JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Analysis of Tensile and Flexural performance of Polymer Matrix Composites reinforced with Hemp fiber, S-Glass fiber, and Carbon Nanotubes

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Abstract: This study investigates the tensile and flexural behavior of hybrid polymer composites reinforced with hemp fiber, S-glass fiber, and carbon nanotube (CNT) nano-fillers using an epoxy resin matrix. The composites were fabricated through the hand lay-up process, incorporating varying fiber weight ratios and CNT contents (1–2 wt.%). Tensile and flexural tests were conducted following ASTM standards to evaluate the mechanical performance. Results revealed a consistent increase in both tensile and flexural strengths with increasing CNT content and S-glass fiber proportion. The highest tensile strength of 66 MPa and flexural strength of 73 MPa were observed for the composite containing 20% hemp, 20% S-glass, and 2 wt.% CNT. The improvement is attributed to enhanced interfacial bonding and load transfer due to the synergistic effect of micro (S-glass) and nano (CNT) reinforcements. The study demonstrates that hybridization of natural and synthetic fibers, combined with nano-fillers, can significantly enhance stiffness, strength, and overall structural performance. These hybrid composites offer a sustainable, lightweight, and high-performance alternative for automotive, aerospace, and structural applications. Future work may focus on optimizing CNT dispersion, analyzing dynamic and thermal behavior, and exploring bio-based resins to improve environmental sustainability.

Index Term: Hemp fiber, S-glass fiber, Carbon nanotubes, Epoxy, Tensile strength, Flexural strength.

I. Introduction

A composite is a material made by combining two or more distinct components, typically a matrix and reinforcement, to achieve superior mechanical, thermal, or chemical properties than individual constituents. Polymer composites reinforced with natural and synthetic fibers have emerged as promising materials for lightweight and high-strength structural applications. Among natural fibers, hemp fiber has gained increasing attention due to its low density, biodegradability, and good specific mechanical properties. However, hemp fiber composites often suffer from limitations such as poor fiber–matrix adhesion and moisture absorption, which reduce their tensile and flexural strength (Kalia et al., 2022; Bledzki & Gassan, 1999). To overcome these drawbacks and enhance mechanical performance, researchers have incorporated nano-scale fillers, particularly carbon nanotubes (CNTs**)**, into polymer matrices. Carbon nanotubes possess exceptional tensile strength (up to 63 GPa) and high modulus (~1 TPa), making them effective reinforcements for improving load transfer, stiffness, and crack resistance in polymer composites (Iijima, 1991; Thostenson et al., 2001). When used in small quantities (0.5–2 wt.%), CNTs improve the dispersion of stress and strengthen the interfacial bonding between the hemp fibers and the polymer matrix. This leads to significant enhancement in tensile and flexural properties, as CNTs bridge microcracks and restrict fiber pull-out during loading (Nayak et al., 2020). Thus, combining hemp fibers and carbon nanotube nano-fillers in polymer composites provides a synergistic improvement in mechanical strength, offering a sustainable yet high-performance alternative for automotive and structural applications.

