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ORIGINAL ARTICLE

Mechanical behavior of snake grass fiber with neem gum filler hybrid composite

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Abstract

In this study, the utilization of neem gum powder and snake grass fiber, gathered from snake grass plants is discussed. The fibers are produced in various volume percentages of 5, 10, 15, 20, 25, 30 and 35% and their mechanical characteristics such as tensile strength, flexural strength, impact strength, and critical stress intensity are investigated. The combination of 30% snake grass fiber, 15% neem gum powder and 55% epoxy resin, in terms of volume, contributes towards the attaining of better mechanical properties. The tensile strength, flexural strength, impact strength, and critical stress intensity of this blend are respectively 36.497±0.429 MPa, 65.87±1.85 MPa, 2682.67±1.866 J/m^2 and 42.291±2.61 Pa mm$^{-1/2}$. The mechanical properties improve with the addition of the fiber. However, as more fiber is added, the adhesion at the interface gets reduced. The automotive and aerospace sectors can use this composite material, which enhances the mechanical characteristics for interior applications.

Keywords: *critical stress intensity, flexural strength, hybrid composite, impact strength, neem gum powder filler.*

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1. Introduction

A composite is a mixture of two materials, of which one is the reinforcing phase and the other is the matrix in which it is embedded. Metal, ceramic, and polymer are all acceptable choices for the matrix and reinforcing materials. Unlike metallic alloys, each material added to the composite maintains its original chemical, physical, and mechanical properties. These composite materials are also widely known for their excellent strength, stiffness, and low density. The primary load-bearing components of composites typically consist of a fiber or particle phase that is stiffer and more powerful than the continuous matrix phase. The matrix serves as the source of the composite as it is more ductile than the fibers.

Materials comprised of two or more physically and chemically distinct phases that are separated by an interface are known as composites[1,2]. The diverse phases are combined to produce composites that perform like the individual components in terms of structural or functional quality[3]. In terms of weight, rust resistance, fatigue strength, and ease of installation, composite materials are superior to non-composite materials[4,5]. Composites are used in the manufacture of transmission towers, electrical gadgets and packing materials, spacecraft, medical equipment, and aircraft structures[6]. Natural fiber and biodegradable polymers are used to create bio-based green composites, which are further classified into hybrid and textile composites[7]. Currently, natural fibers are more often used in the manufacturing of PMC for a range of functions, including structural ones[8]. Natural fibers are produced by plants, animals, and minerals. Due to their accessibility, environmental friendliness, degradability, and renewability, plant fibers have caught the attention of scientists, researchers, and engineers[9]. Abnormally formed fibers may get deboned and start to break apart from one another at lower loads, which cause fibrillation[10]. The fiber treatment is an alternative, for increasing the fiber surface area, chemical bonding, and interface adhesion between matrices of natural fiber[11]. The effect of sequential placing of fiber mats on the improvement of natural fiber (sisal, aloe Vera, and flax) hybrid composite qualities have also been recently studied by Balasubramanian et al.[12]. The effect of Barium sulfate on the mechanical, DMA, and thermal behavior of woven aloe vera /flax hybrid composites were investigated by Arulmurugan et al.[13]. The impact properties new hybrid composite material made of woven flax and carbon fibers in an epoxy matrix was the subject of an investigation by Al-Hajaj et al.[14]. Many researchers have shown interest in the use of natural fibers as reinforcement in polymer matrix composites, such as kenaf fiber[15]. Characterization of the failure surface, impact, and inter laminar strength has been investigated on hybrid composites[16]. So far, studies have been carried out on how the different fiber loadings affect the flexural and thermal properties of banana leaf hybrid composites[17]. In composites containing 50% fiber, the flexural strength, modulus of elasticity (MOE), and tensile strength have all been increased[18]. The matrix-to-reinforcement ratio had a big impact on the performance of sugar palm composites[19].

