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RESEARCH ARTICLE

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Preparation and characterization of snake plant fiber reinforced composite: A sustainable utilization of biowaste

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Abstract

Natural fibers are one of the most attractive materials in biocomposites due to their potential for sustainability. This study aims to prepare sustainable composite materials using fibers from *Sansevieria trifasciata* (snake plant) and to investigate their mechanical, morphological, and water absorption properties. The composite was prepared with epoxy resin through a manual hand lay-up process, maintaining standard parameters with changeable reinforcement (10%, 20%, and 30%). The mechanical properties (tensile, impact, and flexural strength), Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and water absorbency of the composites were evaluated. The result showed that the tensile strength, flexural strength, and impact resistance of the composites are 6.99 MPa, 10.77 MPa, and 14 J, respectively, for 30% fiber components, which are significantly higher than other composite materials. The SEM analysis showed a strong interfacial bond between the snake plant fiber and the epoxy resin. The FTIR analysis revealed a reduction in hemicellulose and lignin and an improvement in the interfacial adhesion between snake plant fiber and epoxy resin. The composites also demonstrated time-dependent increases in water absorption, with the sample containing 30% fiber components showing the best absorbency performance at 0.88%.

Highlights

- A study is being conducted on the effective and sustainable use of biowaste.
- The composite materials loaded with 30% fibers had significantly high tensile strength, flexural strength, and impact resistance.
- The SEM analysis of snake plant fiber-reinforced polymer composite showed a strong interfacial bond between fiber and epoxy resin.
- The FTIR analysis of the composite revealed the reduction of hemicellulose and lignin.
- The use of non-renewable materials is reduced, and eco-friendliness is promoted.

KEYWORDS
biocomposite, mechanical properties, snake plant, sustainability, water absorption

1 | INTRODUCTION

Natural fiber reinforced composite (NFRC) has drawn the attention of researchers, industrialists, and academics in the last few decades due to its minimal cost, easy availability, simple processability, light weight, biodegradability, and lower environmental effects.[1,2] The petroleum-based synthetic fiber composite emits poisonous CO_2 gas into the environment during burning, causing environmental pollution. Unlike synthetic fiber, natural fibers are derived from nature and have no environmental issues. Despite these advantages, NFRCs demonstrate some disadvantages, including poor fiber-matrix adhesion and lower mechanical and thermal properties.[3] Various finishing processes are applied to NFRCs to improve functional properties, such as physical explosion, chemical treatment, thermal treatment, and so on. The finishing treatments enhance the fiber and matrix interfacial bond, make the fiber surface rough, and make the fibers hydrophobic by reducing the water absorption percentage, which ultimately develops the mechanical properties of composites. Due to chemical treatment, the fiber is prone to fracture.[4,5] Besides, nano-additives treated composites significantly enhance the mechanical properties and wear resistance. Althahban et al.[6] investigated the tensile strength of nano additives (Al_2O_3 and TiO_2) based commercial restorative composite. They concluded that nano additives played an important role in improving the tensile properties of composites. They also concluded that the Al_2O_3 (50.8 MPa) nano additive increased higher tensile strength compared to the TiO_2 (26.6 MPa) nano additive. The tensile strength improved because of the strong interfacial adhesion between nano-additive and matrix. The wear resistance of composites depends on the surface contact of the nano-additives with the matrix and hardness of nano-additives. The wide applications of NFRCs are increasing day by day due to their lower weight as lower weight reduces CO_2 emission. Therefore, NFRCs are used in various potential fields like building and construction companies, space technology, sports, the automotive industry, and so on.[7,8]

