analyzer (TGA). The analysis covered a temperature range of 0 to 800 °C, with increments of 20 °C/min. To prevent oxidation, the specimen was heated in a nitrogen atmosphere.

RESULTS AND DISCUSSION

The mechanical analysis of the composite, fabricated from untreated snake grass in accordance with ASTM standards, was conducted, and the findings are presented in Figs. 2 to 4. These figures elucidate the impact of fiber length and fiber volume ratio on ductility, flexural strength, and impact properties.

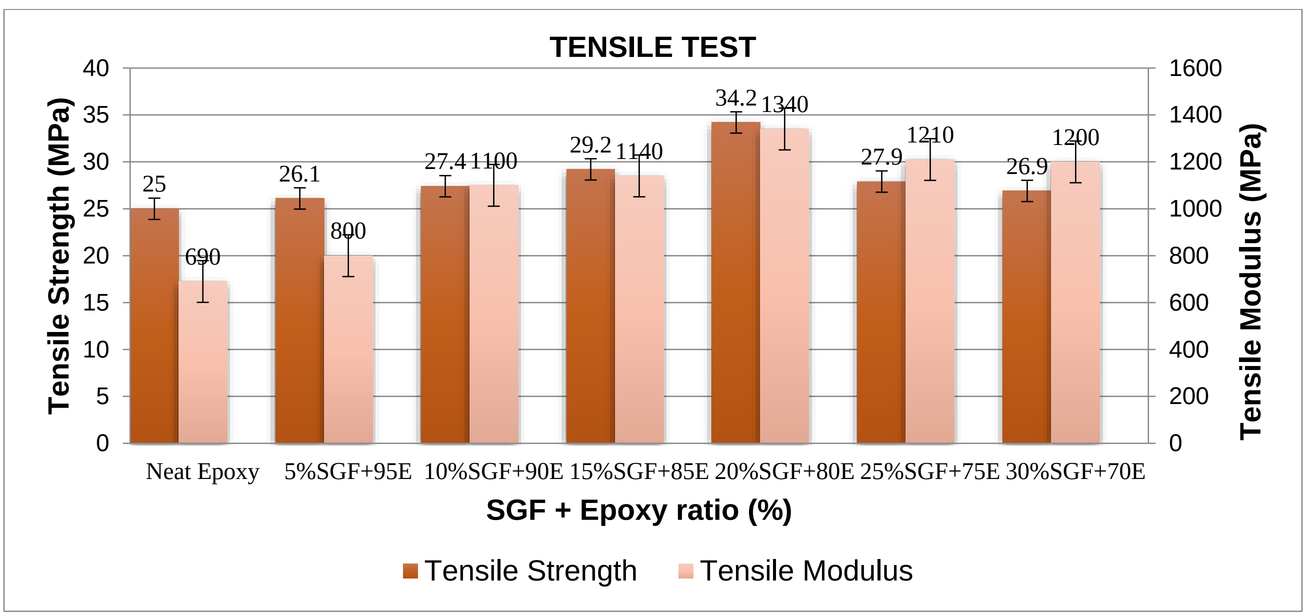

Fig. 2. Evaluation of the tensile characteristics of neat epoxy and epoxy loaded with snake grass fiber

In Fig. 2, the results of the tensile performance for various compositions are depicted. The investigation encompassed the total tensile strength and modulus for diverse combinations of composite samples. Optimal results were observed with a composition comprising 20% untreated snake grass fiber and 80% epoxy resin. The total tensile strength and modulus were measured at 34.2 and 1340 MPa, respectively. These findings indicate the significant influence of the fiber volume ratio on the tensile properties of the composite.

The results underscore the importance of optimizing the composition, specifically the fiber volume ratio, to achieve enhanced mechanical properties in the composite material. Further discussions will delve into the observed trends and relationships between fiber characteristics, volume ratios, and mechanical performance across the various tested parameters.