II. Literature summery

Polymer composites reinforced with hemp fiber and S-glass fiber have received considerable attention due to their contrasting mechanical properties and potential for hybridization. Hemp fiber, a lignocellulosic natural reinforcement, is lightweight, renewable, and environmentally friendly. Its composition—mainly cellulose, hemicellulose, and lignin—provides moderate strength and stiffness but poor interfacial adhesion with hydrophobic polymer matrices. To overcome this limitation, fibers are commonly treated with alkali or silane coupling agents to remove surface impurities and improve bonding (Kalia et al., 2022; Bledzki & Gassan, 1999). Proper surface modification and fiber alignment significantly enhance mechanical performance, resulting in tensile strengths of 60–200 MPa and flexural strengths of 80–150 MPa in hemp-based composites (Sadeghi et al., 2024; Vallejos et al., 2023). However, hemp composites are prone to moisture absorption, leading to matrix debonding and reduced durability. In contrast, S-glass fiber composites offer high mechanical performance due to their excellent strength-to-weight ratio and superior interfacial bonding with polymer matrices. S-glass fibers possess a tensile strength of 4.5–4.9 GPa and a modulus of 86–90 GPa, resulting in composite tensile and flexural strengths of 700–1100 MPa and 600–1000 MPa, respectively (AGY, 2023; Kumar et al., 2021). They are widely used in aerospace, marine, and defence applications where high structural integrity and fatigue resistance are essential. However, the higher cost and non-biodegradable nature of synthetic fibers limit their sustainability and environmental appeal. To balance performance and sustainability, researchers have developed hybrid hemp/S-glass composites that merge the ecological advantages of natural fibers with the mechanical robustness of synthetic reinforcements. These hybrid laminates, typically designed with S-glass outer layers and hemp inner cores, show improved tensile, flexural, and impact properties compared to pure hemp composites (Jawaid & Khalil, 2011; Mohammed et al., 2015). Hybridization not only enhances stiffness but also reduces overall weight, making such materials promising for automotive, sporting, and structural applications. Overall, the literature indicates that fiber–matrix adhesion, fiber orientation, volume fraction, and stacking sequence are key factors influencing tensile and flexural performance. Future research should focus on bio-based coupling agents, hybrid layer optimization, and long-term durability studies to develop sustainable, high-performance polymer composites.

III. OBJECTIVES

- To develop polymer composites reinforced with hemp fiber, S-glass fiber, and carbon nanotube (CNT) nano-fillers.
- To evaluate the tensile and flexural strength of hemp/S-glass/CNT hybrid polymer composites.
- To study the effect of CNT concentration and fiber orientation on the mechanical performance of hemp/S-glass composites.
- To analyze the synergistic influence of S-glass and CNT nano-fillers in enhancing load transfer and stiffness.
- To identify the optimum fiber ratio and CNT content that yield maximum strength and rigidity while maintaining lightweight characteristics.
- To explore the potential of hemp/S-glass/CNT hybrid composites as sustainable, high-performance materials for automotive and structural applications without relying on chemical modification processes.

IV. MATERIALS USED

4.1 Hemp fiber

Hemp fiber, obtained from the stem of the Cannabis sativa plant, is a natural lignocellulosic fiber valued for its strength, low density, and eco-friendly characteristics. It is composed mainly of cellulose (60–70%), hemicellulose (15–20%), and lignin (3–5%). The fiber exhibits a tensile strength of 550–900 MPa, a Young's modulus of 30–60 GPa, and a density of about 1.4–1.5 g/cm³, making it lightweight yet strong. Hemp fibers have good thermal insulation, ultraviolet resistance, and biodegradability. However, their hydrophilic nature causes moisture absorption, which can weaken the fiber–matrix interface in composites. Despite this, hemp is widely used in automotive panels, construction materials, and polymer composites as a sustainable reinforcement alternative.

Fig.4.1.1 Hemp Fabric

4.2 Glass Fiber

S-glass fiber, or structural glass fiber, is a high-strength inorganic material made primarily from alumino-silicate glass with a high magnesium content. It offers superior mechanical and thermal properties compared to conventional E-glass fiber. S-glass exhibits a tensile strength of about 4.5–4.9 GPa, a Young's modulus of 86–90 GPa, and a density of approximately 2.46 g/cm³. These properties make it ideal for high-performance composites used in aerospace, marine, defense, and sports equipment. It also provides excellent chemical resistance, thermal stability, and fatigue performance, though it is relatively expensive and less sustainable compared to natural fibers such as hemp.

Fig.4.2.1 Glass Fabric

4.3 Carbon nanotube

Carbon nanotubes (CNTs) are cylindrical nanostructures composed of rolled graphene sheets with remarkable mechanical, electrical, and thermal properties. They exist as single-walled (SWCNTs) or multi-walled (MWCNTs) forms. CNTs possess an exceptionally high tensile strength of up to 63 GPa, a Young's modulus around 1 TPa, and excellent thermal conductivity (~3000 W/mK). Due to their nanoscale size and high aspect ratio, they significantly enhance the mechanical strength, stiffness, and crack resistance of polymer composites even at low concentrations. CNTs are widely used in advanced composites, sensors, batteries, and aerospace materials due to their lightweight, durability, and multifunctional performance characteristics.

