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Strategic Enhancement of Composite Strength Explored Through Comprehensive Integration of Flax Fiber and Cenosphere in Epoxy Resin Matrices

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Abstract

The Current research delves into the mechanical attributes of composite specimens, integrating flax fiber and cenosphere fillers within an epoxy resin matrix catalyzed by K-6 hardener. Executing a meticulous approach involving a vacuum bagging method and a specific formulation of 10 wt.% cenosphere, 50% epoxy resin, and 40% flax fibers, the study rigorously scrutinized tensile and flexural strengths. Notably, the first specimen exhibited a peak tensile strength of 94.329 MPa, while the second recorded 83.374 MPa. Additionally, corresponding flexural strengths reached 97.05 MPa and 78.32 MPa. Comparative analyses with prior literature underscored the superior strength of the current composite material, particularly in contrast to formulations involving hemp fibers. This investigation also suggests the promising application of the composite in replacing plastic mud guards for bicycles and bikes, owing to its heightened tensile strength and eco-friendly nature.

Keywords: Composite materials, Flax fiber, Cenosphere, Tensile strength, Flexural Strength, and Eco-friendly applications

INTRODUCTION

The composite material landscape has witnessed a transformative journey over the years, evolving into a critical enabler across various industries [1–4]. Defined as the fusion of two or more distinct materials, composites offer unparalleled chemical and mechanical properties, surpassing conventional metals and alloys. In the quest for lightweight structures coupled with exceptional strength, the integration of fillers, reinforcements, and matrices has become a focal point in materials engineering. The historical backdrop of composite materials dates to the 1930s, marked by the inception of metal matrix composites, fiber-reinforced plastics, and ceramic-metal composites [5–8]. As these foundational developments unfolded, subsequent decades brought forth a surge in research, refining processing technologies and expanding the scope of applications in diverse industries. In the contemporary landscape, the advent of modern composites, such as glass fiber-reinforced and carbon fiber-reinforced composites, has revolutionized manufacturing. These materials, characterized by lightweight attributes, corrosion resistance, and low density, find applications ranging from aerospace to automotive manufacturing, embodying the essence of efficiency and innovation. In the pursuit of sustainable and high-performance composite materials, the research under consideration focuses on the integration of flax fiber and cenosphere fillers within epoxy resin matrices. Flax fiber, derived from locally available sources, serves as a reinforcement, imparting favorable chemical and

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mechanical behavior to the composite. The selection of natural fibers aligns with the broader objective of fostering eco-friendly alternatives to traditional composite materials [9, 10].

A comprehensive exploration of studies on the mechanical properties of natural fiber-reinforced epoxy composites, particularly focusing on the influence of cenosphere fillers is explained below. Notably, the research consistently highlights the advantageous mechanical characteristics of bamboo natural fiber composite. Studies [11] and [12] affirm that bamboo composites exhibit superior mechanical and axial strength compared to other natural fibers, specifically coconut coir and jute. The conclusion is drawn based on extensive mechanical tests, including tensile tests on a Universal Testing Machine (UTM). Furthermore, the impact properties of laminated bamboo-fiber [13] composites filled with cenosphere [14] were investigated, revealing that the density of the composites is contingent on filler content, with an enhancement in impact strength observed with an increase in cenosphere lamina. Several studies delve into the effects of cenosphere fillers on erosion and wear resistance of various composite materials. The investigation on woven hybrid jute-glass epoxy composites filled with cenosphere [15] concluded that glass-jute epoxy composites are semi-ductile, and the wear resistance is notably higher when filled with cenosphere compared to hybrid composite materials. Similarly, the study on erosion wear response in natural bamboo-reinforced polymer composites [16] emphasized that erosion rates are smaller in fly ash-filled glass epoxy composites than in glass composites, underlining the potential of cenosphere fillers in enhancing erosion resistance. These findings collectively contribute to a deeper understanding of the mechanical behavior of natural fiber-reinforced composites, offering valuable insights for applications ranging from automotive components to aerospace structures. The investigation into the influence of cenosphere particles on thermal properties of silicon rubber [17] underscores the multifaceted role of cenosphere fillers beyond mechanical strength. As the studies suggest, the type of filler used significantly affects the thermal stability of the composite material. This diversification of research themes [18] illustrates the wide-ranging applications and considerations associated with natural fiber-reinforced epoxy composites, providing a nuanced perspective on their mechanical, thermal, and wear properties in various contexts. Continuing the exploration of cenosphere-filled composites, the study on the impact of cenosphere addition on erosion wear resistance in natural bamboo-reinforced polymer composite [19] adds another layer to the understanding of composite materials.

The research suggests that the erosion property of thermoplastic polymers tends to show ductile erosion, while thermosetting polymers exhibit brittle erosion. Furthermore, the erosion rate is observed to be smaller in fly ash-filled glass epoxy composites compared to their glass-filled counterparts. This finding is crucial for applications [20] in which erosion wear resistance is paramount, such as in components subjected to abrasive environments. The investigation into the effect of filler material on natural fiber-reinforced polymer matrix hybrid composites for automobile applications [21] provides insights into the practical use of these materials. The study emphasizes that although flexural strength may be higher in syntactic composites compared to natural fiber composites, the latter finds utility in specific applications like bike mud guards, showcasing the balance between material properties and practical considerations in real-world applications. Moreover, the review paper on cenospheres [22] contributes a broader perspective by discussing the behavior of cenospheres collected from coal fly ash [23]. The separation methods, wet and dry, are detailed, highlighting the potential of utilizing waste materials, such as fly ash, for electricity generation and structural applications in aircraft. This paper serves as a foundational understanding of the cenosphere material itself, offering context for the subsequent studies that incorporate cenospheres into composite materials. In essence, these studies collectively paint a rich tapestry of the diverse aspects of natural fiber-reinforced epoxy composites and the impact of cenosphere fillers [24] on their mechanical, thermal, and erosion properties. From enhancing mechanical strength to addressing erosion wear challenges and exploring practical applications [25], the literature underscores the multifaceted nature of these composite materials and their potential across various industries.