Numerous researches have been conducted on natural fibers like jute, pineapple, hemp, bamboo, sisal, wood, kenaf, ramie, banana, and so forth.[9,10] There are other little-known potential natural fibers like *Sansevieria trifasciata* that also have the potential to replace synthetic fibers. The *S. trifasciata* plant, known as the snake plant or mother-in-law's tongue, belongs to the family Asparagaceae. The leaves of snake plants are sword-shaped, have zebra-like markings, grow vertically, and are thick in nature.[11] This plant has the ability to reduce bacteria as it contains phytochemicals.[12] Pamonpol et al.[13] used *S. trifasciata* in their experiment to reduce indoor air quality. They reported that the plant reduced the CO_2 concentration by about 16% and the electricity cost by about 24%. This plant has an exclusive character of corrosion protection, which adds an extra quality for being composite.[14] Like other natural fibers, snake plants have cellulose, hemi-cellulose, lignin, and other contaminants in their composition. Hemicellulose is hydrophilic, dissolve in alkali, and lignin is hydrophobic. In snake plant, the cellulose portion is higher (more than 50%) which is the crucial for the reinforcement of composites. The good quality of composites found from the base of the fiber.[15] Alkali treatment in snake plants reduces hemi-cellulose, lignin, and other contaminants. Therefore, the thickness of the fiber reduces, the fiber surface becomes rough, fiber-matrix interfacial bonding enhances and eventually the mechanical strength increases. After alkali treatment, neutralization is required to remove the alkali effect.[16] In our work, we rinsed the fiber samples in distilled water several times to remove the unwanted, foreign particles or grain particles from the fiber surface.

Many studies have been carried out on *S. trifasciata* fibers (STF) including its properties analysis,[11,17] surface treatment of fiber for better improvement of physical, mechanical and thermal properties,[18,19] effect of fiber length,[1,20] fiber orientation[18,19,21] on mechanical properties of STF composites, hybrid STF composite preparation and properties analysis,[5,22,23] comparative analysis of STF composite with other natural fiber composite.[24] Shieddieque et al.[21] prepared biocomposites varying STF fiber content (0%, 5%, 10%, and 15%) and combining with high impact polypropylene vinyl ester. They concluded that the tensile strength of STF increases with increasing the fiber content. The result showed that the tensile strength of 15 wt% STF/high impact polypropylene and 15 wt% STF/vinyl ester was 59.77 and 121.1 MPa, respectively. Another study on STF/polyester composites conducted by Hariprasad et al.[15] showed that due to the presence of ceramic fillers (SiO_2 and B_4C), the mechanical properties of the hybrid composites increased. They experimented with the sample varying fiber weight percentage (0%–20%) and filler percentage (0%–15%) and found that the tensile, flexural, and impact strength of STF/polyester

composites were 44.92 MPa, 103.58 MPa, and 27.4 kJ/m^2, respectively for 20% fiber loading and 15% SiO_2.

Only a very few studies[21,25] have been carried out to prepare and characterize composites varying STF loading and investigate their relative mechanical, morphological properties, etc. so far. As far as we are aware, no paper has been published so far that involves the preparation of composites with varying reinforcement percentages, while also investigating their tensile, flexural, impact strength, morphological, and water absorbency properties simultaneously. There are many opportunities for snake plant fibers as it is yet new to many. There is a lot of scope for exploring this new fiber and its composite. As a biocomposite material and being light weight, ecofriendly and inexpensive, the STF composites have a wide range of application sectors including packaging industry, automotive industry, in lieu of plastic doors, building and construction industries and so on.

The objective of this study is to create sustainable composites using STF and examine their mechanical, morphological, and water absorption characteristics. The experiment involved utilizing different percentages (10%, 20%, and 30%) of snake plant fibers in conjunction with epoxy resin. These fibers were obtained from snake plant leaves, treated with NaOH solution, and combined with epoxy resin to form the snake plant/epoxy resin composite. To determine the viability of these composites, various tests were conducted including assessing their mechanical properties (tensile strength, impact strength, and flexural strength), examining their morphology through Scanning Electron Microscopy (SEM), analyzing their chemical composition using Fourier Transform Infrared Spectroscopy (FTIR), and measuring their water absorbency.

2 | MATERIALS AND METHODOLOGY

2.1 | Materials

Snake plants (*S. trifasciata*) (density 887 kg/m^3, diameter 45–250 μm) were collected from local sources. The industrial-quality Epoxy LY556 (viscosity 12,000–13,000 cP, density 1.08–1.20 g/cm^3) and the hardener Araldite HY951 were sourced locally.

2.2 | Fiber modification

The snake plants fibers were soaked in a 10% w/v NaOH solution for over 4 h at room temperature. Then, the fibers were thoroughly washed with distilled water. To neutralize the pH, an acetic acid solution was used. Finally, the fibers were dried at room temperature. Through this pretreatment process, a major portion of impurities were removed and, simultaneously, the adhesion with the matrix material was improved.

2.3 | Composite preparation

The snake plant/epoxy composite was made using a manual hand lay-up process. The epoxy resin and hardener were mixed carefully in an appropriate ratio. Different weight percentage of fibers (10%, 20%, and 30%) were added to the epoxy resin (90%, 80%, and 70%) and hardener mixture to prepare the desired composite.