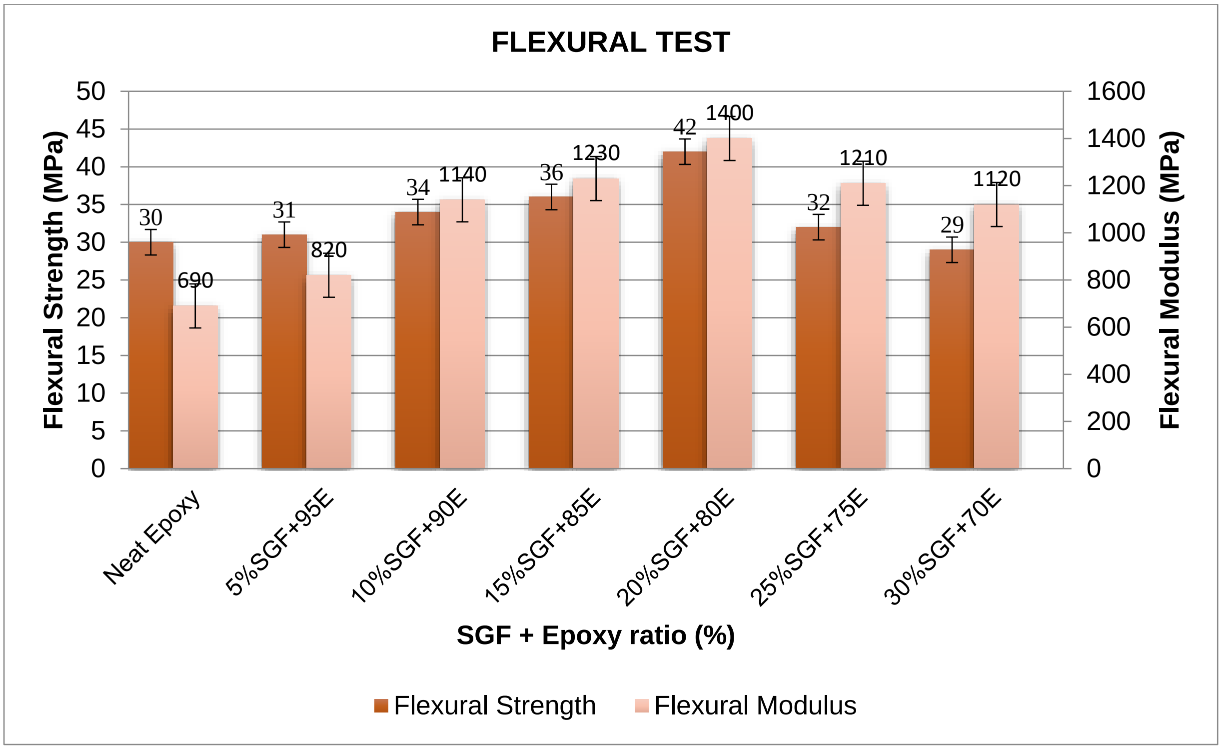

Fig. 3. Evaluation of the flexural characteristics of neat epoxy and epoxy loaded with snake grass fiber

Figure 3 illustrates the results of the flexural analysis conducted on different composite samples. Notably, the graph highlights the variations in flexural strength and modulus across different compositions. Within the graph, the composition featuring 20% neat snake grass fiber and 80% epoxy resin exhibited the highest flexural strength and modulus, measured at 42 and 1400 MPa, respectively. It is noteworthy that as more fiber material was integrated, there was a discernible decrease in both the modulus and flexural strength of the composite material. This observed trend will be further discussed in relation to the influence of fiber content on the flexural properties of the composite.

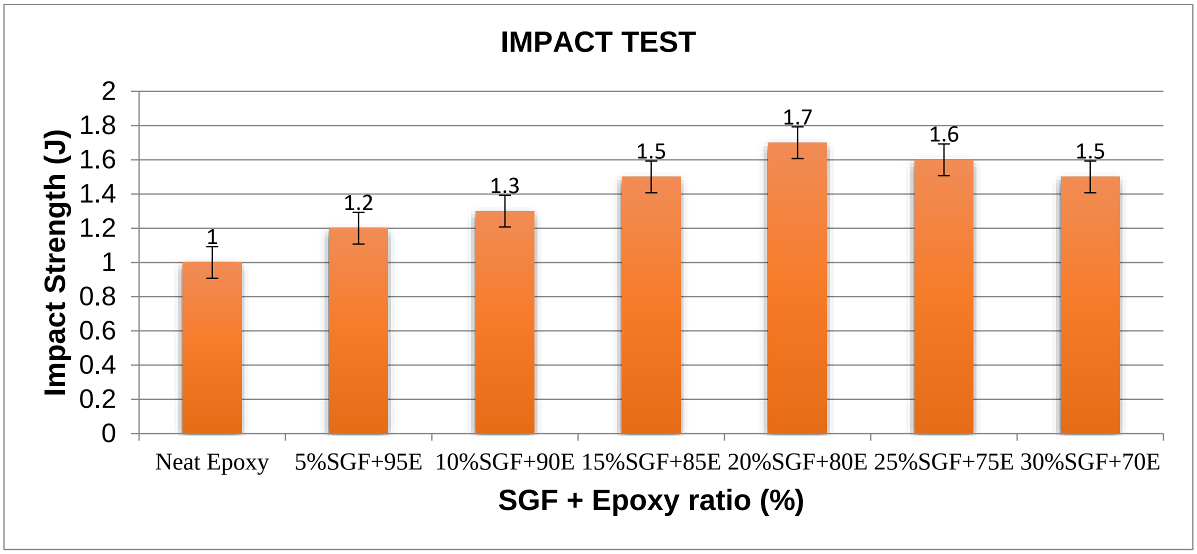

Fig. 4. Evaluation of the impact characteristics of neat epoxy and epoxy loaded with snake grass fiber