MATERIALS AND FABRICATION METHOD

Flax fiber serves as a reinforcement material in the form of a fiber mat, derived from the flax plant. Possessing high specific strength and favorable chemical and mechanical attributes, flax fiber faced a decrease in demand due to its lower elasticity. However, extensive research in the field has led to innovative treatments, such as alkylation and acetylation, which mitigate water absorption. The application of appropriate fillers further enhances the strength of flax fiber [26–29]. Despite being an inexpensive material, flax fiber exhibits superior mechanical properties compared to synthetic fibers.

The properties of natural fibers, including flax as shown in Figure 1, undergo continuous variations influenced by environmental factors. This environmental impact significantly affects the mechanical characteristics of fibers, such as tensile strength and elongation [30]. The regions of the flax plant, particularly the mid-span and tip of the stem, rich in cellulose, are considered as raw material sources. To address the challenges associated with poor fiber-matrix [31–32] compatibility and inadequate interfacial bonding, various modification techniques come into play. Methods such as alkylation, acetylation, and treatment with NaOH are employed to reduce water absorption capacity and augment the overall strength of composites. The incorporation of flax fiber mats into thermoplastic, thermosets, and polymer matrices showcases commendable mechanical properties as shown in Table 1. By implementing precise chemical and physical modifications, along with an optimal fabrication process [33, 34], we can achieve outstanding mechanical behavior in composite materials.

Among the integral components of the composite matrix, cenosphere stands out as a revolutionary filler. This industrial waste product, sourced from fly ash generated in thermal power plants, not only addresses environmental concerns but also contributes to enhancing the mechanical properties of the composite. By adopting cenosphere as shown in Figure 2 as a cost-effective filler, the research aims to mitigate the environmental impact associated with fly ash disposal while unlocking new dimensions in composite material applications [35–37]. The filler material as used in this experiment is supplied by kulin corporation Ltd, Mumbai, India. Tables 2 and 3 depict the Physical Properties of CIL 150 cenosphere (grade 150) and Chemical constituents of Cenosphere.

Figure 1. Flax Fibre Mat.

Table 1. Properties of natural fibre (flax fibre)

S.N.	Property	Value
1	Colour of the fibre	Yellowish, Grey, Brownish (Brown)
2	Diameter of the fibre	0.02 mm (average)
3	Length of the fibre	90–125 cm
4	Elongation at break	1.8% (dry), 2.2% (wet)
5	Tensile strength of fibre	6.5–8 gm/denier
6	Specific gravity of fibre	1.54
7	Dimension stability	Good, but tends to crease easily
8	Thickness	0.35 mm to 0.40 mm
9	Fibre type	Flax fibre
10	Density	1.29 g/m^3
11	Weight	200 g/m^2
12	Thickness	0.25–0.40 mm
13	Compressive strength	121 MPa
14	Tensile strength	106 MPa

Figure 2. Cenosphere.

Table 2. Physical Properties of CIL 150 cenosphere (grade 150).

S.N.	Property	Value
1	Bulk density of CIL-150	400–450 Kg/m^3
2	Compression strength of CIL-150	180–280 Kg/m^3
3	Shape of cenosphere particle	Spherical
4	Packing factor of particle	60–65%
5	Shell wall thickness of CIL-150	5–10% of shell dia
6	Cenosphere colour	Light Grey
7	CIL-150 melting point	1200°C-1300°C
8	pH of cenosphere in water	6–7
9	Cenosphere Particle density CIL-150	930 Kg/m^3

Table 3. Chemical constituents of Cenosphere.

S.N.	Component	Percentage Range
1	SiO_2	52–62%
2	Al_2O_3	32–36%
3	K_2O	1.2–3.2%
4	Fe_2O_3	1–2%
5	TiO_2	0.8–1.3%
6	MgO	1–2.5%
7	Na_2O	0.2–0.6%
8	CAO	0.1–0.5%

Figure 3. Filler Material.

Table 4. Chemical Name and Density of Resin and Hardener.

S.N.	Constituent	Trade Name	Chemical Name	Density (kg/m^3)
1	Resin	LAPOX L-12	Diglycidyl Ether of Bisphenol A (DGEBA)	1163
2	Hardener	K-6	Triethylene Tetraamine (TETA)	953

In the intricate composition of composites, fillers play a pivotal role in enhancing performance and reducing costs. The inclusion of filler-calcium carbonate as shown in Figure 2 influences smoke and fire resistance, mechanical strength, water resistance, surface smoothness, and overall performance characteristics. The deliberate choice of fillers as shown in Figure 3 contributes to the improvement of composite properties and the economic feasibility of the manufacturing process [38–39].