This mixing process was conducted by a manual lay-up process. To laminate the composite, a thin plastic plate was placed on the mold. Then epoxy resin and hardener mixture were settled down evenly on the plate. Next, the sample fiber was placed over the resin layer, followed by another layer. Then, the composite arrangement was sealed out with another laminating plate. The thickness of each sample was kept fixed (1.85 mm) to facilitate the comparison among the composite samples. To avoid any bubble formation, a roller was used to roll up the composite mold and, a 25 kg load was placed on the top. The composite was cured for 24 h at room temperature. After curing, the composite was opened out by isolating it from the laminating plate. The composite samples were prepared based on different fiber loading percentage (10%, 20%, and 30%). Figure 1 illustrates the

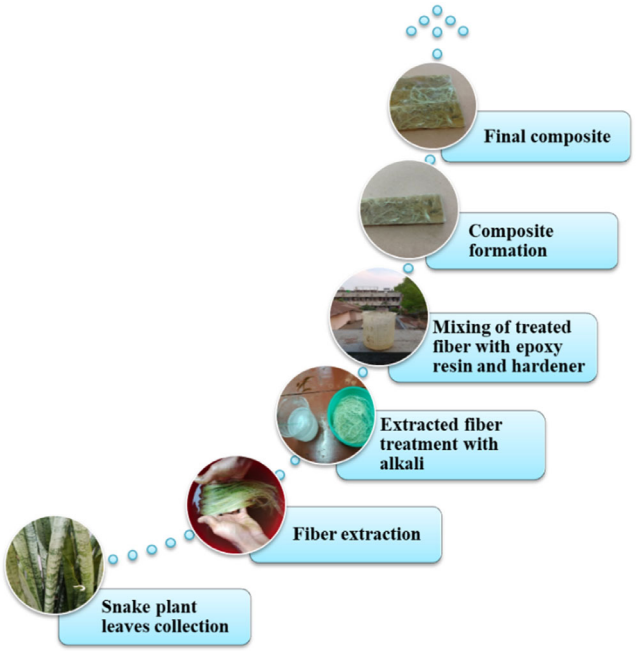

FIGURE 1 Process diagram of composite manufacturing.

TABLE 1 Composite specification.

Sample identification	Composite composition		Composite thickness (mm)	Preparation method	Fiber mixing
	Resin%	Fiber%			
A	70	30	1.85	Compression molding	Hand lay-up
B	80	20	1.85	Compression molding	Hand lay-up
C	90	10	1.85	Compression molding	Hand lay-up

process diagram of composite manufacturing, while Table 1 indicates the samples identification along with resin percentage, fiber percentage, composite preparation method and fiber mixing method.

2.4 | Testing and characterization

2.4.1 | Fourier transform infrared spectroscopy (FTIR)

In this experiment, IR tracer 100, Shimadzu (Japan) Fourier Transform Infrared (FTIR) Spectrophotometer equipped with the ATR configuration is used where the specimen spectrum was obtained extending the 4000–400 cm^{-1} wavenumber range.

2.4.2 | Scanning electron microscope (SEM)

A Schottky field emission scanning electron microscope (SEM), model Jeol-Jsm 7600, Japan, with an accelerating 10 kV voltage was used to see the bonding of the composite.

2.4.3 | Tensile test

The tensile test is performed by Universal Testing Machine (Model Titan, James Heal, UK), provided with a 5-kN load cell where the crosshead speed was 10 mm/min. The composite samples (250 mm × 25 mm × 3 mm) were prepared following ASTM D3039 standard for tensile test.[26] The samples were grasped with the use of a tensile grip, which was then pulled until the specimen broke.

2.4.4 | Flexural test

ASTM D7264 standard was followed to prepare composite samples (250 mm × 13 mm × 3 mm) for flexural test.[27] A three-point bend test was conducted on the samples at a crosshead speed of 1 mm/min. The gauge length was 96 mm with a 120 mm total length due to the 20% extra support span. The loading nose was cylindrical with a radius of 3 mm.

2.4.5 | Impact test

The test is done with a Charpy setup on an impact testing machine. It is done according to the guidelines of ASTM D256.[28] An un-notched IZOD impact tester (Izod, Computerized, International Equipments, India), having 7.5-J pendulum was used for impact test and the data was recorded at room temperature. The pendulum hits the sample until it breaks. The composite samples (64 mm × 13 mm × 3 mm) were prepared following ASTM D256 standard.