Figure 4 presents the impact strength results for different composite compositions. Notably, the graph indicates that the highest impact strength, reaching 1.7 J, was observed in the composition comprising 20% neat snake grass fiber and 80% epoxy resin. It is important to consider that impact strength is a measure of a material's ability to withstand sudden and intense loads for a short duration, as noted by Venkateshwaran *et al.* (2011). Given the nature of impact tests, where materials experience a significant volume of strain over a brief period, minimal notable changes in impact strength values are expected across the tested compositions. Further discussions will delve into the implications of these impact strength findings for the overall performance and applicability of the composite material.

Figure 5 illustrates the tensile strength and modulus of various composites treated with NaOH.

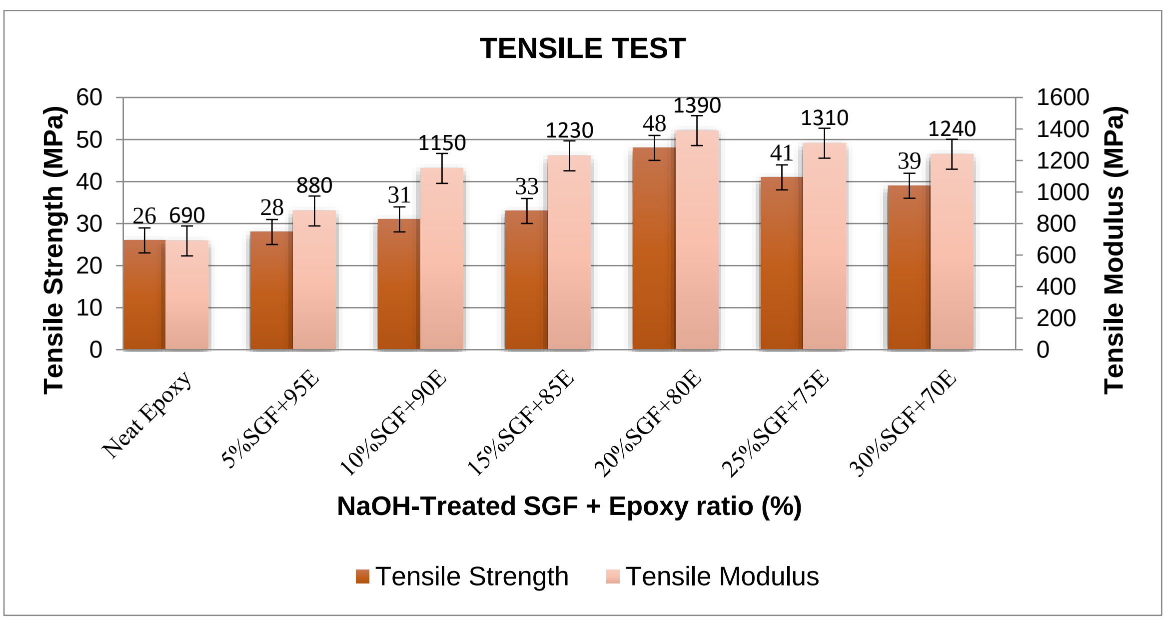

Fig. 5. Evaluation of the tensile characteristics of neat epoxy and epoxy loaded with NaOH-treated snake grass fiber

The graph showcases the impact of NaOH treatment on the tensile properties of the composite material. Notably, the composition featuring 20% NaOH-treated snake grass fiber and 80% epoxy resin exhibited the highest tensile strength and modulus, measured at 48 and 1390 MPa, respectively. These results highlight the influence of NaOH treatment on enhancing the tensile performance of the composite. The discussion will further explore the implications of NaOH treatment on the mechanical properties and overall suitability of the composite for specific applications.

Figure 6 presents the outcomes of the tensile performance analysis for various compositions of NaOH-treated composites. The graph investigates the total flexural strength and modulus across different composite sample combinations. The optimal result, as indicated by the highest total flexural strength and modulus, was achieved with a composition comprising 20% NaOH-treated snake grass fiber and 80% epoxy resin. The measured values were 72 MPa for flexural strength and 1410 MPa for modulus. These findings underscore the positive impact of NaOH treatment on the flexural properties of the composite material and will be further discussed in the context of fiber treatment and its implications for mechanical performance.