At the heart of composite material fabrication lies the matrix [40, 41], with epoxy resin emerging as a key player. Functioning as a thermoset polymer, epoxy resin boasts the ability to create robust bonds between reinforcing materials and the matrix [42]. The research experimentally utilizes epoxy resin matrices, specifically the L-12 variant, complemented by the K-6 hardener, to further explore the mechanical properties and bonding characteristics of the composite as shown in Table 4.

As the research endeavors to unravel the untapped potential of natural fiber reinforcements, innovative fillers, and advanced resin matrices, the research unfolds with a commitment to redefining the boundaries of composite materials [43–45]. Through the exploration of flax fiber and cenosphere reinforced epoxy resin, this study aims to contribute to the ongoing dialogue surrounding sustainable, cost-effective, and high-performance composites for diverse applications in modern industries.

The Vacuum Bagging Method [46], a closed-mold process, is chosen for composite fabrication, particularly when a high reinforcement-to-resin ratio is essential. This technique is particularly well-suited for composite systems involving materials like carbon fiber, boron fiber, and silica fiber reinforcement in high molecular polymer resin, where achieving optimal compaction and continuous removal of entrapped air and volatile substances is crucial. The Vacuum Bagging Method is one of three approaches in bag molding, alongside Pressure Bag Molding and Autoclave Molding. For this specific fabrication, the Vacuum Bagging Method was employed. In Vacuum Bag Molding, the technique utilizes only vacuum pressure, while Pressure Bag Molding [47] involves pressurizing with air at room temperature. Autoclave Bag Molding, on the other hand, utilizes hot gases in a closed chamber. The bags themselves are thin, flexible membranes typically crafted from materials such as cellophane, polyvinyl acrylate films, or silicone rubber sheets. These bags serve the essential function of separating the laminate lay-up from pressurizing gases and protecting against atmospheric contamination.

The primary objectives of employing the Vacuum Bagging Method include creating a vacuum to facilitate the escape of entrapped air and volatiles through vents. This step is crucial for achieving excellent wettability of the interface between the reinforcement and matrix. The mechanical behavior and properties of an open-mold laminate can be significantly enhanced by employing the Vacuum Bagging Method as shown in Figures 4 and 5 [6]. The bag exerts external pressure, and as the pressure inside the bag reduces, it effectively removes air bubbles, excess resin, and strongly compresses the laminates. This method ensures a steady degree of consolidation over time, reducing voids in the specimen [48]. The decision to use the Vacuum Bagging Method is deliberate, as it allows for the removal of excess resin, avoiding the non-uniform distribution of resin found in hand lay-up methods, ultimately resulting in strength variations in the laminate. Moreover, the Vacuum Bagging Method enhances core bonding, a critical aspect of composite material fabrication. Thus, the deliberate choice of employing the Vacuum Bagging Method in the fabrication process is grounded in its ability to ensure uniformity, strength, and the removal of excess resin to produce high-quality composite specimens.

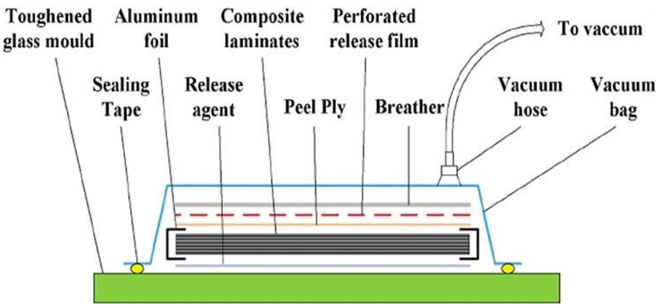


Figure 4. Components of Vacuum Bag Molding [Hang X et al., 2017].

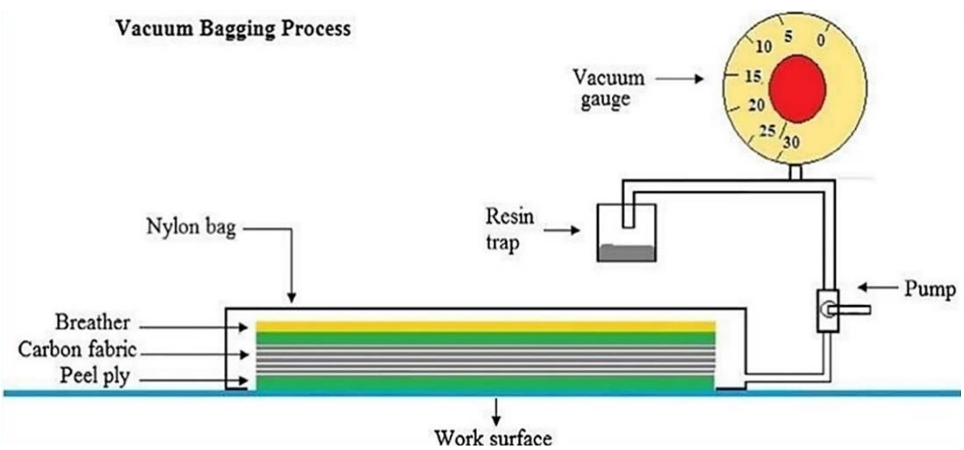


Figure 5. Process of Vacuum Bag Molding [Hang X et al., 2017].