The best mechanical properties were attained by the composite specimen with a 10 mm fiber length and a 15 percent fiber loading[20]. Changes in fiber orientations will have a significant impact on the storage modulus, loss tangent, and other mechanical parameters that are investigated[21]. It has been shown that jute fibers may be chemically treated to enhance matrix-fiber adhesion by increasing the interfacial bonding with the polymer matrix, which in turn improved the composites' tensile properties[22]. Natural fiber reinforced polymer composite materials are used to make wind turbine blades[23]. Unsaturated polyester hybrid composites bonded with sugar palm yarn and glass fiber have been developed for use in automobile components[24]. Fiber orientation and loading have an impact on the mechanical and thermal characteristics of composites that are reinforced with sugar palm yarn and an unsaturated polyester resin[25]. Bio composites must possess the desired qualities in order to displace synthetic fiber-reinforced composites for being used in new industrial applications[26]. Natural fibers are used in automobile structures because of their moderate tensile strength, better stiffness, and high damping capability[27]. Natural fiber-reinforced composites are intended for lowering vibration and noise levels, in addition to component weight when used in automotive applications. Additionally, composites have exceptional resistance to corrosion and fatigue[28]. One of the hybrid composites, specimen D, has 20% weight of snake grass fibre, with increased tensile strength. However, when the snake grass fibre content is increased, the tensile strength got abruptly decreased. The findings suggest that the alkali treatment enhances the elastic behavior and boosts the material's resilience to failure. The elastic region is formed when the strain rate is reduced and above this region, the specimen experiences plastic deformation. This behaviour due to the resin in the area which begins to deform plastically, causing it to produce small cracks[29]. Hybrid composites made by Rangaraj et al. [30] with 20% weight of snake grass and 10% weight of areca fibre provided the highest tensile, flexural, impact, and hardness values[30]. In the hardness test, fiber-reinforced polyester composite materials that have been calcium carbonate-treated, have the highest hardness values, scoring 27 BHN, outperforming untreated snake grass fiber-reinforced polyester composite materials by more than 50%. The calcium carbonate-treated reinforced composite has a high mean ultimate strength of 45.335 N/mm^2 according to the tensile test. A fiber-reinforced composite coated with calcium carbonate has high impact strength of 3.35 J. A fiber-reinforced composite that has been treated with Ca2CO3 has a high ultimate flexural strength of 4.5 N/mm^2[31]. The composites demonstrated that at 30% fibre volume, the maximum mechanical characteristics are obtained. Additionally, adding silica nano filler improved the inter laminar structure's cohesive strength. The material is strengthened by these behavioral changes at the ideal concentration of 30% hybrid fibers and 3% nano silica[32]. The outcomes showed that banana fibre with 20% by weight produced good results, maintaining the mechanical strength values at the desired level[33]. SiO_2 and B_4C significantly increase the tensile, flexural, and impact strength of snake grass fiber, according to research by Hariprasad et al.[34]. To create a new composite, Kevlar and Napier grass fibres are reinforced with epoxy matrix, and it was assessed that sample A had the highest mechanical strength[35]. The tensile, flexural, interlaminar shear, impact, and hardness of the natural fibre reinforced hybrid composite, which combines jute, snake grass, and kenaf fibres as reinforcement with varying fibre quantities, were evaluated in this research effort. Additionally, by adding Annona reticulata (custard apple) seed powder as a filler, the hybrid composites' wear behaviour was improved. This analysis showed that the sample, which contains kenaf fibre (without filler) and snake grass in similar amounts (12.5% of each), had outstanding mechanical properties. The sample with 5 wt% filler exhibits a lower wear rate than other samples in terms of wear behavior[36]. The tensile, compression, and flexural properties of the epoxy hybrid composites reinforced with banana and snake grass fibres were examined for various stacking orders. To achieve greater interfacial strength, the fibres were properly treated with an alkali solution[37]. The investigations showed that, up to a 20% increase in weight of African tefl fibre, the mechanical qualities increased before degrading. Additionally, it has been shown that natural fibres and bio castor seed shell powder had a stronger combined effect on the mechanical qualities[38]. The chair made of snake grass fiber-reinforced polymer composites is manufactured and utilised in place of wood chairs in commercial settings. The mechanical characteristics, including flexural and compressive strength, as well as the water absorption with time, have been studied. These characteristics are contrasted with those of SAL wood, and the conclusions arrived at are listed[39]. From the study of this literature survey, it is understood that the nature of composite extraction, processing techniques and their change in the chemical and the mechanical properties with different composition of materials is utilized for various applications. Also, it is inferred that snake grass fiber acts as the best alternative for glass fiber in all its applications. Neem gum powder as a filler is used in the biomedical field for making prosthetics, and dentistry. A Combination of neem gum powder with snake grass fiber will open the way to many more applications in both mechanical and biomedical fields.

2. Materials and Methods

2.1 Materials

2.1.1 Snake grass fiber

The southernmost state of India, Tamil Nadu has an abundance of snake grass from which fibers are extracted using a straightforward water retting method. It is succulent and extremely thick with sturdy leaves that hold the water. The extracted snake grass fibers are used as reinforcement in fabricating composites.

2.1.2 Neem gum (filler)

The Neem tree when scratched, naturally yields neem gum. Neem gum is a non-bitter substance that is soluble in cold water and it is clear and amber in color. It is a biodegradable natural filler substance which is inexpensive and widely accessible. The parameters of the neem gum powder taken for this study are, particle size ranging from 1 to 15 microns, tensile strength of 12.5 MPa, flexural strength of 18.1 MPa, impact energy of 1 joule, and density of 1.08 g/cm^3.

Different volume fractions of Acacia Nilotica bio filler were used to create composite specimens. The effects of filler loading and chemically treated reinforced fibers influenced the mechanical properties of the composites. When the bio filler content in the polyester matrix increased from 15% to 20% of volume fractions, a little decrease in the mechanical properties was noticed. This could be because the bio filler agglomerates in the composite material at higher volume fractions[40]. In the present investigation, neem gum powder has been used as a bio filler with a 15% volume fraction, because it was found after reading numerous texts on the subject that higher composite characteristics could only be attained below this level.

2.1.3 Epoxy resin (matrix)

One of the most important roles played by the resins or matrix in a polymer composite is binding the reinforcements together, maintaining the shape of a component, and passing applied loads to the reinforcing fibers. It protects the reinforcing fibers from abrasion and damaging the environment. Despite its widespread use, thermosetting plastics like polyester and epoxy resins help in determining the mechanical properties of composites. Epoxy resin serves as the paper's matrix material. Epoxy resins outperform polyester resins in terms of strength and cost, whereas Polyester resins are less susceptible to moisture absorption than epoxy resins. Resins adhere to glass and organic fibers quite well. The LY556 epoxy and the HY951 hardener, with density values of 1.15–1.20 g/cm^3 and 0.97–0.99 g/cm^3 respectively are combined to create the composite plate. The weight ratio of the hardener to epoxy is 10:1.

2.2 Methods

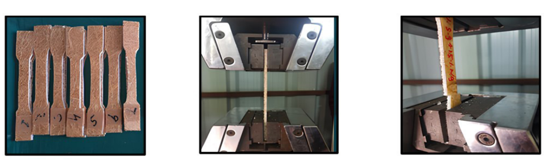
A simple hand lay-up method is utilized to create the composite plate with different volume percentages of fiber, such as 5%, 10%, 15%, 20%, 25%, 30%, and 35%.The fiber volume percentage varies according to the matrix and fiber densities. The male and female steel dies are used to create the composite plates. The male and female portions of the die are initially coated with a releasing agent to facilitate the removal of the specimens after the solidification procedure. The fibers are laid one by one over the resin on the female die. This is followed by sealing the mold, putting it in a hydraulic press, and applying 5 bars of compressive pressure for 4 hours at 30°C ambient temperature. In the 300 x 300 x 3 mm mold chamber, the matrix is used to reinforce the fibers. Table 1 provides a detailed of the composites' volume percentage used in this work.