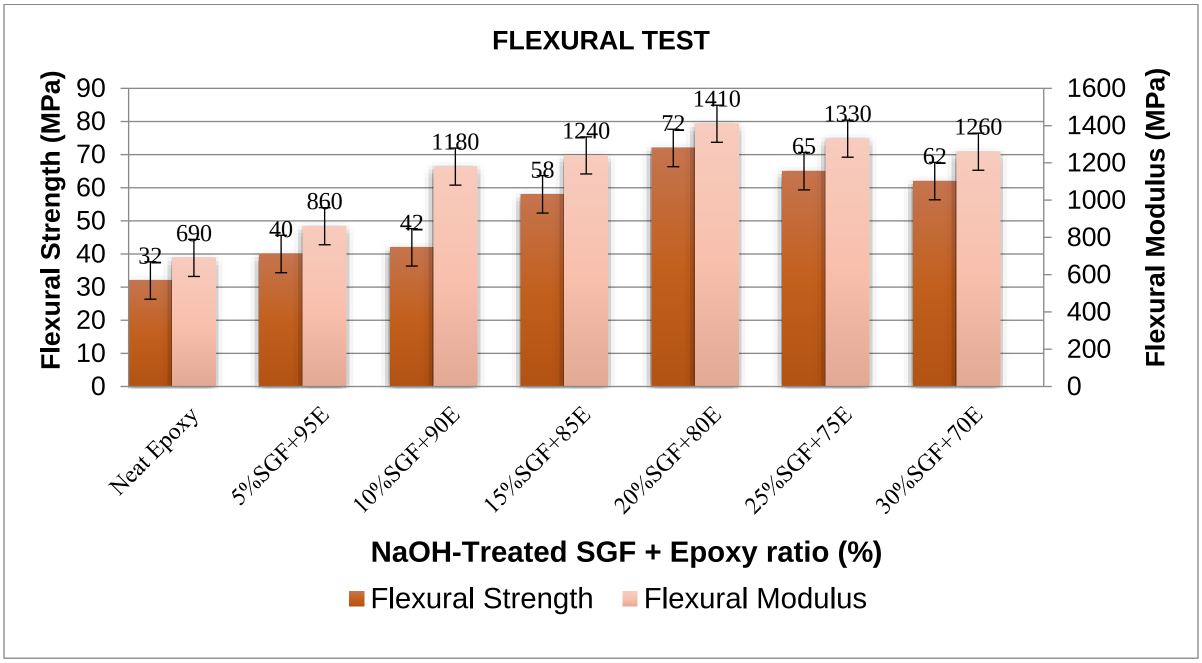

Fig. 6. Evaluation of the flexural characteristics of neat epoxy and epoxy loaded with NaOH-treated snake grass fiber

Figure 7 depicts the impact strength results for various NaOH-treated composite compositions. Notably, the graph illustrates that the highest impact strength, reaching 1.8 J, was observed in the composition comprising 20% NaOH-treated snake grass fiber and 80% epoxy resin. These findings emphasize the influence of NaOH treatment on enhancing the impact strength of the composite material. The discussion will delve into the significance of these impact strength results and their implications for the overall performance and durability of the NaOH-treated composite in applications requiring resistance to sudden and intense loads.

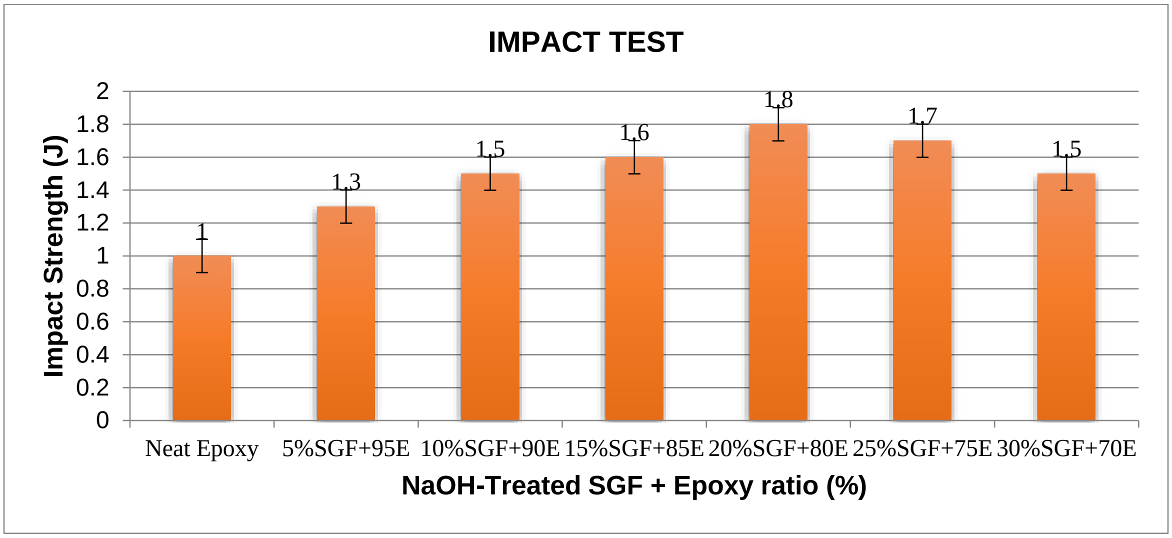

Fig. 7. Evaluation of the impact characteristics of neat epoxy and epoxy loaded with NaOH-treated snake grass fiber