The composition of a composite is a pivotal factor in the fabrication process, wielding significant influence over the mechanical behavior of the resulting specimen. The interplay of elements in the composition, including the chemical bonding between fibers and matrix, and the reactions between materials, such as those between the matrix and filler or the fiber and matrix, holds paramount importance. The mechanical properties of the specimen are intricately tied to the composition, emphasizing the need for a carefully curated blend. Achieving optimal strength is a multifaceted process, involving the addition of fillers to enhance bonding between fibers and matrix. This strategic incorporation [49] not only fosters excellent bonding but also serves to elevate the overall strength of the composite material. In essence, the composition used in the fabrication process acts as a cornerstone, influencing the chemical interactions within the material. The deliberate selection and balance of constituents as shown in Table 5 are imperative to yield a composite with superior mechanical properties, ensuring the desired strength and performance characteristics.

Preparation of Composite Composition: The meticulous preparation of the composite composition involves a systematic process to ensure optimal blending of epoxy, cenosphere filler, and hardener. The following steps outline the preparation procedure:

1. *Epoxy Resin Handling:* Measure the required amount of epoxy resin and place it into a beaker. Utilize a mechanical stirring machine to maintain precise control over the stirring process.
2. *Temperature Adjustment:* Set the stirring machine temperature to a range of 50–60°C, optimizing conditions to reduce the viscosity of the epoxy resin.
3. *Cenosphere Addition:* Gradually introduce cenospheres into the pre-heated epoxy resin. Stir the mixture thoroughly until the cenospheres are uniformly dispersed, ensuring the expulsion of any air bubbles.
4. *Hardener Incorporation:* Weigh the designated amount of hardener, maintaining the ratio of 10:1 with respect to the epoxy resin. Add the hardener to the mixture while continuing the stirring process, ensuring consistent and thorough blending.
5. *Continuous Mixing:* Simultaneously stir the composite composition to guarantee the proper and even distribution of the hardener within the epoxy resin.
6. *Transfer for Application:* After achieving a homogenous blend, transfer the composite composition into another beaker. This prepared composition is now ready for application onto fibers during the subsequent fabrication process.

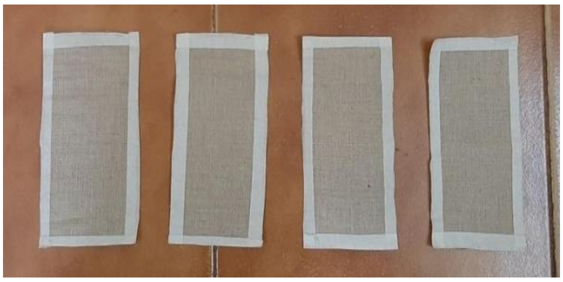
By meticulously following these steps, the composition is thoughtfully prepared, ensuring that each element is incorporated with precision. The controlled mixing and careful addition of cenosphere filler and hardener contribute to a well-balanced composite composition, laying the foundation for successful fabrication.

Composite Fabrication Using Vacuum Bagging Method: The fabrication of composite using the vacuum bagging method involves a meticulous step-by-step process [50], ensuring precision and uniformity as shown in the Figure 6 (a to h).

The meticulous preparation of flax fiber is a fundamental aspect of the composite fabrication process, depicted in Figure 6 (a). This initial step involves cutting the flax fiber mat to specific dimensions, ensuring precision in the arrangement of reinforcing elements within the composite. Additionally, the edges of the flax fiber mat are carefully sealed to prevent any unintended unraveling or displacement during subsequent stages of fabrication [50]. The sealed edges serve as a protective measure, maintaining the integrity of the fiber arrangement and positioning the composite for the application of epoxy resin and cenosphere filler in subsequent steps. In Figure 6 (b), a pivotal stage in the composite fabrication process is depicted, showcasing the meticulous mixing of epoxy resin, cenosphere, and hardener. The success of this step hinges on maintaining a precise ratio of 10:1 between the epoxy resin and hardener to ensure an optimal chemical reaction for the composite material. The process initiates with the introduction of cenosphere into the epoxy resin as per the predetermined composition. After this, a rigorous stirring process ensues, aiming to achieve homogeneity and eradicate any entrapped air bubbles. This meticulous approach guarantees a uniform distribution of cenosphere within the epoxy matrix, laying the groundwork for the composite's structural integrity [51].

Table 5. Composition of Specimens Prepared

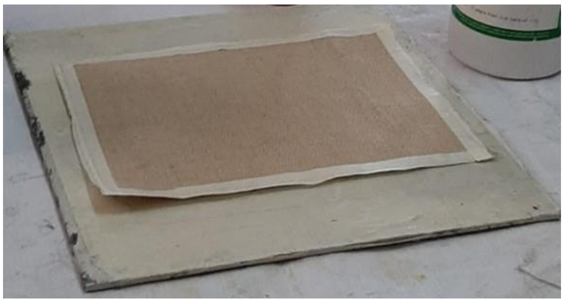
S.N.	Flax fibre (in wt.%)	Epoxy resin (in wt.%)	Cenosphere (in wt.%)
1.	40	50	10



(a). Preparation of flax fibre and sealing the edges of fibre

(b). Preparation of mixture of composite

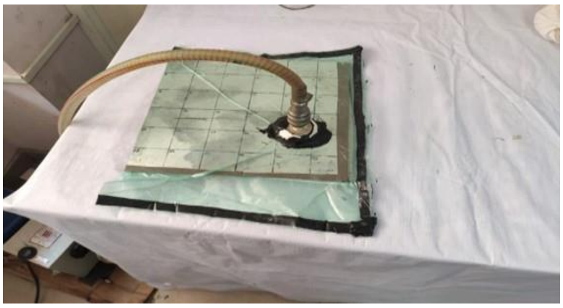
(c). Applying first layer epoxy mixture on steel plate



(d). Applying first layer of flax fibre.