Tensile testing was done on the composite in accordance with ASTM D638 at a test speed of 5 mm/min utilizing TinusOlesan UTM. The specimens (a) The equipment used for testing and Specimen before (b) and Specimen after fracture (c) are shown in Figure 1.

Flexural testing of the composite was carried out using the Tinus Olesan UTM in the three-point bending mode in compliance with the ASTMD790 standard. Specimen Dimensions: Thickness (d) = 4mm, Width (b) =13 mm, Support Span (L) = 52 mm, $\sigma f = 3FL/2bd^2$ where, σf = Flexural Strength F = Break load (value taken from graph.) Figure 2 shows the Flexural testing samples (a), Equipment used for testing and specimen before fracture (b) and specimen after fracture (c)

Table 1. Composition of all volume percentages of the composites.

S. No	Snake grass fiber(%)	Neem Gum Powder(%)	Epoxy(%)
Sample 1	5	15	80
Sample 2	10	15	75
Sample 3	15	15	70
Sample 4	20	15	65
Sample 5	25	15	60
Sample 6	30	15	55
Sample 7	35	15	50



(a) Specimens
(b)The equipment used for testing and Specimen before fracture
(c) Specimen after fracture

Figure 1. Various composition specimens and test setup for testing of tensile properties of hybrid composites.

(a) Flexural Testing Samples
(b) Equipment used for testing and specimen before fracture
(c) Specimen after fracture

Figure 2. Various composition specimens and test setup for testing of flexural properties of hybrid composites.

Using impact testing equipment, the ASTM D256 standard calls for Izod mode impact testing of the composite was carried out. Specimen Dimensions: Width (b) = 13.1 mm, Thickness (t) = 3.2 mm, area = 13.1 × 3.2 = 41.92 mm^2, Izod Impact Value = 0.6 J, Impact Strength = (0.6/41.92) × 1000 = 14.31 N-mm/mm^2. Figure 3 displays the testing samples.

According to ASTM D709 standards, the crack is in the opening mode, which is a tensile stress normal to the crack's plane. The Formula for calculating the fracture toughness factor for stress intensity K can be used to estimate the fracture toughness.

It relies on (i) the load, (ii) Flow depth and (iii) the Geometry

Critical stress intensity factor for mode 1 is

$$K_{ic} = \frac{P}{B\sqrt{W}}\left\{F\left(\frac{A}{W}\right)\right\}[30] \quad (1)$$

$$\left\{F\left(\frac{A}{W}\right)\right\} = \frac{2+\left(\frac{A}{W}\right)}{\left(1-\frac{A}{W}\right)^{1.5}} \left\{\begin{matrix} 0.866+4.66\left(\frac{A}{W}\right)-13.32\left(\frac{A}{W}\right)^2 \\ +14.72\left(\frac{A}{W}\right)^3-5.6\left(\frac{A}{W}\right)^4 \end{matrix}\right\} \quad (2)$$

Where F(A/W)- geometry crack length factor, P is the load at which the first crack appears, B is the test specimen's thickness, w is the specimen's length, and A is the initial crack size. The test samples are cut into the required dimensions as shown in Figure 4a and 4b displays the testing samples.

3. Results and Discussions

Five samples per composition were tested and the average values of mechanical properties with standard deviation are shown in Tables 2, 3, 4 and 5.

Standard Deviation for each composition of five samples for all mechanical properties are calculated using the formula

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X_i-\mu\right)^2} \quad (3)$$

σ = Population standard deviation

N = Number of observations in population

X_i = i^{th} observation in the population

μ = Population mean

Figure 3. Various composition specimens for testing of impact strength of hybrid composites.

Table 2. Tensile test results.

SAMPLE ID	BREAK LOAD (N)	TENSILE STRENGTH (MPa)	TENSILE MODULUS (MPa)
Sample 1	520± 3.033	13.460±0.073	562.820±3.35
Sample 2	614±2.828	16.075± 0.118	591.871± 3.87
Sample 3	755± 2.93	20.063±0.105	695.763±2.83
Sample 4	870+± 2.39	23.038± 0.292	794.488± 2.11
Sample 5	950± 2.40	29.713± 0.517	898.378± 3.66
Sample 6	1010± 2.60	36.497± 0.429	1082.712± 2.58
Sample 7	915±3.60	24.303± 0.320	943.854± 4.12

Table 3. Flexural test results.

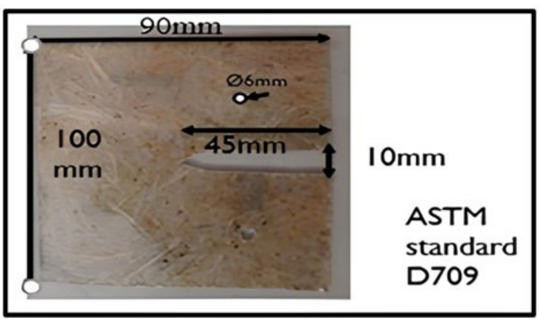
SAMPLE ID	BREAK LOAD (N)	Flexural Strength(MPa)	Flexural Modulus (MPa)
Sample 1	54.986± 2	20.62± 1.96	1652.820± 3.87
Sample 2	63.317± 3.6	23.75± 2.4	1681.871± 2.01
Sample 3	76.647±2.2	28.75± 2.58	1765.763± 3.17
Sample 4	107.626±2.2	40.37± 1.41	1874.488± 2.86
Sample 5	140.631±1.83	52.75± 2.58	1898.378± 3.162
Sample 6	175.609± 3.13	65.87±1.85	1952.712± 2.46
Sample 7	71.635± 2.64	26.87± 1.96	1743.854± 3.288

Table 4. Impact test results.