Satyanarayana *et al.* (1990) observed that the stress-strain curve of the cured polyester resin closely resembles that of brittle materials. Figure 8 illustrates the transformation of the polyester resin from a brittle to a ductile nature upon the addition of fibers. In comparison to the composite specimens, the cured resin displayed a reduced elongation at break. The peak stress occurred at a 20% fiber volume fraction, corresponding to elevated strain values. The stress-strain curve maintained a consistent nature beyond a 20% volume fraction, suggesting that 20% represents the optimal fiber volume fraction. The determination of the specimens' Young's modulus involves considering the elastic segment of the stress-strain curve and calculating with the corresponding machine compliances.

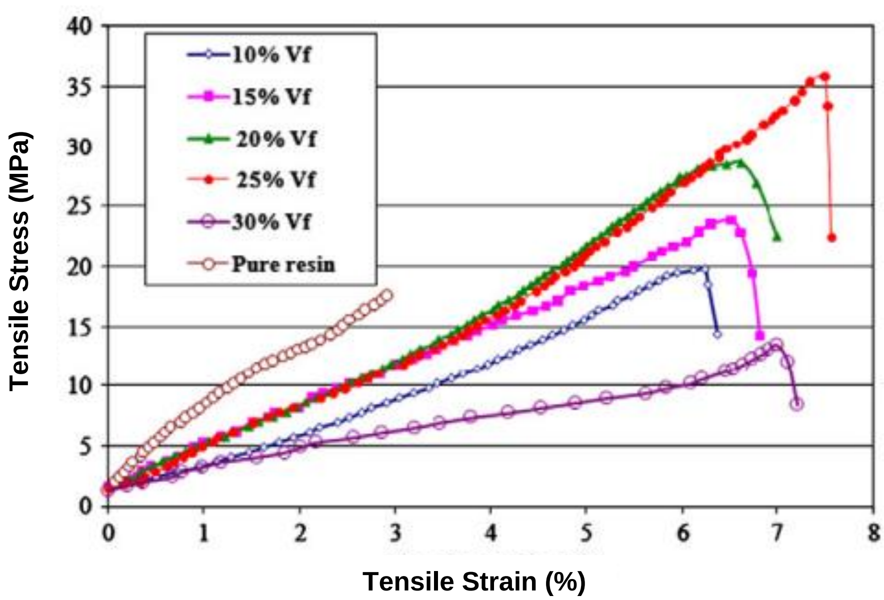

Fig. 8. A stress-strain graph for various fiber volume

The surface morphological qualities of both treated and untreated composite samples were meticulously examined using field emission scanning microscopy (SU5000, Hitachi High Technology Co., Tokyo, Japan). Figure 9 presents a 2000x magnification micrograph of untreated snake grass fiber, while Fig. 10 displays a 2000x magnification micrograph of NaOH-treated snake grass fiber within the composite samples.