(e). Applying epoxy mixture on flax fibre

(f). Applying second layer of flax fibre.



(g). Laminate is sandwiched between two steel plates

(h). Laminate after vacuum bagging

Figure 6. (a to h) The fabrication of the composite using the vacuum bagging technique.

In Figure 6 (c), a pivotal moment in the composite fabrication process is depicted, highlighting the meticulous application of the epoxy mixture onto the steel plate, followed by the strategic layering of flax fibre. This sequential process is fundamental to the creation of a robust composite material with a well-integrated structure. In Figure 6 (d), a pivotal stage in the composite fabrication process is depicted, showcasing the careful application of the first layer of flax fibre after the precise coating of the steel plate with the epoxy mixture. It underscores the systematic layering approach employed in the fabrication process, where the strategic placement of the flax fibre follows the even distribution of the epoxy-cenosphere blend.

In Figure 6 (e), a pivotal step in the composite fabrication process is illustrated, portraying the application of the epoxy mixture onto the already laid flax fibre, preparing the groundwork for the addition of subsequent layers. This visual depiction encapsulates a continuous process where the epoxy-cenosphere mixture is systematically applied to facilitate the sequential layering of flax fibre. The repetitive nature of this process, as indicated by the figure, signifies its continuation until the desired thickness of the composite material is attained. The careful application of the epoxy mixture on each layer of flax fibre is crucial for ensuring uniformity, adhesion, and structural integrity throughout the composite laminate. Figure 6 (f) provides a visual representation of a critical stage in the composite fabrication process, depicting the application of a second layer of flax fibre after the careful coating with an additional layer of the epoxy-cenosphere mixture. This iterative process is systematically repeated until the composite material reaches the required thickness, aligning with ASTM standards, which specify a thickness of 3 mm. To meet this standard, three layers of flax fibre are sequentially applied, each interspersed with the epoxy-cenosphere mixture. Following the layering process, the composite laminate undergoes a final consolidation step within a vacuum bagging setup for a duration of 4-5 hours, facilitating the curing of the specimen. Once the consolidation process is complete, the specimen is extracted from the vacuum bagging apparatus, marking the conclusion of the fabrication process and the preparation of a composite material adhering to specified standards and thickness criteria.

The integral step of the composite fabrication process as shown in Figure 1.6 (g) involves sandwiching the laminate between two steel plates, a technique essential for ensuring uniformity and enhancing the structural integrity of the composite material. This procedure is crucial for promoting optimal bonding and compression throughout the composite, aligning the fibers and matrix in a consistent manner. The use of steel plates provides a stable and controlled environment for the final stages of the fabrication process, contributing to the overall quality and performance of the composite material. Figure 1.6 (h) encapsulates a pivotal moment in the composite fabrication process, illustrating the removal of specimens from the vacuum bagging setup after a curing duration of 4-5 hours. This step marks the culmination of the meticulous fabrication procedure, during which the composite laminate undergoes a critical phase of consolidation and curing. The removal of specimens from the vacuum bagging apparatus signifies the completion of the manufacturing process, with the cured composite material now ready for subsequent testing and evaluation.

ASTM Standards of Specimen: The composite material is prepared in the form of laminates and the laminates are cut into specimens according to the following ASTM standards as shown in Table 6 [51].

Table 6. ASTM Standards of Specimen.

S.N.	Test Method	ASTM Standards	Specimen sizes (LxWxT), mm
1.	Tensile test	ASTM D3039-76	140 × 15 × 5
2.	Flexural test	ASTM D2344-84	150 × 20 × 5

Tensile Test Specimen Size

L=Length (140 mm); W=Width (15 mm); t = Thickness (5 mm)

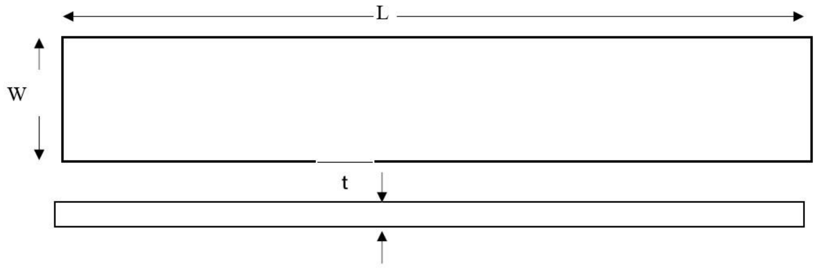


Figure 7. Tensile Test according to ASTM Standards [29].

Figure 8. Tensile Test Specimen.

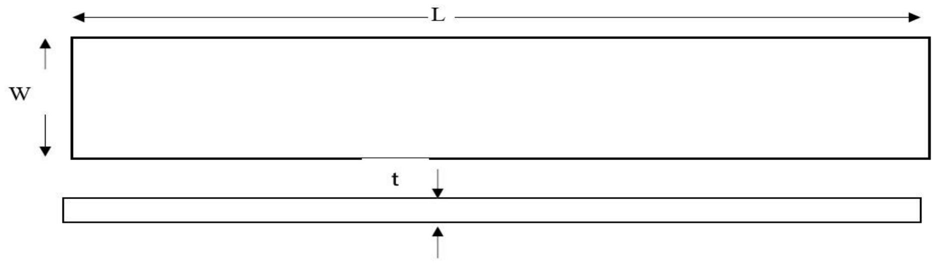


Figure 9. Flexural Test Specimen according to ASTM Standards [29].