SAMPLE ID	Impact Energy (J)	Impact Strength (J /m^2)
Sample 1	0.6± 0.1609	2214.31± 0.265
Sample 2	0.8± 0.1135	2319.08± 0.293
Sample 3	1.5± 0.172	2429.27± 0.426
Sample 4	2.4± 0.219	2555.41±1.744
Sample 5	4.11± 0.273	2593.85± 2.338
Sample 6	5.5± 0.231	2682.67± 1.866
Sample 7	3.3±0.313	2667.16± 1.721

Table 5. Mode I fracture test result.

SAMPLE No	Ult. Stress (MPa)	Displacement (mm)	Peak Load (N)	Critical Stress Intensity Factor (KIC) (Pa mm$^{-1/2}$)
Sample 1	17.81 ±2.228	2.1±0.279	140±1.853	19.125±1.469
Sample 2	25.434±-2.28	2.5± 0.141	145± 2.316	20.252±2.059
Sample 3	30.22±2.115	2.9± 0.256	185± 2.786	22.561±1.853
Sample 4	33.274± 2.5	3.2± 0.185	205± 3.349	25.005± 1.414
Sample 5	38.21±2.961	3.8± 0.261	215± 2.786	33.213± 2.315
Sample 6	44.232±1.28	4.2±0.287	235± 2.442	42.291±2.61
Sample 7	30.42 ±1.766	4.8± 0.311	285±3.547	50.664± 1.744



(a) Testing Samples cut required dimensions

(b) Testing samples

Figure 4. Various composition specimens for testing of mode I crack test of composites.

3.1 Tensile property

Measurements of the tensile properties of the various fiber volume percentages in the hybrid composites are made. With every 5% increase in volume of Snake grass fiber in the hybrid composites, the tensile strength gradually increases. Figure 5 and Table 2 demonstrate that the composition of 30% snake grass fiber, 15% neem gum powder and 55% epoxy resin achieve the maximum tensile strength and tensile modulus of 36.497±0.429 MPa & 1082.712±2.58 MPa respectively, which are higher than the corresponding values of 14.02 MPa & 960.621 MPa obtained by Vimalanathan et al.[41] and 3.56 MPa & 1023 MPa by Palanikumar et al.[42], due to the increased interfacial adhesion between the fiber and the matrix. A further increase in the fiber volume percentage in hybrid composites to 35% causes a decline in the tensile properties due to insufficient bonding between the fiber and the matrix as shown in the SEM image in Figure 6.

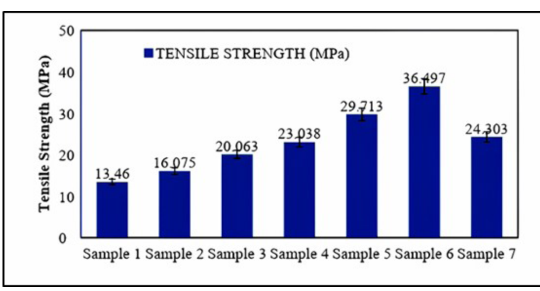


Figure 5. Comparison of tensile strength for various composition specimens of hybrid composite.

3.2 Flexural property

The flexural properties of the hybrid composites are evaluated for each fiber volume percentage.

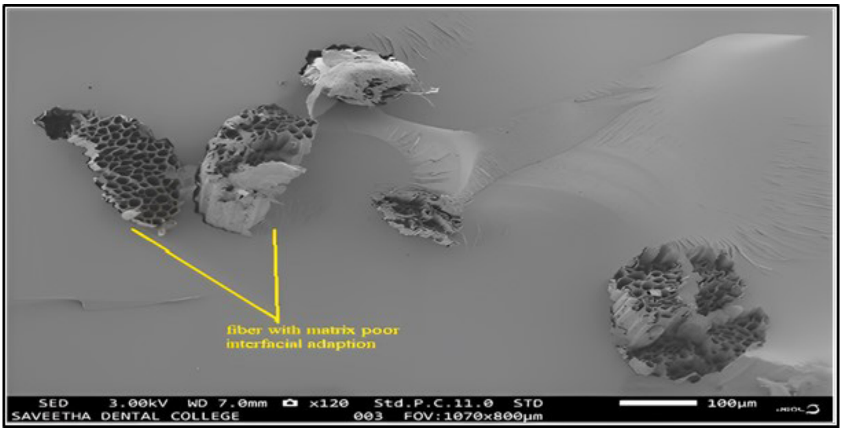


Figure 6. SEM image of 35% snake grass fiber with matrix poor interfacial adaption.

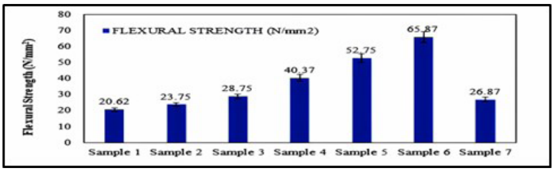


Figure 7. Comparison of flexural strength for various composition specimens of the hybrid composite.

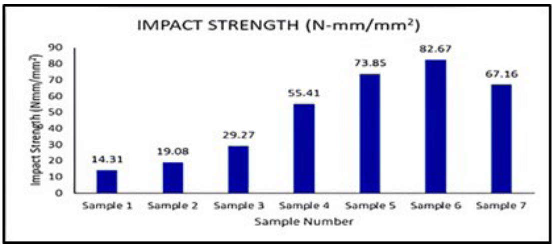


Figure 8. Comparison of izod impact strength for various composition specimens of the hybrid composite.

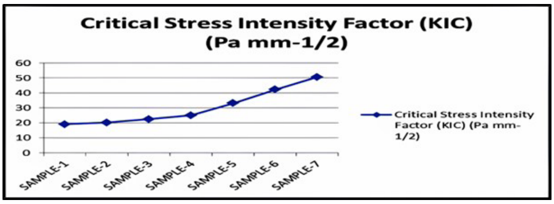


Figure 9. Comparison of critical stress intensity factor for various composition specimens of the hybrid composite.