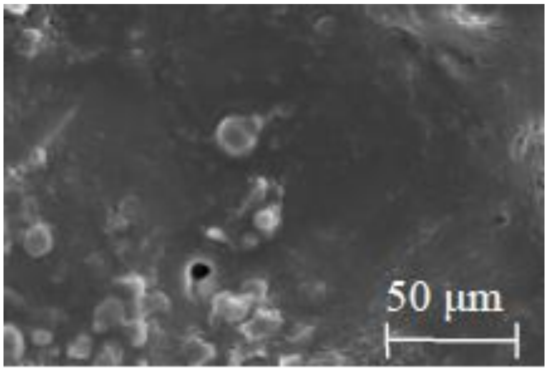

Fig. 9. SEM image of neat SGF and epoxy

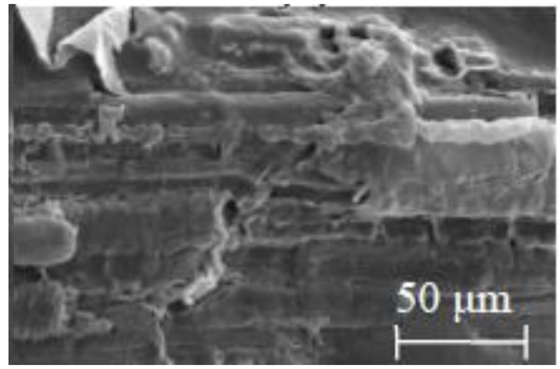

Fig. 10. SEM image of NaOH-treated SGF and epoxy

In these micrographs, the strong attachments between the grid and fibers are evident. The composite exhibited resilience even when individual filaments were broken, thanks to the robust connection points. This essential characteristic enables the composite to maintain structural integrity and withstand stress, showcasing the effectiveness of the treatment process in enhancing the interfacial bonding between the snake grass fibers and the matrix. Further discussions will explore the implications of these surface morphological observations on the overall mechanical performance and durability of the composite material.

Figure 10, akin to Fig. 9, depicts the uniform distribution of filaments, a crucial condition for pressure circulation that enhances mechanical strength. However, with the further expansion of the fiber volume division, the elasticity began to decrease due to fiber aggregation at higher volume percentages. Additionally, bunching of the fibers resulted in poor wetting by the matrix, leading to inadequate bonding between the strands, as observed by Omar *et al.* (2014). Consequently, the mechanical qualities decline. The twisting and bending of the fibers caused by fiber length extension further affect the pressure transfer between the matrix and the fiber.

The SEM images in Fig. 10 vividly illustrate these characteristics and the impact of surface modification on the mechanical properties of the composite materials. The observations align with the data presented in Figs. 2 to 4, emphasizing the critical role of fiber parameters, such as volume and length, in determining the vigor of composite materials. The SEM photos highlight that the interaction between the fiber and the matrix significantly influenced the characteristics of fiber-reinforced composites, with fiber length and volume being pivotal factors in determining composite strength.

To enhance the interaction between the fiber and matrix, chemical treatments were employed to modify the outer layer of the natural fibers. This modification improved the surface attachment between the matrix and the fiber, ultimately enhancing the overall composite strength. In this study, four synthetic chemicals were applied to snake grass filaments, with sodium hydroxide [NaOH] being one of them. A 5% concentration of each chemical was used in the formulations, as an optimal concentration (5%) is crucial for improved retention without damaging the natural fiber. The comparison between treated and untreated fiber-based composites revealed that chemical treatment significantly influenced the mechanical properties of the composite material.

The NaOH-treated fiber-supported composite exhibited superior performance in terms of tensile strength, flexural strength, and impact strength compared to composites treated with other chemicals. This suggests that, in comparison to other treatments, the alkaline-treated fiber provided improved bonding between the fiber and matrix. The hydroxyl groups in cellulose chains form stronger intermolecular and intramolecular connections during material processing, providing the fibers with enhanced stability. Figures 5 to 7 display how chemical treatment has affected the actual structure of the fibers.

Figure 9 illustrates how untreated fiber surfaces can hinder the bonding with the matrix, resulting in a weak connection point. In contrast, the smooth surface shown in Fig. 10 illustrates how surface modification can strengthen the bond at the connection points, leading to improved mechanical properties. The primary effect of chemical treatment is to disrupt the organization structure's ability to store hydrogen, increasing surface roughness. Additionally, this process removes some of the oils, wax, and lignin that accumulate within the fiber surface.

Dynamic Mechanical Analysis

Storage modulus (E')

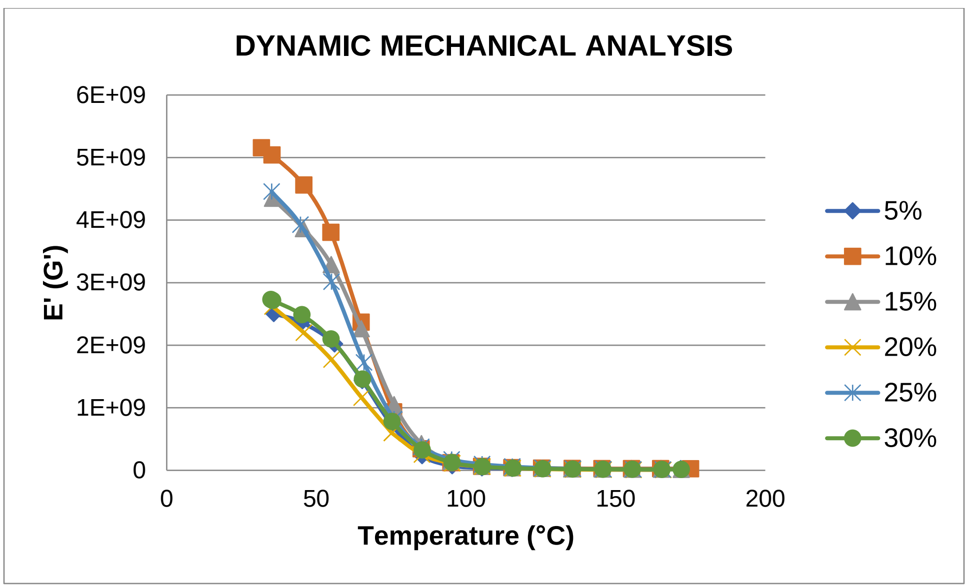

Fig. 11. Storage modulus of epoxy resin and snake grass fiber composite at 10 Hz frequency