Fig.4.3.1 CNT Powder

4.4 Epoxy Resin

Epoxy resin is a thermosetting polymer widely used as a matrix material in composite fabrication due to its excellent mechanical strength, chemical resistance, and strong adhesion to various reinforcements. It is formed through the reaction of epoxy monomers with hardeners, resulting in a highly cross-linked, rigid structure. Epoxy resins exhibit high tensile strength (70–85 MPa), good dimensional stability, and low shrinkage during curing. They also provide excellent electrical insulation and resistance to moisture and corrosion. Due to their versatility and superior bonding properties, epoxy resins are extensively used in aerospace, automotive, marine, and structural composite applications.

V. METHODOLOGY

5.1 The Hand lay-up process

The hand lay-up process is a simple and cost-effective method for fabricating hemp/S-glass/carbon nanotube (CNT) reinforced epoxy composites. A clean mold coated with a release agent ensures easy removal after curing. Epoxy resin and hardener (10:1 ratio) are mixed, and CNTs are dispersed uniformly using ultrasonication. Hemp and S-glass fiber mats (300×300 mm) are alternately layered, with CNT–epoxy applied using a brush for proper impregnation. Each layer is compacted to remove air and excess resin. The laminate cures for 24 hours at room temperature or 50–60°C, then trimmed to 300×300×3 mm. This method produces strong, lightweight composites suitable for automotive and structural uses.

Fig.5.1.1 Developed slab of 300x300x3mm

5.2 Sample Preparations

Composite laminate of 300mm X 300mm X 3mm (9 laminates) were fabricated and machined according to ASTM standards (D3039 and D790) for Tensile and Flexural tests. The specifications of developed slabs are shown in the table 5.2.1.

Table 5.2.1 Developed composite slab specifications (Reinforcements)

Samples	Sample Combinations			
	Hemp fiber (wt.%)	S glass fiber (wt.%)	Epoxy resin (wt.%)	CNT (wt.%)
1	40	0	59	1
	40	0	58.5	1.5
	40	0	58	2
2	30	10	59	1
	30	10	58.5	1.5
	30	10	58	2
3	20	20	59	1
	20	20	58.5	1.5
	20	20	58	2

5.3 Tensile Testing

The tensile test for hemp/S-glass/carbon nanotube (CNT) reinforced epoxy composites is performed to determine tensile strength, modulus, and strain at break, following ASTM D3039 standards. Specimens are precisely cut from cured laminates using a diamond saw to avoid edge damage, typically measuring 250 mm × 25 mm, with fibers aligned along the loading direction. Aluminium or glass-epoxy end tabs are bonded to both ends to prevent grip damage or slippage. Before testing, specimens are conditioned at 23 ± 2 °C and 50 ± 5% relative humidity for 48 hours. Dimensional measurements are taken to calculate the cross-sectional area. The test is conducted using a universal testing machine with appropriate grips and an extensometer to record strain. The load is applied gradually at a crosshead speed of 1–2 mm/min until failure. Load and displacement data generate the stress–strain curve, from which tensile strength, modulus, and strain at fracture are calculated. Post-test fracture analysis reveals fiber pull-out, matrix cracking, and delamination characteristics.

5.4 flexural test Testing

The flexural strength test for hemp/S-glass/carbon nanotube (CNT) reinforced epoxy composites evaluates the material's resistance to bending under load, following ASTM D790 standards using a three-point bending setup. Rectangular specimens, typically 100 mm long, 12.7 mm wide, and 3–5 mm thick, are cut from cured laminates using a fine cutter to prevent edge damage. Before testing, specimens are conditioned at 23 ± 2 °C and 50 ± 5% relative humidity for 48 hours. The test is performed on a universal testing machine with a three-point bending fixture, where the specimen rests on two supports and a central load is applied at a constant crosshead speed of 1–2 mm/min until failure. The load–deflection data are recorded to calculate flexural strength and modulus from the beam theory formula. Post-test examination reveals failure modes such as fiber pull-out, matrix cracking, and delamination. The test helps assess stiffness, interfacial bonding, and overall flexural performance of hybrid composites.