Figure 10. Flexural Test Specimen.

Flexural Test Specimen Size

L = Length (150 mm); W=Width (20 mm); t = Thickness (5 mm)

MECHANICAL TESTING

Tensile Testing: The Tensile testing is a crucial component of the experimental analysis, conducted using the Nano 25 universal testing machine with a maximum load-carrying capacity of 25 KN. The test employs specimens of standardized dimensions (140 × 15 × 5 mm) following the ASTM D 3039-76 standard as shown in Figures 7 and 8. The specimen is securely mounted in the UTM, with one end fixed in a wedge grip while the load is applied to the other end. The testing conditions involve a deformation rate of 2 mm/min and a cyclic frequency of 0-65 Hz on a standard system and Figure 11 shows the test specimen after testing. The testing machine stands out for its virtually noiseless operation, high precision servocontrol, and fully automated system. Equipped with software capabilities, the

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machine generates comprehensive data, including stress-strain graphs, the number of cycles to fracture, elongation at the fracture point, and modulus of elasticity. Throughout the testing process, the digital display provides real-time information on load, elongation, stress, and yield point, capturing critical insights into the material's mechanical behavior under tension.

Flexural Testing: The fatigue testing machine (FTM) plays a pivotal role in the experimental setup, utilizing a 3-point bending fixture for testing. With a capacity of 25 KN and an adjustable span width range spanning from 35 to 100 mm, the FTM is versatile enough to accommodate flat specimens and those with a single edge bend. The machine features a roller with a 5 mm diameter, and its software capabilities enable the generation of crucial data, including load versus displacement graphs for various inputs. The testing procedure follows the ASTM D2344-84 standard, employing specimens sized at 150 × 20 × 5 mm as shown in Figure 9 and 10 and utilizing the 3-point bending technique. In this method, the load is concentrated at the center, and the initial span length of the specimen (L) is marked between the center lines of the support rollers. The specimen is then placed on the support rollers at the center, and a dial gauge is attached at the load point. The loading process initiates at the center, progressing at a rate of 1 mm/min as shown in Figure 12. The automated computer system captures and generates comprehensive results, providing insights into the material's behavior under fatigue conditions.

Figure 11. Test Specimen after testing.

Figure 12. Flexural specimen after testing.

RESULTS AND DISCUSSION

The tests are conducted in a universal testing machine. The results of the sample are tabulated in Table 7 shown below and the test specification is as shown in Table 8.

Tensile Test Specification

The potential observations and insights of the Tensile test results based on the provided data are:

1. *Comparison of Tensile Strength:* Trial 1 has a higher peak load (7.075 KN) compared to Trial 2 (6.253 KN) as shown in Figure13 and 14. Correspondingly, Trial 1 also exhibits a higher tensile strength (94.329 MPa) compared to Trial 2 (83.374 MPa) as shown in Figures 15 and 16.
2. *Consistency and Variability:* The variation in peak load and tensile strength between the two trials indicates some level of variability in the specimens or testing conditions. Further trials or additional data could help assess the consistency of the results.
3. *Quality of Specimens:* The tensile strength values provide insights into the quality and performance of the specimens under load. A higher tensile strength suggests better material performance in resisting axial loads.
4. *Application of Results:* The obtained tensile strength values can be used for design considerations, ensuring that the material can withstand expected loads in real-world applications.

Flexural Test

The results of the sample are tabulated in Table 9 shown below and the test specification is as shown in Table 10.

Table 7. Maximum Tensile strength of specimens.

Trial.no	Peak load in kN	Tensile Strength in MPa
1.	7.075	94.329
2.	6.253	83.374

Table 8. Tensile Test Specification

S.N.	Parameter	Values
1	Area	75 mm^2
2	Gauge length	110 mm
3	Width	15 mm
4	Thickness	5 mm
5	Rate	2 mm/min

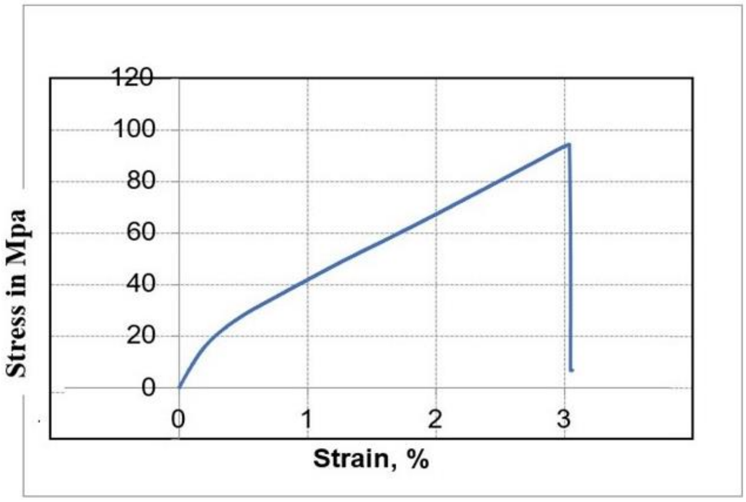

Figure 13. Trial-1 Stress v/s Strain.