2.4.6 | Water absorption

ASTM D570 standard was followed to measure the water absorption characteristics.[29] The specimen (4 mm × 4 mm × 3 mm) is impregnated in water at room temperature for different time range. Water absorption percentage is determined by using formula (1).[30]

$$\text{Water absorption}\,(\%) = \frac{W_a - W_b}{W_b} \times 100, \qquad (1)$$

where, W_b = weight of sample before absorption; W_a = weight of sample after absorption.

All data were expressed as the means of the triplicate measurements. All investigations were conducted in a controlled environment following LST EN ISO 139:2005.

3 | RESULTS AND DISCUSSION

3.1 | FTIR analysis

FTIR analysis shows the connections between various parts by receiving light at different frequencies. Figure 2 states the FTIR of snake plant fiber/epoxy composite.

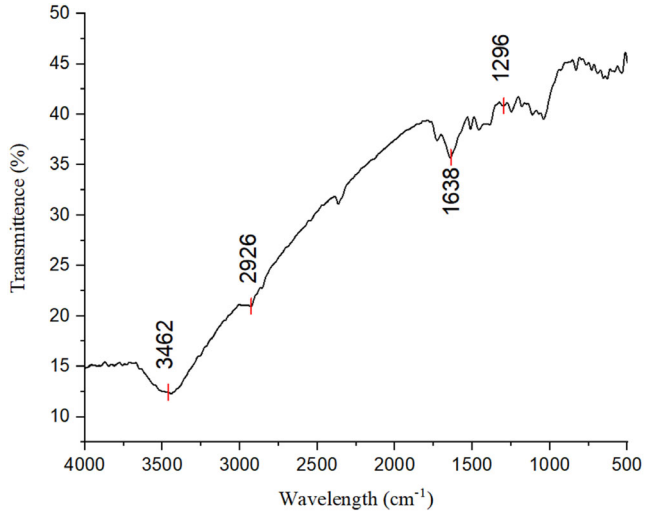

FIGURE 2 FTIR analysis of snake plant fiber/epoxy composite.

Sansevieria trifasciata fiber is enriched with cellulose and lignin. The presence of an acetyl group in lignin is suggested by the peak at 1247 cm^{-1}, which represents C—O stretching. The peak at 1638 cm^{-1} indicates the stretching of carbonyl (C═O) groups.[11] The peak at 2926 cm^{-1} is likely due to the stretching of C—H bonds in hemicellulose and cellulose, while the peak at 3462 cm^{-1} corresponds to the stretching of O—H groups.[31] The peak at 1296 cm^{-1} is assigned to the epoxy ring mode of C—C and C—O bonds.[32] The image shows a decrease in the lower range of lignin and hemicellulose, which can be attributed to the alkaline treatment applied to the sample. This treatment effectively reduces the amount of lignin, hemicellulose, and other impurities present on the surface of snake plant fiber.

3.2 | SEM analysis

SEM analysis of snake plant fiber reinforced composites provides valuable insights into the microstructure and interfacial properties of the material. Figure 3 indicates the SEM images of snake plant composite samples using 10%, 20%, and 30% fiber loading at a magnification of ×500.

In the pictures provided, the reinforcement and matrix are visually represented. The reinforcement region, resembling a tree root, is depicted, while the black empty region represents epoxy resin. A crack can be observed in the pictures, which was caused by alkali treatment on the sample, resulting in a rough surface. SEM analysis reveals that the 30% reinforcement has a denser region compared to the 20% or 10% reinforcement. This indicates that the 30% reinforcement has formed a stronger bond with the epoxy resin than the other two percentages. The stronger bond is a result of modifying higher fiber loading percentages. The amount of fiber in a composite plays a crucial role in enhancing both the bonding between fiber and matrix and the mechanical performance of the composite. Additionally, alkali treatment roughens the surface of fibers, leading to increased bonding between fibers and matrix, ultimately improving composite material performance. This treatment removes impurities such as oil, wax, and lignin from the fiber surface.[33] In the case of the 20% fiber sample, there is evidence of fiber pull-out; however, for the 30% fiber sample, there is breakage instead of pull-out fibers, demonstrating strong interfacial adhesion for this particular fiber content percentage.[21]

3.3 | Tensile test

The tensile strength and tensile modulus of snake plant fiber/epoxy composites can vary depending on several factors, including the fiber content, fiber orientation, composite fabrication method, and the specific properties of the epoxy matrix. The average value, standard deviation, and coefficient of variation of tensile strength of snake plant fiber/epoxy composites are mentioned in Table 2. Figure 4 indicates the effect of fiber loading on tensile strength and tensile modulus of snake plant fiber/epoxy composites.