The Flexural strength increases gradually with every 5% increase in the volume of Snake grass fiber in the hybrid composites. The mixture of 30% snake grass fiber, 15% neem gum powder and 55% epoxy resin was found to have the highest flexural strength and flexural modulus of 65.87±1.85 MPa and 1952.712±2.46 MPa respectively, which are higher than the corresponding values of 26.16 MPa and 1810 MPa obtained by Vimalanathan et al.[41] and 27.26 MPa and 1873 MPa by Palanikumar et al.[42], due to better interfacial adhesion between the fiber and the matrix. The best results are obtained by Sample 6 (30% snake grass fiber), as shown in Figure 7 and Table 3. Flexural strength is observed to decrease as the fiber volume percentage is increased in hybrid composites made of 35% snake grass fiber, 15% neem gum, and 50% epoxy resin due to an inadequate bonding between the fiber and the resin.

3.3 Impact property

The hybrid composite's impact characteristics are measured for each fiber volume percentage. Every 5% increase in volume of the snake grass fiber in hybrid composites results in a progressive rise in the impact strength. It has been noted that stronger interfacial adhesion between the fiber and the matrix on the composition of 30% snake grass fiber, 15% neem gum powder and 55% epoxy resin attained the maximum impact strength of 2682.67 ±1.866 J/m^2 which is higher than the value of 2500 J/m^2 obtained by Vimalanathan et al.[41] and 2671 J/m^2 by Palanikumar et al.[42]. Sample 6 (30% snake grass fiber) produces the highest results as seen in Figure 8 and Table 4. Due to the poor bonding between the fiber and the resin in the composition of 35% snake grass fiber, 15% neem gum, and 50% epoxy resin, it was noticed that further increasing the fiber volume percentage in hybrid composites causes a drop in the impact strength.

3.4 Mode I fracture

In the Mode I fracture test, the hybrid composite' fracture properties were measured for different fiber volume fractions. With every 5% increase in volume of Snake grass fiber in hybrid composites, the Critical Stress Intensity Factor and the Ultimate Stress increased rapidly. Due to improved interfacial adhesion between the fiber and the matrix, it was seen that the composition of 30% snake grass fiber, 15% neem gum powder, and 55% epoxy resin gave the highest ultimate strength of 44.232 ±1.28 MPa and Critical Stress Intensity Factor of 42.291±2.61 Pa mm$^{-1/2}$. Figure 9 and Table 5 demonstrate that sample 6 (30% snake grass fiber) produces the best outcome. The ultimate strength drops when the fiber content in hybrid composites is increased further.

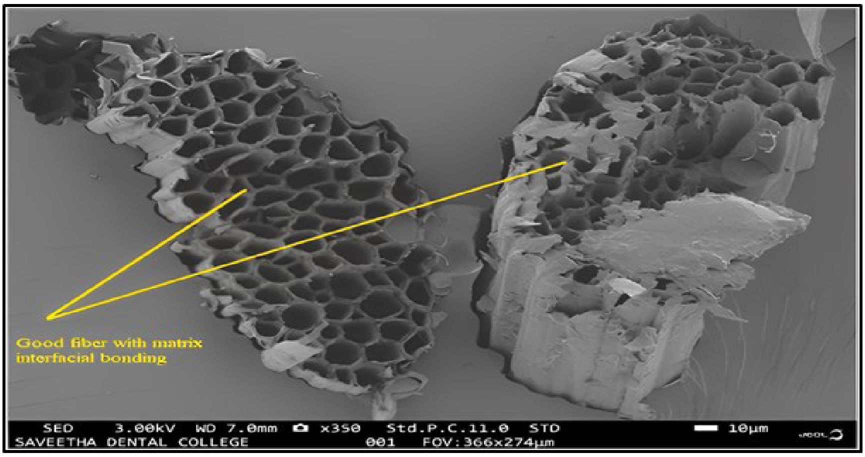


Figure 10. SEM image of 30% snake grass fiber with good matrix interfacial bonding.

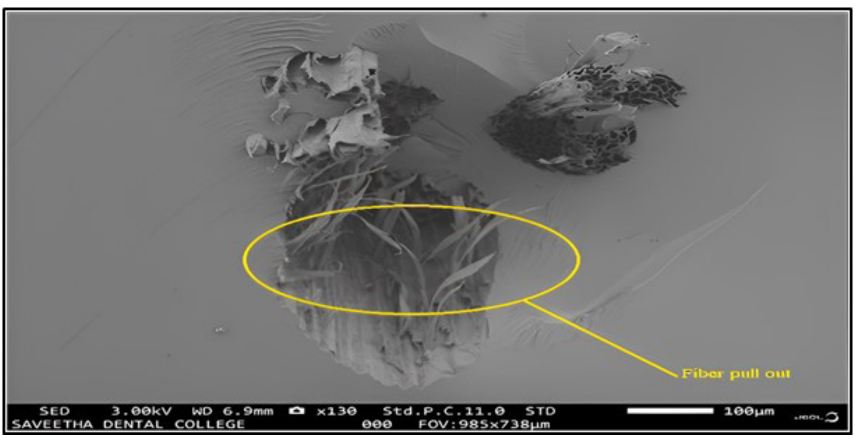


Figure 11. SEM image of 35% snake grass fiber breakage and fiber pull out.

Figure 10 shows the existence of good adhesion between the fiber and the matrix. A strong interface permits the composite to withstand the applied load even if multiple fibers break the load, which can be transferred by the integral portion of the fibers, which in turn increases the mechanical strength.

The fiber pullout and fiber breakage of the tensile fracture and impact fracture of the composite specimens have been examined using a scanning electron microscope (SEM). Fiber pullout and fiber breakage are evidently noticed on 35% snake grass fiber, in the fiber binding zone. Flexural strength and tensile strength were tested for fiber pullout and fiber breakage are evident in Figure 11. With further increase in the fiber volume fraction, the tensile strength and flexural strength start reducing, due to fiber agglomeration at higher volume fraction. Further, clustering of fiber leads to poor wetting of the fiber by the matrix and hence there is a poor bonding between the fibers[19]. This results in reduction in the mechanical properties.