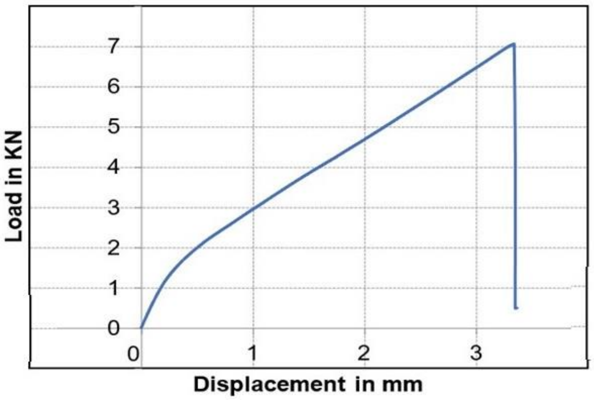

Figure 14. Trial-1 Load in KN v/s Displacement, mm.

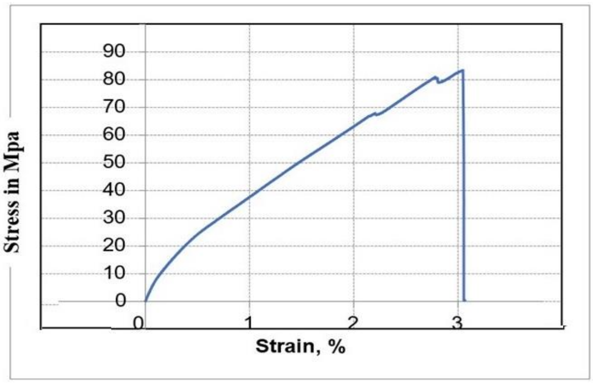

Figure 15. Trial-2 Stress v/s Strain.

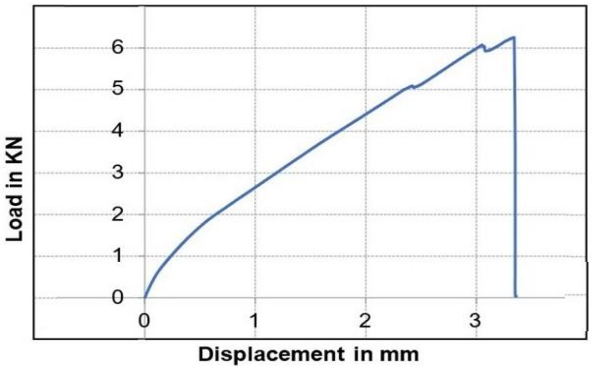

Figure 16. Trial-2 Load in KN v/s Displacement, mm.

Table 9. Maximum Flexural strength of specimen

Trial. No.	Peak load in kN	Flexural Strength in MPa
1.	0.4043	97.05
2.	0.326	78.32

Table 10. Flexural Test Specification

S.N.	Parameter	Values
1	Area	100 sq-mm
2	Span	80 mm
3	Width	20 mm
4	Thickness	5 mm
5	Rate	1 mm/min

Flexural Test Specification

The potential observations and insights of the Flexural test results based on the provided data are:

1. *Comparison of Flexural Strength:* Trial 1 exhibits a higher peak load (0.4043 KN) compared to Trial 2 (0.326 KN) as shown in Figures 17 and 18. Correspondingly, Trial 1 also shows a higher flexural strength (97.05 MPa) compared to Trial 2 (78.32 MPa) as shown in Figure 19 and 20.
2. *Flexural Strength Variation:* The data indicates a notable variation in flexural strength between the two trials. Understanding the reasons behind this variation is crucial for quality control and improvement.
3. *Quality of Specimens Under Flexural Load:* Flexural strength is a key property in materials science, especially for materials subjected to bending or flexural loads. Higher flexural strength suggests better resistance to bending forces.
4. *Consistency and Quality Control:* Consistency in flexural strength is essential for ensuring the reliability and predictability of the material's performance. Quality control measures may need to be implemented to reduce variability.
5. *Application of Flexural Strength Data:* The obtained flexural strength values can be used in structural engineering and design to ensure that the material can withstand bending stresses in real-world applications.

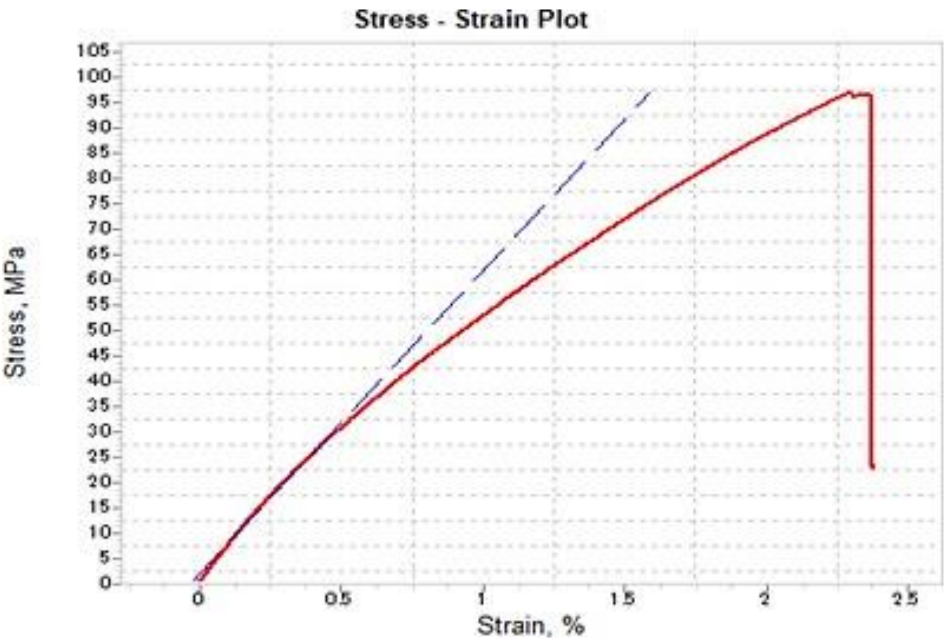

Figure 17. Trial-1 Stress v/s Strain.