Composite A had the highest tensile strength at 6.99 MPa, while composite B had a tensile strength of 5.07 MPa and composite C had a tensile strength of 3.97 MPa. The tensile strength of composite A increased by approximately 38% compared to composite B and by 76% compared to composite C. In comparison to composite C, composite B showed an increase in tensile strength of about 28%. SEM analysis revealed that a higher percentage of fibers resulted in better bonding with the resin, which explains the superior tensile strength. Pradipta et al.[34] support this finding, suggesting that it leads to improved mechanical compatibility for composite A compared to the other two composites. Moreover, higher fiber loading % distributes force along the axis of composites, as a result the tensile strength becomes higher.

A similar trend has been observed for the tensile modulus. Composite A exhibits the highest value at 357 MPa, followed by composite B at 264 MPa, and composite C at 205 MPa. This indicates that the tensile modulus of composite A is more favorable compared to the other two composites. The bonding background is responsible for this discrepancy in tensile modulus values.

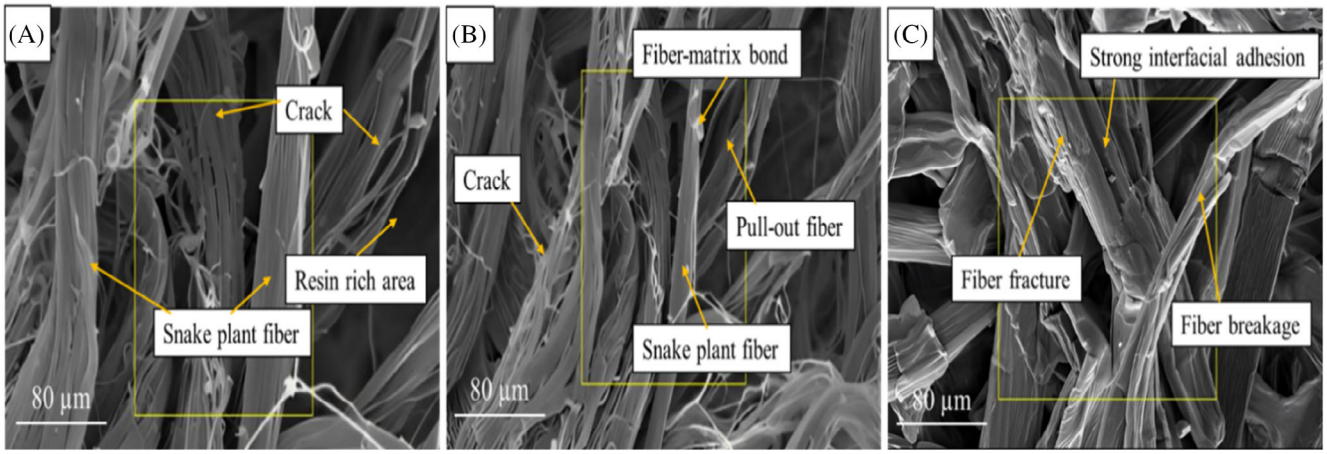

FIGURE 3 SEM analysis of snake plant composite samples at (A) 10%, (B) 20%, and (C) 30% fiber loading at a magnification of ×500.

TABLE 2 The average value, standard deviation, and coefficient of variation of tensile strength, flexural strength, and impact energy of snake plant fiber/epoxy composites.