In Fig. 11, the impact of temperature and frequency on the storage modulus (*E′*) of a composite comprising epoxy resin, NaOH-treated snake grass fiber, and 20 vol% fiber is depicted. The test temperature spanned from 30 to 200 °C, with a frequency of 10 Hz. The data reveals that, up to 140 °C, the composite exhibited superior storage modulus regardless of frequency. As the testing temperature increased, both the resin and the composite demonstrated nearly identical energy utilization. This indicates that, up to 140 °C, the fibers and filler were effectively supporting the load, but beyond this point, they may gradually lose their grip on the matrix, affecting their ability to perform as intended, as noted by George *et al.* (1996).

Analysis results suggest that incorporating filler/fiber into the polymer matrix enhances the composite's storage modulus or stiffness. Figure 11 further illustrates that the inclusion of filler-containing treated fiber elevates the expected storage modulus over a shorter duration, resulting in increased strength. However, the graph also indicates that over an extended period (at lower frequencies), the values decrease. This is attributed to particles subjected to lower frequencies undergoing more frequent adjustments than those exposed to higher frequencies. These molecular changes within the material lead to a reduction in stiffness within a specific frequency range.

Loss factor

The loss factor is often represented as the product of the material's storage modulus and its loss modulus. This signifies the material's energy dissipation during loading and the extent of molecular movement within the polymer chain. The plot of the loss factor for the snake grass fiber-reinforced composite material is presented in Fig. 12.

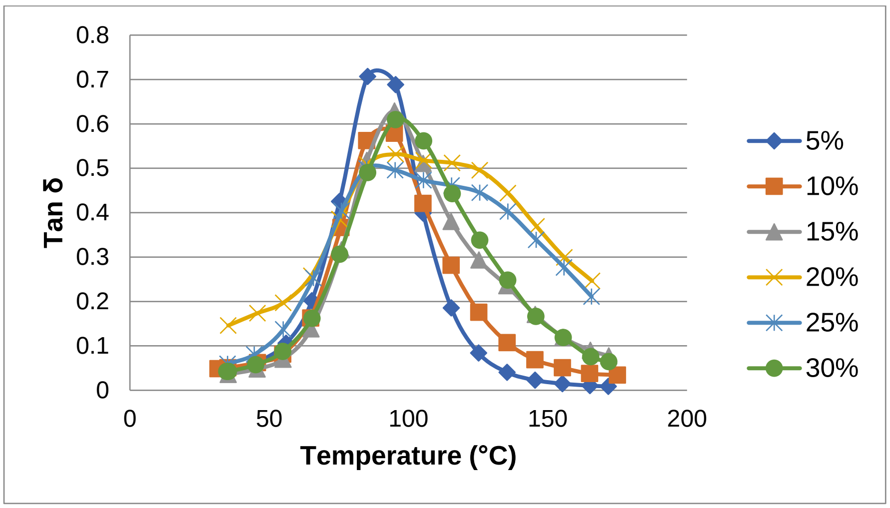

Fig. 12. Storage modulus of epoxy resin and snake grass fiber composite at 10 Hz frequency

The results indicate that the addition of reinforcement reduces the loss component of the composite material, suggesting that the energy dissipation mechanism is influenced by the composite rather than the matrix alone. At low temperatures, the material is considered to be in its glassy state or energy complex state. As the temperature increases, the material undergoes a phase transition into the elastic or entropy complex state, known as the glass transition, where the glass phase transforms into the elastic flexible phase. The temperature at which this transition occurs is typically associated with the highest loss factor (tan max.) or the maximum loss modulus (E'' max.). In this study, the highest tan value was utilized to determine the glass transition temperature.

Regardless of the applied frequency, the peak of the tan curve decreases compared to epoxy resin, indicating a distinct shift in glass transition temperatures (T_g). This suggests that the change in T_g value was a result of the synergistic interaction between the filler and fiber. The peak of damping is linked to the glass transition region, which is when a material transitions from a rigid to a more flexible state. The initial particle stability, akin to the boost in temperature, prepares the polymer structure for the formation of small clusters and chains of atoms. Consequently, the degree of molecular flexibility in the stages of inhomogeneity increases with the rising tan peak.