VI. RESULTS AND DISCUSSIONS

6.1 Tensile Test

Table. 6.1.1 Results of Tensile Test

Samples	Sample Combinations				Tensile Strength (MPa)
	Hemp fiber (wt.%)	S glass fiber (wt.%)	Epoxy resin (wt.%)	CNT (wt.%)	
1	40	0	59	1	44
	40	0	58.5	1.5	46
	40	0	58	2	47
2	30	10	59	1	52
	30	10	58.5	1.5	56
	30	10	58	2	57
3	20	20	59	1	59
	20	20	58.5	1.5	64
	20	20	58	2	66

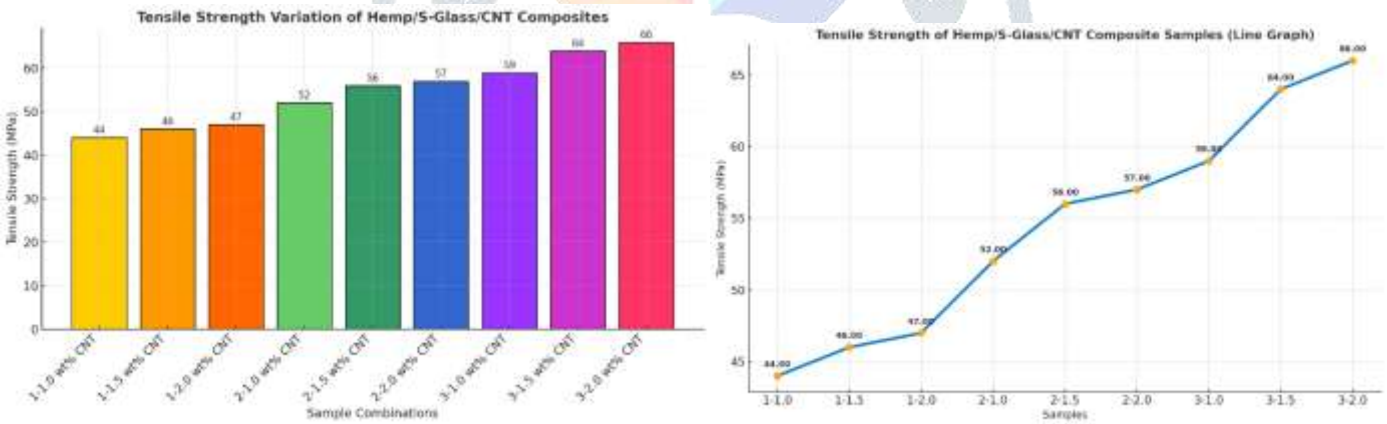

Fig. 6.1.1 Bar and Line graphs of Results of tensile test

The above bar and line graphs (Fig. 6.1.1) illustrate the relationship between CNT (carbon nanotube) content and the tensile strength of hybrid hemp/S-glass/epoxy composites for three different fiber combinations. It is observed that for all samples, the tensile strength increases with increasing CNT concentration. For sample 1 (40% hemp fiber, no S-glass), the tensile strength rises from 44 MPa at 1 wt.% CNT to 47 MPa at 2 wt.% CNT, showing a modest improvement due to limited fiber reinforcement. For sample 2 (30% hemp and 10% S-glass), the strength improves more significantly from 52 MPa to 57 Mpa indicating better fiber–matrix bonding and load transfer between natural and synthetic fibers. Sample 3 (20% hemp and 20% S-glass) exhibits the highest tensile strength values, reaching 66 MPa at 2 wt.% CNT. This trend demonstrates that the addition of CNTs enhances tensile performance by improving the interface between fibers and the epoxy matrix, while the inclusion of S-glass fiber contributes additional stiffness and strength. Thus, the combined reinforcement of S-glass and CNTs provides superior tensile properties compared to hemp fiber alone. The optimum result occurs at higher CNT loading (2 wt.%) and balanced fiber hybridization, confirming the synergistic effect of multi-scale reinforcement.