	Tensile strength, MPa			Flexural strength, MPa			Impact energy, Joule		
Sample code	Average	Standard deviation	Coefficient of variation, CV%	Average	Standard deviation	Coefficient of variation, CV%	Average	Standard deviation	Coefficient of variation, CV%
A	6.99	0.09	1.29	16.19	0.29	1.79	14.00	0.40	2.85
B	5.07	0.12	2.37	10.77	0.27	2.50	12.00	0.35	2.91
C	3.97	0.07	1.76	5.60	0.30	5.35	8.00	0.30	3.75

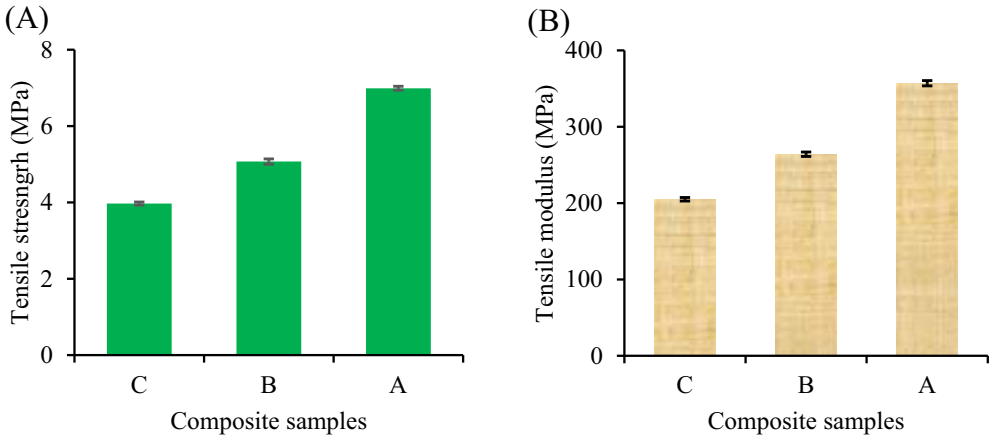

FIGURE 4 Effect of fiber loading on (A) tensile strength and (B) tensile modulus of snake plant fiber/epoxy composites.

3.4 | Flexural test

Flexural testing is a common method used to evaluate the flexural properties of materials. The flexural test provides valuable information about the composite's stiffness, strength, and deformation behavior under bending loads. The average value, standard deviation, and coefficient of variation of flexural strength of snake plant fiber/epoxy composites are stated in Table 2. Figure 5 indicates the effect of fiber loading on flexural strength and flexural modulus of snake plant fiber/epoxy composites.

The flexural strengths of composite A, composite B, and composite C were measured to be 16.2, 10.8, and 5.6 MPa, respectively. Composite A demonstrated a 50% increase in flexural strength compared to composite B and a 190% increase compared to composite C. Additionally, the flexural strength of composite B increased by approximately 93% when compared to composite C. The higher fiber loading and improved bonding behavior between the sample fiber and epoxy resin resulted in a significant increase in both flexural strength and flexural modulus. As a result, composite A exhibited superior flexural strength due to its better bonding

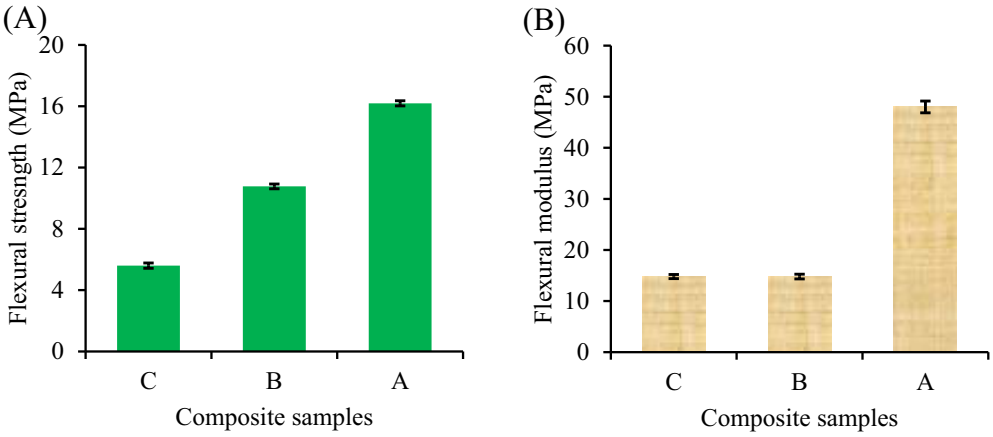

FIGURE 5 Effect of fiber loading on (A) flexural strength and (B) flexural modulus of snake plant fiber/epoxy composites.

capacity compared to the other composites. This is because more fiber content means higher strength and good bonding between fiber and matrix which ensures the robustness of composites under stress. As a result, the flexural strength becomes higher for higher fiber content (sample A) and vice-versa.