Similar effect was noticed in this case due to poor interfacial bonding also, at higher volume fraction, as shown in Figure 6.

4. Conclusion

Tests were conducted to evaluate the effect of fiber volume percentage and filler on the mechanical properties of the hybrid composite. The volume of 30% snake grass fiber with 15% neem gum powder and 55% epoxy resin contributes in achieving better mechanical properties such as tensile strength, flexural strength, impact strength and critical stress intensity factor (KIC) of 36.497±0.429 MPa, 65.87±1.85 MPa, 2682.67±1.866 J/m^2 and 42.291±2.61 Pa mm$^{-1/2}$ respectively. The results show that adding fiber increased the mechanical properties to some extent, but too much of fiber impaired the adhesion at the interface, which in turn reduced the mechanical properties of the composite material. The SEM images Figures 6 and 11 prove it. Stress transfers within the matrix material are made more efficient by the inclusion of the filler material as secondary reinforcement. The benefits of combining this snake grass fiber with other comparable biopolymers in composite applications is found to be substantial. Hence, this new sustainable biodegradable material can be taken up for future research for interior applications in automotive and aerospace industries.

5. Author's Contribution

- **Conceptualization –** Arumugam Pachiappan; Senthil Kumar Velukkudi Santhanam.
- **Data curation –** NA.
- **Formal analysis –** Arumugam Pachiappan.
- **Funding acquisition –** NA.
- **Investigation –** Arumugam Pachiappan; Senthil Kumar Velukkudi Santhanam.
- **Methodology –** Arumugam Pachiappan.
- **Project administration –** Senthil Kumar Velukkudi Santhanam.
- **Resources –** Arumugam Pachiappan; Senthil Kumar Velukkudi Santhanam.
- **Software –** NA.
- **Supervision –** Senthil Kumar Velukkudi Santhanam.
- **Validation –** Senthil Kumar Velukkudi Santhanam.
- **Visualization –** NA.
- **Writing – original draft –** Arumugam Pachiappan.
- **Writing – review & editing –** Senthil Kumar Velukkudi Santhanam.