6.2 Flexural test

Table. 6.2.1 Results of Flexural Test

Samples	Sample Combinations				Flexural Strength (MPa)
	Hemp fiber (wt.%)	S glass fiber (wt.%)	Epoxy resin (wt.%)	CNT (wt.%)	
1	40	0	59	1	39
	40	0	58.5	1.5	42
	40	0	58	2	46
2	30	10	59	1	52
	30	10	58.5	1.5	51
	30	10	58	2	56
3	20	20	59	1	62
	20	20	58.5	1.5	67
	20	20	58	2	73

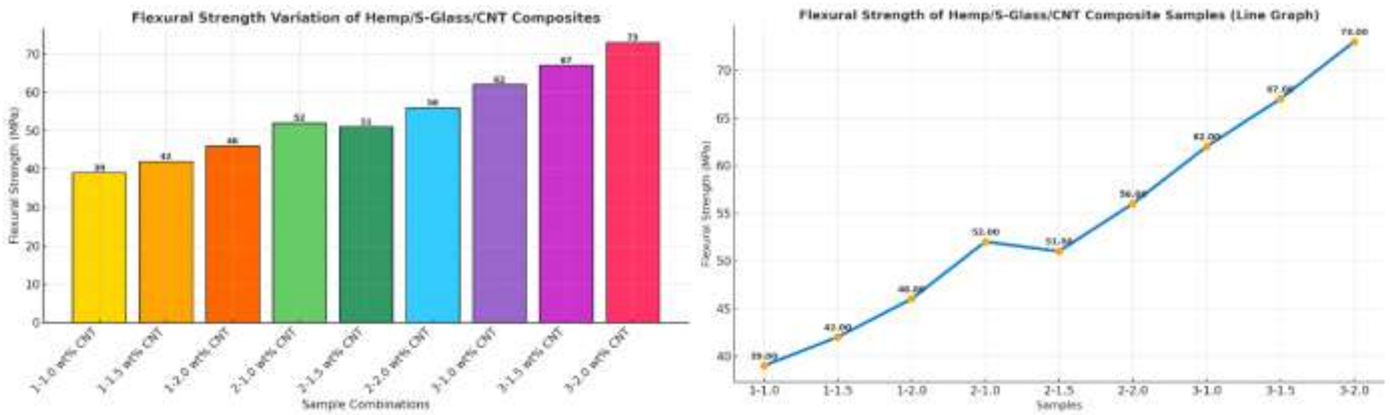

Fig. 6.2.1 Bar and Line graphs of Results of Flexural test

The above both graphs (Fig 6.2.1) show the relationship between CNT (carbon nanotube) content and the flexural strength of hemp/S-glass/epoxy composites for three different sample combinations. The flexural strength results of the hemp/S-glass/carbon nanotube (CNT) reinforced epoxy composites show a clear improvement with increasing CNT content and higher proportions of S-glass fiber. For Sample 1, which contains only hemp fiber, the flexural strength rises gradually from 39 MPa at 1 wt.% CNT to 46 MPa at 2 wt.% CNT, indicating the positive influence of CNTs in enhancing matrix stiffness. In Sample 2, with 30% hemp and 10% S-glass fiber, the strength improves from 52 MPa to 56 MPa, suggesting that the inclusion of S-glass provides better load-bearing capacity and interfacial bonding. The highest flexural strength is observed in Sample 3, containing 20% hemp and 20% S-glass fiber, where it increases significantly from 62 MPa to 73 MPa with CNT addition. This overall improvement is attributed to the synergistic effect of S-glass reinforcement and CNT dispersion, which enhances the fiber–matrix adhesion and load transfer efficiency.

VII. Conclusions

From the tensile and flexural strength analysis of hemp/S-glass/carbon nanotube (CNT) reinforced epoxy composites, it can be concluded that the mechanical performance of the composites improves significantly with the addition of both S-glass fiber and CNT nano-fillers. The tensile strength results show a steady rise from 44 MPa for the pure hemp composite to 66 MPa for the hybrid composite containing 20% hemp, 20% S-glass, and 2 wt.% CNT. Similarly, the flexural strength increases from 39 MPa to 73 MPa under the same conditions. This improvement can be attributed to the synergistic effect of S-glass fibers, which enhance stiffness and strength, and CNTs, which act as nanoscale reinforcements improving interfacial bonding and load transfer between fibers and the epoxy matrix. The hybrid configuration of natural (hemp) and synthetic (S-glass) fibers provides a balance between strength, weight reduction, and sustainability. Overall, the study confirms that hemp/S-glass/CNT hybrid composites exhibit superior tensile and flexural performance, making them suitable for lightweight structural and automotive applications.