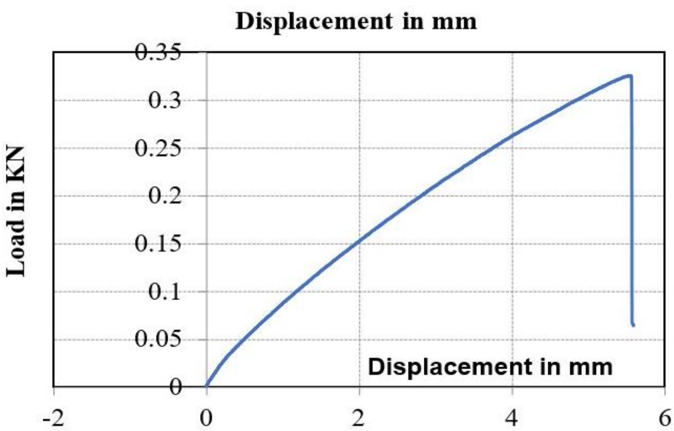

Figure 18. Trial-1 Load in KN v/s Displacement in mm.

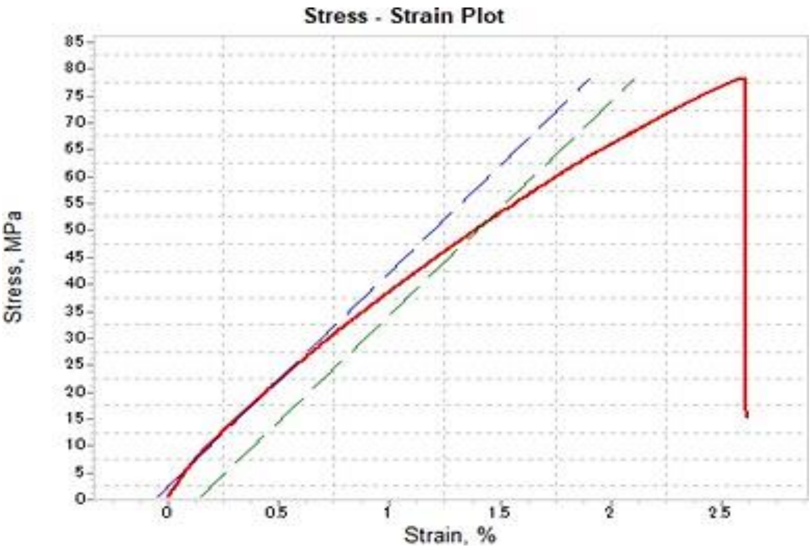

Figure 19. Trial-2 Stress v/s Strain.

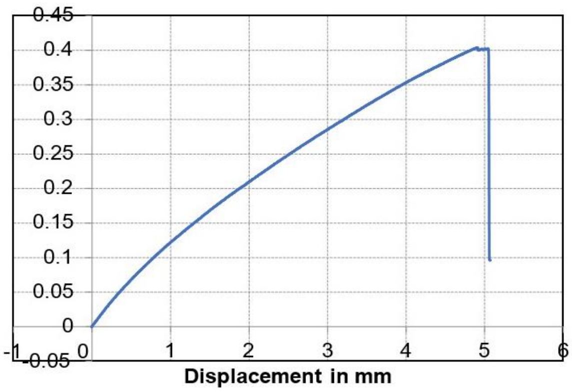

Figure 20. Trial-2 Load in KN v/s Displacement in mm.

CONCLUSIONS

In the course of this experimental study, a series of tests were conducted, and subsequent analyses yielded noteworthy conclusions. Composite specimens, integrating flax fiber and cenosphere as fillers, epoxy resin as the matrix, and K-6 hardener, underwent rigorous testing for both tensile and flexural strength. The specimens, meticulously prepared with a composition featuring 10 wt.% cenosphere, 50% epoxy resin, and 40% flax fibers, were crafted using the recommended vacuum bagging method for flax fiber. The first specimen showcased an impressive tensile strength of 94.329 MPa at the point of maximum load, equivalent to 7.075 kN. Meanwhile, the second specimen demonstrated a commendable tensile strength of 83.374 MPa, coinciding with a peak load of 6.253 kN. The first specimen exhibited a robust flexural strength of 97.05 MPa, reached at a peak load of 0.4043 kN. In comparison, the second specimen displayed a flexural strength of 78.32 MPa, corresponding to a peak load of 0.326 kN. These findings, delineating the material's capacity to withstand tension (tensile strength) and bending (flexural strength), are pivotal. Higher values signify superior performance, reflecting the maximum forces the composite can endure before failure under tension or bending conditions. The dual performance in tensile and flexural tests holds paramount importance in evaluating the overall mechanical robustness of the composite, thus influencing its potential suitability for diverse applications. A noteworthy revelation emerged when comparing the composite material, consisting of 10% cenosphere, 40% flax fiber, and 50% epoxy resin, with traditional plastic mud guards in bicycles. The composite exhibited superior tensile and flexural strength, suggesting promising applications as a replacement for synthetic plastic fibers. This underscores its potential to offer a biodegradable and eco-friendly alternative in relevant industries.

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