6. References

1. Ilyas, R. A., Sapuan, S. M., Asyraf, M. R. M., Atikah, M. S. N., Ibrahim, R., Dele-Afolabi, T. T., & Hazrol, M. D. (2020). *Introduction to biofiller reinforced degradable polymer composites*. In R. Jumaidin, S. M. Sapuan & H. Ismail (Eds.), *Biofiller-reinforced biodegradable polymer composites* (pp. 1-23). Boca Raton: CRC Press. http://dx.doi.org/10.1201/9780429322112-1.
2. Sari, N. H., Pruncu, C. I., Sapuan, S. M., Ilyas, R. A., Catur, A. D., Suteja, S., Sutaryono, Y. A., & Pullen, G. (2020). The effect of water immersion and fiber content on properties of corn husk fibers reinforced thermoset polyester composite. *Polymer Testing*, *91*, 106751. http://dx.doi.org/10.1016/j.polymertesting.2020.106751.
3. Sapuan, S. M., Aulia, H. S., Ilyas, R. A., Atiqah, A., Dele-Afolabi, T. T., Nurazzi, M. N., Supian, A. B. M., & Atikah, M. S. N. (2020). Mechanical properties of longitudinal basalt/woven-glass-fiber-reinforced unsaturated polyester-resin hybrid composites. *Polymers*, *12*(10), 2211. http://dx.doi.org/10.3390/polym12102211. PMid:32992450.
4. Ilyas, R. A., & Sapuan, S. M. (2019). The preparation methods and processing of natural fibre bio-polymer composites. *Current Organic Synthesis*, *16*(8), 1068-1070. http://dx.doi.org/10.2174/1570179416082001201056l6. PMid:31984916.
5. Ilyas, R. A., & Sapuan, S. M. (2020). Biopolymers and biocomposites: chemistry and technology. *Current Analytical Chemistry*, *16*(5), 500-503. http://dx.doi.org/10.2174/157341101605200603095311.
6. Asyraf, M. R. M., Ishak, M. R., Sapuan, S. M., Yidris, N., Ilyas, R. A., Rafidah, M., & Razman, M. R. (2020). Potential application of green composites for cross arm component in transmission tower: a brief review. *International Journal of Polymer Science*, *2020*, 8878300. http://dx.doi.org/10.1155/2020/8878300.
7. Atikah, M. S. N., Ilyas, R. A., Sapuan, S. M., Ishak, M. R., Zainudin, E. S., Ibrahim, R., Atiqah, A., Ansari, M. N. M., & Jumaidin, R. (2019). Degradation and physical properties of sugar palm starch/sugar palm nanofibrillated cellulose bionanocomposite. *Polimery*, *64*(10), 680-689. http://dx.doi.org/10.14314/polimery.2019.10.5.
8. Zhao, K., Xue, S., Zhang, P., Tian, Y., & Li, P. (2019). Application of natural plant fibers in cement-based composites and the influence on mechanical properties and mass transport. *Materials*, *12*(21), 3498. http://dx.doi.org/10.3390/ma12213498. PMid:31731435.
9. Jumaidin, R., Khiruddin, M. A. A., Saidi, Z. A. S., Salit, M. S., & Ilyas, R. A. (2020). Effect of cogon grass fiber on the thermal, mechanical and biodegradation properties of thermoplastic cassava starch biocomposite. *International Journal of Biological Macromolecules*, *146*, 746-755. http://dx.doi.org/10.1016/j.ijbiomac.2019.11.011. PMid:31730973.
10. Viel, Q., Esposito, A., Saiter, J.-M., Santulli, C., & Turner, J. (2018). Interfacial characterization by pull-out test of bamboo fibers embedded in poly(lactic acid). *Fibers*, *6*(1), 7. http://dx.doi.org/10.3390/fib6010007.
11. Sepe, R., Bollino, F., Boccarusso, L., & Caputo, F. (2018). Influence of chemical treatments on mechanical properties of hemp fiber reinforced composites. *Composites. Part B, Engineering*, *133*, 210-217. http://dx.doi.org/10.1016/j.compositesb.2017.09.030.
12. Balasubramanian, K., Rajeswari, N., & Vishvak, R. (2020). Influence of sequential positioning of fiber mats in enhancing the properties of natural fiber mat hybrid composite. *Materials Today: Proceedings*, *28*(Part 2), 1144-1148. http://dx.doi.org/10.1016/j.matpr.2020.01.097.
13. Arulmurugan, M., Selvakumar, A. S., Prabu, K., & Rajamurugan, G. (2020). Effect of barium sulfate on mechanical, DMA and thermal behavior of woven aloe vera/flax hybridcomposites. *Bulletin of Materials Science*, *43*(1), 58. http://dx.doi.org/10.1007/s12034-019-2018-7.
14. Al-Hajaj, Z., Sy, B. L., Bougherara, H., & Zdero, R. (2019). Impact properties of a new hybrid composite material made from woven carbon fibres plus flax fibres in an epoxy matrix. *Composite Structures*, *208*, 346-356. http://dx.doi.org/10.1016/j.compstruct.2018.10.033.
15. Manap, N., Jumahat, A., Rahman, N. A., & Rahman, N. A. A. (2020). NaOH treated Kenaf/Glass hybrid composite: the effects of nanosilica on longitudinal and transverse tensile properties. *Journal of Physics: Conference Series*, *1432*(1), 012046. http://dx.doi.org/10.1088/1742-6596/1432/1/012046.
16. Sanjay, M. R., Arpitha, G. R., Senthamaraikannan, P., Kathiresan, M., Saibalaji, M. A., & Yogesha, B. (2019). The hybrid effect of jute/kenaf/E-glass woven fabric epoxy composites for medium load applications: impact, interlaminar strength, and failure surface characterization. *Journal of Natural Fibers*, *16*(4), 600-612. http://dx.doi.org/10.1080/15440478.2018.1431828.
17. Zin, M. H., Abdan, K., & Norizan, M. N. (2019). *The effect of different fiber loading on flexural and thermal properties of banana/pineapple leaf (PALF)/glass hybrid composite*. In M. Jawaid, M. Thariq & N. Saba (Eds.), *Structural health monitoring of biocomposites, fibre-reinforced composites and hybrid composites* (pp. 1-17). Amsterdam: Elsevier. http://dx.doi.org/10.1016/B978-0-08-102291-7.00001-0.
18. Richard, B. D., Wahi, A., Nani, R., Lling, E., Osman, S., & Ali, D. S. H. (2019). Effect of fiber loading on the flexural and tensile strength of oil palm frond fiber reinforced polymer composite. *International Journal of Integrated Engineering*, *11*(7), 122-128. http://dx.doi.org/10.30880/ijie.2019.11.07.016.
19. Baihaqi, N. M. Z. N., Khalina, A., Nurazzi, N. M., Aisyah, H. A., Sapuan, S. M., & Ilyas, R. A. (2021). Effect of fiber content and their hybridization on bending and torsional strength of hybrid epoxy composites reinforced with carbon and sugar palm fibers. *Polimery*, *66*(1), 36-43. http://dx.doi.org/10.14314/polimery.2021.1.5.
20. Karthick, R., Adithya, K., Hariharaprasath, C., & Abhishek, V. (2018). Evaluation of mechanical behavior of banana fiber reinforced hybrid epoxy composites. *Materials Today: Proceedings*, *5*(5), 12814-12820. http://dx.doi.org/10.1016/j.matpr.2018.02.265.