VIII. Future scope

The future scope of hemp/S-glass/CNT reinforced epoxy composites includes optimizing fiber orientation, stacking sequence, and CNT dispersion methods to enhance mechanical strength and uniformity. Further studies can focus on dynamic mechanical, thermal, and fatigue behavior to evaluate long-term durability under real-world conditions. Exploring bio-based resins and surface-functionalized CNTs will improve sustainability and interfacial bonding. Advanced modeling techniques, such as finite element analysis and machine learning, can help predict performance more accurately. Additionally, scaling up fabrication for industrial applications in automotive, aerospace, and structural sectors will promote wider adoption of these eco-friendly, high-performance hybrid composites in modern engineering applications.

Acknowledgement

I would like to express my heartfelt gratitude to my project guide, Dr. H. K. Shivanand, for their continuous guidance, encouragement, and valuable suggestions throughout the course of this project on Hemp/S-glass/Carbon Nanotube Reinforced Epoxy Composites. Their expertise and constant support were instrumental in the successful completion of this work. I would also like to extend my sincere thanks to the SLN Testing Laboratory for providing the essential testing facilities and technical assistance during the experimental analysis, particularly in conducting the tensile and flexural strength tests.

REFERENCES

Books

[1] Callister, W. D., & Rethwisch, D. G. (2020). Materials Science and Engineering: An Introduction. Wiley.Mallick,

[2] P. K. (2007). Fiber-Reinforced Composites: Materials, Manufacturing, and Design. CRC Press.

[3] Gibson, R. F. (2016). Principles of Composite Material Mechanics. CRC Press.

[4] Bledzki, A. K., & Gassan, J. (1999). Composites Reinforced with Cellulose-Based Fibres. Progress in Polymer Science, 24(2), 221–274

Journals & Conferences

[1] Kalia, S., Kaith, B. S., & Kaur, I. (2022). Pretreatments of Natural Fibers and Their Application as Reinforcing Material in Polymer Composites: A Review. Polymer Engineering and Science, 62(3), 450–472.

[2] Sadeghi, P., et al. (2024). Experimental and Statistical Investigations for Tensile Behavior of Hemp Fibers. MDPI Polymers, 16(2), 456–469.

[3] Vallejos, M. E., et al. (2023). Behavior of the Flexural Strength of Hemp/Polypropylene Composites. Materials (MDPI), 16(15), 5345.

[4] AGY LLC. (2023). S-2 Glass Fibers for Composite Materials – Technical Datasheet. AGY Technical Bulletin.

[5] Kumar, N. S., et al. (2021). Tensile and Flexural Strength of Glass Fiber Epoxy Composites. IOP Conference Series: Materials Science and Engineering, 1158(1), 012034.

[6] Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., & Islam, M. S. (2015). A Review on Natural Fiber Reinforced Polymer Composites and Its Applications. Journal of Reinforced Plastics and Composites, 34(24), 2149–2170.

[7] Jawaid, M., & Khalil, H. A. (2011). Cellulosic/Synthetic Fiber Reinforced Polymer Hybrid Composites: A Review. Carbohydrate Polymers, 86(1), 1–18.

[8] Iijima, S. (1991). Helical Microtubules of Graphitic Carbon. Nature, 354(6348), 56–58.

[9] Thostenson, E. T., Ren, Z., & Chou, T. W. (2001). Advances in the Science and Technology of Carbon Nanotubes and Their Composites: A Review. Composites Science and Technology, 61(13), 1899–1912.

[10] Nayak, R. K., Behera, P., & Jena, S. (2020). Effect of Carbon Nanotubes on Mechanical and Thermal Behavior of Polymer Nanocomposites: A Review. Materials Today: Proceedings, 26, 2500–2506