Thermogravimetric analysis

In Fig. 13, the Thermal Gravimetric Analysis (TGA) curves of epoxy resin and the composite are presented. The graph illustrates that, compared to pure epoxy resin, the composite with filler exhibited higher thermal stability. The inclusion of snake grass in the epoxy matrix is shown to have had a negligible impact on thermal stability, while the filler components contributed to a slight improvement in the TGA results.

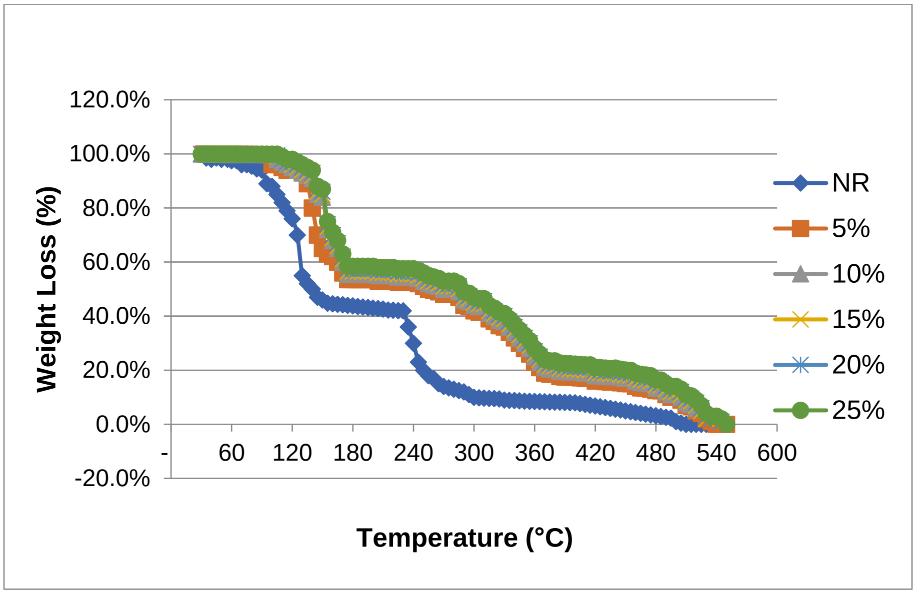

Fig. 13. TGA curves of epoxy resin and snake grass fiber reinforced epoxy composites

The initial weight loss in the curves is attributed to water evaporation from the sample. Notably, the addition of snake grass to the epoxy matrix enhanced the thermal stability of the polymer. The thermal stability of pure epoxy resin is evident up to 540 °C, beyond which the resin underwent rapid degradation with a residue level of only 0.2%. In contrast, the composite containing 25% v/v snake grass maintained a stable residue content at 11%.

Consistent with various test findings, the incorporation of reinforcement has been shown to enhance the properties of the raw fiber. The mechanical characteristics of the treated samples are reported to be superior to those of untreated samples. These promising outcomes suggest the potential use of this composite material in the fabrication of medium and small-scale automobile components, which will be the focus of future research and investigation.

CONCLUSIONS

1. This study extensively explored the influence of snake grass fiber on the mechanical properties of epoxy resin. Utilizing snake grass fiber as a biofiber, various epoxy composites were developed.
2. Through a comprehensive assessment of mechanical properties, it was determined that the composite containing 20% v/v biofiber exhibited enhanced values for impact, tensile, and flexural strengths.

3. While the addition of biofiber had a minor impact on tensile and flexural strengths, it significantly influenced tensile and flexural moduli, indicating an increased stiffness in the composite. The accumulation of biofiber became more pronounced at volume fractions of 25% and above.
4. The optimized outcome was realized because of the strong compatibility between the fiber and resin at a volume fraction of 20% snake grass fiber and 80% epoxy.
5. Thermogravimetric analysis (TGA) revealed swift degradation of untreated fiber, leaving a residue level of 0.2%. In contrast, the snake grass composite (25% v/v) displayed a stable residue content of 11%.
6. The mechanical properties of treated samples were found to be superior to those of untreated samples based on test results. In scanning electron microscopy (SEM) analysis, the distribution of treated snake grass fiber (SFG) was notably superior to that of untreated SFG.
7. The enhanced stiffness observed in the composite material is important for practical applications, particularly in industries prioritizing mechanical strength and rigidity. For example, in the aerospace sector, stiffer epoxy composites can be used in aircraft components, contributing to weight reduction and improved structural performance, leading to enhanced fuel efficiency. Similarly, the automotive industry seeks lightweight yet stiff composite materials to boost fuel efficiency without compromising structural strength, making stiffer epoxy composites valuable for manufacturing vehicle components like chassis and body panels.

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