21. Doddi, P. R. V., Chanamala, R., & Dora, S. P. (2020). Effect of fiber orientation on dynamic mechanical properties of PALF hybridized with basalt reinforced epoxy composites. *Materials Research Express*, *7*(1), 015329. http://dx.doi.org/10.1088/2053-1591/ab6771.
22. Wang, H., Memon, H., Hassan, E. A. M., Miah, M. S., & Ali, M. A. (2019). Effect of jute fiber modification on mechanical properties of jute fiber composite. *Materials*, *12*(8), 1226. http://dx.doi.org/10.3390/ma12081226. PMid:30991643.
23. Kalagi, G. R., Patil, R., & Nayak, N. (2018). Experimental study on mechanical properties of natural fiber reinforced polymer composite materials for wind turbine blades. *Materials Today: Proceedings*, *5*(1), 2588-2596. http://dx.doi.org/10.1016/j.matpr.2017.11.043.
24. Nurazzi, N. M., Khalina, A., Sapuan, S. M., & Rahmah, M. (2018). Development of sugar palm yarn/glass fiber reinforced unsaturated polyester hybrid composites. *Materials Research Express*, *5*(4), 045308. http://dx.doi.org/10.1088/2053-1591/aabc27.
25. Nurazzi, N. M., Khalina, A., Chandrasekar, M., Aisyah, H. A., Rafiqah, S. A., Ilyas, R. A., & Hanafee, Z. M. (2020). Effect of fiber orientation and fiber loading on the mechanical and thermal properties of sugar palm yarn fiber reinforced unsaturated polyester resin composites. *Polimery*, *65*(2), 115-124. http://dx.doi.org/10.14314/polimery.2020.2.5.
26. Ayu, R. S., Khalina, A., Harmaen, A. S., Zaman, K., Isma, T., Liu, Q., Ilyas, R. A., & Lee, C. H. (2020). Characterization study of Empty Fruit Bunch (EFB) fibers reinforcementin Poly(Butylene) Succinate (PBS)/starch/glycerol composite sheet. *Polymers*, *12*(7), 1571. http://dx.doi.org/10.3390/polym12071571. PMid:32679865.
27. Balla, V. K., Kate, K. H., Satyavolu, J., Singh, P., & Tadimeti, J. G. D. (2019). Additive manufacturing of natural fiber reinforced polymer composites: processing and prospects. *Composites. Part B, Engineering*, *174*, 106956. http://dx.doi.org/10.1016/j.compositesb.2019.106956.
28. Sathish, S., Prabhu, L., Gokulkumar, S., Karthi, N., Balaji, D., & Vigneshkumar, N. (2021). Extraction, treatment and applications of natural fibers for bio-composites - a critical review. *International Polymer Processing*, *36*(2), 114-130. http://dx.doi.org/10.1515/ipp-2020-4004.
29. Sathish, S., Kumaresan, K., Prabhu, L., & Vigneshkumar, N. (2017). Experimental investigation on volume fraction of mechanical and physical properties of flax and bamboo fibers reinforced hybrid epoxy composites. *Polymers & Polymer Composites*, *25*(3), 229-236. http://dx.doi.org/10.1177/096739111702500309.
30. Rangaraj, R., Sathish, S., Mansadevi, T. L. D., Supriya, R., Surakasi, R., Aravindh, M., Karthick, A., Mohanavel, V., Ravichandran, M., Muhibbullah, M., & Osman, M. (2022). Investigation of weight fraction and alkaline treatment on *Catechu Linnaeus/Hibiscus cannabinus/Sansevieria Ehrenbergii* plant fibers-reinforced epoxy hybrid composites. *Advances in Materials Science and Engineering*, *2022*, 4940531. http://dx.doi.org/10.1155/2022/4940531.
31. Jenish, I., Sahayaraj, A. F., Appadurai, M., Raj, E. F. I., Suresh, P., Raja, T., Salmen, S. H., Alfarraj, S., & Manikandan, V. (2021). Fabrication and experimental analysis of treated snake grass fiber reinforced with polyester composite. *Advances in Materials Science and Engineering*, *2021*, 6078155. http://dx.doi.org/10.1155/2021/6078155.
32. Jenish, I., Sahayaraj, A. F., Suresh, V., Mani raj, J., Appadurai, M., Raj, E. F. I., Nasif, O., Alfarraj, S., & Kumaravel, A. K. (2022). Analysis of the hybrid of mudar/snake grass fiber-reinforced epoxy with nano-silica filler composite for structural application. *Advances in Materials Science and Engineering*, *2022*, 7805146. http://dx.doi.org/10.1155/2022/7805146.
33. Nguyen, T. A., & Nguyen, T. H. (2022). Study on mechanical properties of banana fiber-reinforced materials poly (lactic acid) composites. *International Journal of Chemical Engineering*, *2022*, 8485038. http://dx.doi.org/10.1155/2022/8485038.
34. Hariprasad, P., Kannan, M., Ramesh, C., Sahayaraj, A. F., Jenish, I., Hussain, F., Khedher, N. B., Boudjemline, A., & Suresh, V. (2022). Mechanical and morphological studies of *Sansevieria trifasciata* fiber-reinforced polyester composites with the addition of SiO_2 and B_4C. *Advances in Materials Science and Engineering*, *2022*, 1634670. http://dx.doi.org/10.1155/2022/1634670.
35. Ganesamoorthy, R., Reddy, R. M., Raja, T., Panda, P. K., Dhoria, S. H., Nasif, O., Alfarraj, S., Manikandan, V., & Jenish, I. (2021). Studies on mechanical properties of Kevlar/Napier grass fibers reinforced with polymer matrix hybrid composite. *Advances in Materials Science and Engineering*, *2021*, 6907631. http://dx.doi.org/10.1155/2021/6907631.
36. Kumar, R. P., Muthukrishnan, M., & Sahayaraj, A. F. (2022). Experimental investigation on jute/snake grass/kenaf fiber reinforced novel hybrid composites with annona reticulata seed filler addition. *Materials Research Express*, *9*(9), 095304. http://dx.doi.org/10.1088/2053-1591/ac92ca.
37. Sahoo, M. R., Gopinathan, R., Kumar, K. V. P., Rani, J. J. A., Pradhan, R., & Parida, L. (2022). Study on the influence of stacking pattern on mechanical behaviour of banana/snake grass fibers hybrid epoxy composite. *Materials Today: Proceedings*, *69*(Part 3), 1164-1168. http://dx.doi.org/10.1016/j.matpr.2022.08.185.
38. Manickaraj, J., Ramamoorthi, R., Sathish, S., & Makeshkumar, M. (2022). Effect of hybridization of novel African teff and snake grass fibers reinforced epoxy composites with bio castor seed shell filler: experimental investigation. *Polymers & Polymer Composites*, *30*, 09673911221102288. http://dx.doi.org/10.1177/09673911221102288.
39. Sathishkumar, T. P. (2016). Development of snake grass fiber-reinforced polymer composite chair. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, *230*(1), 273-281. http://dx.doi.org/10.1177/1464420715569291.
40. Bhaskar, K. B., Santhanam, V., & Devaraju, A. (2020). Dielectric strength analysis of acacia nilotica with chemically treated sisal fiber reinforced polyester composite. *Digest Journal of Nanomaterials and Biostructures*, *15*(1), 107-113. http://dx.doi.org/10.15251/DJNB.2020.151.107.
41. Vimalanathan, P., Venkateshwaran, N., & Santhanam, V. (2016). Mechanical, dynamic mechanical, and thermal analysis of *Shorea robusta*-dispersed polyester composite. *International Journal of Polymer Analysis and Characterization*, *21*(4), 314-326. http://dx.doi.org/10.1080/1023666X.2016.1155818.
42. Palanikumar, V., Narayanan, V., & Vajjiram, S. (2018). Experimental investigation of mechanical and viscoelastic properties of *Acacia Nilotica* filler blended polymer composite. *Polymer Composites*, *39*(7), 2535-2546. http://dx.doi.org/10.1002/pc.24238.

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