Composite A has the highest flexural modulus value at 48 MPa, while composite B and composite C have flexural modulus values of 14.8 MPa each. The flexural modulus value of composite A is significantly better than the other two composites. Therefore, it can be concluded that these composites are suitable for conducting flexural tests.

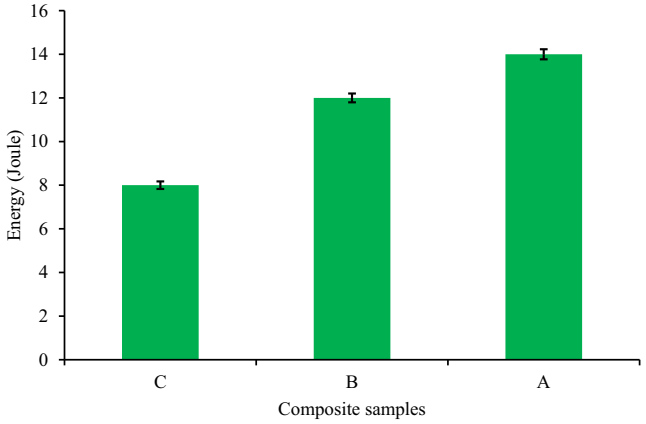

FIGURE 6 Effect of fiber loading on impact strength of snake plant fiber/epoxy composites.

3.5 | Impact energy test

The impact energy test is commonly used to evaluate the impact resistance and toughness of materials. This impact energy test provides information about the material's ability to absorb energy and resist fracture under sudden impact or dynamic loading conditions. The average value, standard deviation, and coefficient of variation of impact energy of snake plant fiber/epoxy composites are mentioned in Table 2. Figure 6 indicates the effect of fiber loading on impact strength of snake plant fiber/epoxy composites.

The impact strength of three composites with different compositions was compared, and it was found that a higher fiber loading improves the impact strength. In tensile test section, it was proved that higher fiber loading % results in higher tensile strength of the composites. And more fiber content helps to distribute the load along axis of the composites therefore, for more fiber content impact strength is more and for lower fiber content impact strength is lower. Composite A, which had 30% STF in the entire amount of fiber and epoxy, exhibited the highest impact strength of 14 J. This was followed by the composite reinforced with 20% STF, which had an impact strength of 12 J, and the composite reinforced with 10% STF, which had an impact strength of 8 J. The improvement in impact strength for composite A compared to composite B and composite C was approximately 17% and 75%, respectively. Additionally, the improvement in impact strength for composite B compared to composite C was approximately 50%.

3.6 | Water absorption analysis

Water absorption increases the weight of the composite due to the incorporation of water molecules. This weight gain can lead to a decrease in the specific strength (strength-to-weight ratio) of the material, potentially affecting its suitability for certain applications, particularly those where weight is a critical factor. Figure 7 depicts the water absorbency of different composites of snake plant fiber. The results were recorded at 6 h interval until the end of the observation, that is, 60 h. The initial sample weight was 3 g for all samples.

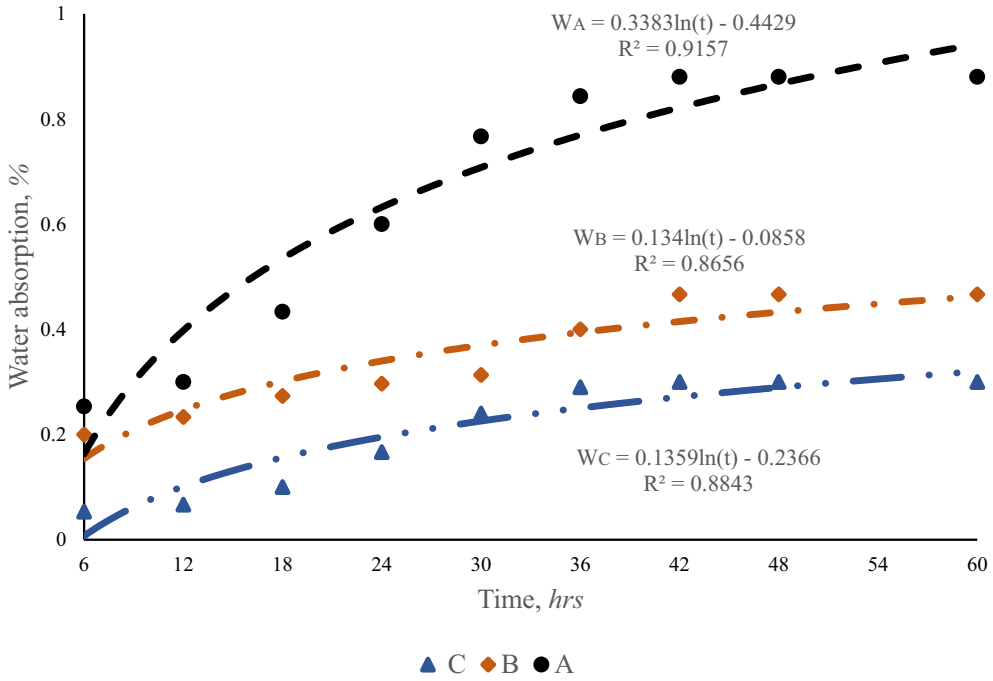

FIGURE 7 Effect of fiber loading on water absorbency of snake plant fiber/epoxy composites.

In all observations, the dependence of the water absorption on the soaking time has a logarithmic character (coefficient of determination R^2 varies between 0.8656 and 0.9157).

Composite A has shown best water absorbency than the two other samples in different time ranges. This is attributed to the higher percentage of fiber in composite A. The increase in fiber content directly increases the water absorbency of composite.[35] Because sample with higher fiber loading % provides more pores and voids, which helps to absorbs more water and vice-versa. Therefore, for sample B, water absorbency is lower than sample A and for sample C, water absorbency is lower than previous two. As the soaking time increased, it was observed that the sample weight also increased, leading to a subsequent increase in water absorbency. Additionally, in STF, the —OH group forms hydrogen bonds that are responsible for water absorption.[36] The experiment determined that the saturation point occurs at 42 h after initiation. Once this point is reached, the composite material can no longer absorb any more water. The excessive water absorbency frequently impedes the enhancement of mechanical properties in composites.[37]

4 | CONCLUSION

The application of snake plant fibers as a reinforcing agent in composite materials has shown great promise as a sustainable and eco-friendly alternative to traditional composites. The FTIR test confirmed the identification of different compounds and particles, as well as their bonding. The SEM test clearly revealed the fiber matrix orientation, bonding and fracture mechanism indicating that the snake plant fibers had good compatibility with the matrix. Furthermore, the mechanical properties of snake plant composites (tensile strength, bending strength, and impact resistance) have been found to be improved with increasing fiber loading. According to the analysis, composite A provided a higher tensile strength (6.99 MPa), flexural strength (10.77 MPa), and impact resistance (14 J) than the other two composites. Composite A also had higher tensile modulus (357 MPa) and flexural modulus (48 MPa) compared to composite B (tensile modulus: 264 MPa; flexural modulus: 14.8 MPa) and composite C (tensile modulus: 205 MPa; flexural modulus: 14.8 MPa). However, it is worth noting that increasing fiber content also led to higher water absorbency, which may be undesirable in certain applications as it negatively affects mechanical properties. After 42 h of soaking, composite A had a water absorbency of 0.88%, while composite B and composite C had absorbencies of 0.47% and 0.3%, respectively. In conclusion, composite A demonstrated superior tensile, flexural, impact resistance properties along with higher water absorbency results compared to composites B and C. This suggests that increasing fiber content improves the overall properties of the composite material but may also increase water absorbency levels.

However, further research is necessary to enhance the fiber-matrix interface and explore the various physical, mechanical, chemical, and thermal properties of

composites under different processing conditions. Subsequent efforts should focus on comprehensively understanding the complete physical and chemical compositions, developing innovative fabrication techniques, conducting in-depth investigations into thermal characteristics, evaluating the lifecycle, collection of fiber from source to recycling from discarded waste, circular recycling and cost factors associated with composites, mainly the production cost. The cost of natural fibers normally is higher than synthetic fibers as natural fibers require additional process of extracting from natural sources to pretreatment.

AUTHOR CONTRIBUTIONS

Kaniz Fatima Mishfa, Md. Abdul Alim, and Md. Reazuddin Repon have contributed to conceptualization, methodology, data collection, and original draft preparation. MD Habibullah and Mohd Abir Hossen Tonmoy have contributed to data collection and analysis. Sigita Jurkonienė and Sharof Shukhratov contributed to editing and reviewing. Md. Reazuddin Repon has supervised all stages of preparing the manuscript. All authors have read and agreed to the published final version of this manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors have no relevant conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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