Fabrication and Performance Analysis of Multi-Phase Hybrid Composites with Glass Fiber, Jute Yarn, and Nano-Silica"

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ABSTRACT:

This study deals with the investigation of the effect of Nano – Silica powder on the mechanical properties of Glass Fiber Reinforced Composite with Jute yarn by using the comparative study method between Glass Fiber Reinforced composites with Epoxy, Jute and Nano Silica (GFEJNS) and Glass Fiber Reinforced Composites with Epoxy and Jute (GFEJ) This study presents a detailed characterization of glass reinforced epoxy composites hybridized with jute yarn and nano silica .The composites were fabricated using a hand layup technique, And the effects of nano silica addition on the composites properties were examined. The mechanical properties including tensile strength, flexural Strength, impact resistance and hard ness Were evaluated using standardized testing methods. The results show significant improvements in tensile strength (150.72N/mm²), Flexural strength (634.532N/mm²), impact strength (4.24J/mm²), and Rockwell Hardness Number (89), with the addition of nano silica. The study demonstrates the potential of nano silica and jute yarn hybridization for developing high-performance, eco-friendly composite materials. The findings of this research can be used to design and manufacture advanced composite structures for various industrial applications including aerospace, automotive, and construction. The results of this study provide valuable insights into the effects of nano silica addition on the properties of Glass Fiber Reinforced Composites with Epoxy, Jute yarn and Nano silica and highlight the potential of hybrid composites for sustainable and high-performance applications.

Keywords: Glass fibre, Nano silica, Jute yarn, Epoxy, Hybrid composites, Mechanical properties.

1.INTRODUCTION

Composite materials are revolutionizing various industries owing to their outstanding properties and versatility. The synergistic integration of natural fibers, such as jute, with glass fibers yields innovative materials that exhibit an optimal balance of eco-friendliness and high-performance capabilities. The incorporation of epoxy resin enhances durability, rendering these materials eminently suitable for a diverse array of applications. Ongoing research endeavors continue to unlock novel possibilities, thereby driving technological advancements and innovation. These materials hold considerable promise for the future, harmonizing sustainability with performance. Consequently, they are profoundly impacting the field of material science.

[1] M. M. Hasan et al. Heliyon 10 (2024) e40924, Researchers developed a composite material with epoxy, jute, and glass fibres, testing its physical, mechanical, and microstructural properties. The results showed improved durability and lightweight nature, with varying fibre configurations affecting performance, making it promising for various applications.[2] M. Ramesh, K. Hemachandra Reddy, Hybrid composites like sisal-jute-glass fibre reinforced polyester are gaining attention as eco-friendly alternatives to traditional materials, offering superior properties like high tensile strength and biodegradability. These innovative materials are poised to replace conventional options, providing a more sustainable solution for various applications. [3] Materials Research Express 6 (8), 085102, 2019, Researchers found that woven jute-glass hybrid composites can be more eco-friendly by partially replacing glass fibres, although tensile properties and fatigue life decreased, while jute fibres reduced fatigue sensitivity and stiffness degradation. [4] Fibers Polym 15, 1251–1262 (2014), By combining jute, flax, and glass fibres, hybrid natural fibre composites like Jute+ Flax+ GFRP offer a sustainable and cost-effective solution with enhanced mechanical properties, outperforming traditional Jute+ GFRP composites. [5] Subrata Chandra Das, Debasree Paul, Natural fibre composites like jute fabric reinforced polymer, Natural fibre composites like jute fabric reinforced polymer are emerging as eco-friendly alternatives to traditional glass fibre composites, offering a greener solution for non-structural applications in industries like automotive. [6] Hybrid Composites, Muftil Badria, [(68) 2: 82-87], 2024, Researchers have created a hybrid composite using pineapple leaf and glass fibres, achieving promising mechanical properties that make it a potential game-changer for lightweight and strong shipbuilding materials, like for unmanned speedboats. [7] Hybrid Advances 9 (2025) 100402, Researchers have created sustainable composite materials from rice straw and glass fibres,

offering excellent mechanical properties, eco-friendliness, and cost-effectiveness for various applications, from maritime to food packaging. [8] Hybrid Advances 9 (2025) 100416, Researchers in Indonesia have successfully developed bamboo-glass fibre hybrid composites that boast optimized strength-to-weight performance, paving the way for sustainable and high-performance materials in industries like sports and automotive. [9] Polymer Composites 42 (5), 2396-2407, 2021, Researchers created hybrid epoxy composites. They discovered that adding 2% silica nanoparticles greatly enhanced the materials' mechanical qualities and resistance to wear.[10] Materials Today: Proceedings 38, 584-589, 2021, By combining nano-silica and polypropylene fibres, researchers have created a stronger and more durable fibre-reinforced concrete, achieving significant improvements in compressive and tensile strength. [11] Polymers for advanced technologies 27 (10), 1308-1316, 2016, Researchers have developed a cost-effective glass-jute fibre composite that boosts strength and cuts costs by over 30%, making jute a promising substitute for glass fibres in various applications. [12] Structures 50, 954-962, 2023, Researchers investigated the vibration and bending properties of hybrid jute-glass fibre composite beams, using a combination of experiments and simulations to understand how different factors affect their performance. [13] A Fathy, M Abdel Hamid, Adding alumina and silica nanoparticles to glass fibre-reinforced epoxy composites boosts their tensile strength and fatigue life, with alumina having a greater impact, especially at optimal concentrations. [14] Journal of Composite Materials 48 (20), 2537-2547, 2014, Researchers discovered that jute-epoxy composites had better tribological qualities and better properties than neat epoxy, which made them appropriate for wear-resistant applications. [15] Akash Gupta, J. S. Saini, Researchers found that adding 3wt% nano-silica to glass fibre-reinforced epoxy composites enhances tensile and fatigue strength, but repeated stress still causes stiffness loss and damage over time.

2. Materials and Methodology

In this study, the mould is covered with the mylar film. The woven fibres are inserted directly into the mould and the resin is applied with the help of brush and the roller to obtain uniform thickness of resin. The raw materials used in this study consists jute yarn, woven glass fibre mats, nano silica, resin and hardener. Glass fibre of thickness 0.36 mm and the jute fibre thickness is 0.65mm was collected from Vaishnav composites, Hyderabad. Uni-directional glass-fibres mat of 360 GSM and Uni-directional jute fibres mat which are available commercially were taken for the reinforcement. Before stacking the fibres mats of piles together, the resin-hardener were mixed thoroughly, the filler material nano silica is also added to the resin-hardener and then mixed thoroughly according to the ratio.

2.1 Composite Fabrication Process

The hand layup process, a traditional composite material fabrication method, involves manual placement and shaping of fibres or fabrics within a mould. Researchers utilized this simple and cost-effective technique to create hybrid composites, opting for a plate shape. A mixture of 1 kg LY556 epoxy resin and 100 gm HY951 hardener (10:1 ratio) was prepared and applied in layers with glass and jute fibres. A cold press removed excess resin and air voids. Two hybrid composites were fabricated: one with glass fibres and jute yarn, and another with added nano-silica (3% of total weight). The nano-silica was mixed with epoxy resin and hardener at 60-150 rev/min. The composites were then prepared for further processing. This method offers flexibility and control, making it suitable for various industrial applications. The fabricated composites exhibit potential for advanced material applications. The two composite types had similar structures, with four jute mat layers and five layers of 360 GSM glass fibre. The main difference was the addition of nano-silica in the second type, which was mixed with the epoxy resin and hardener before application.

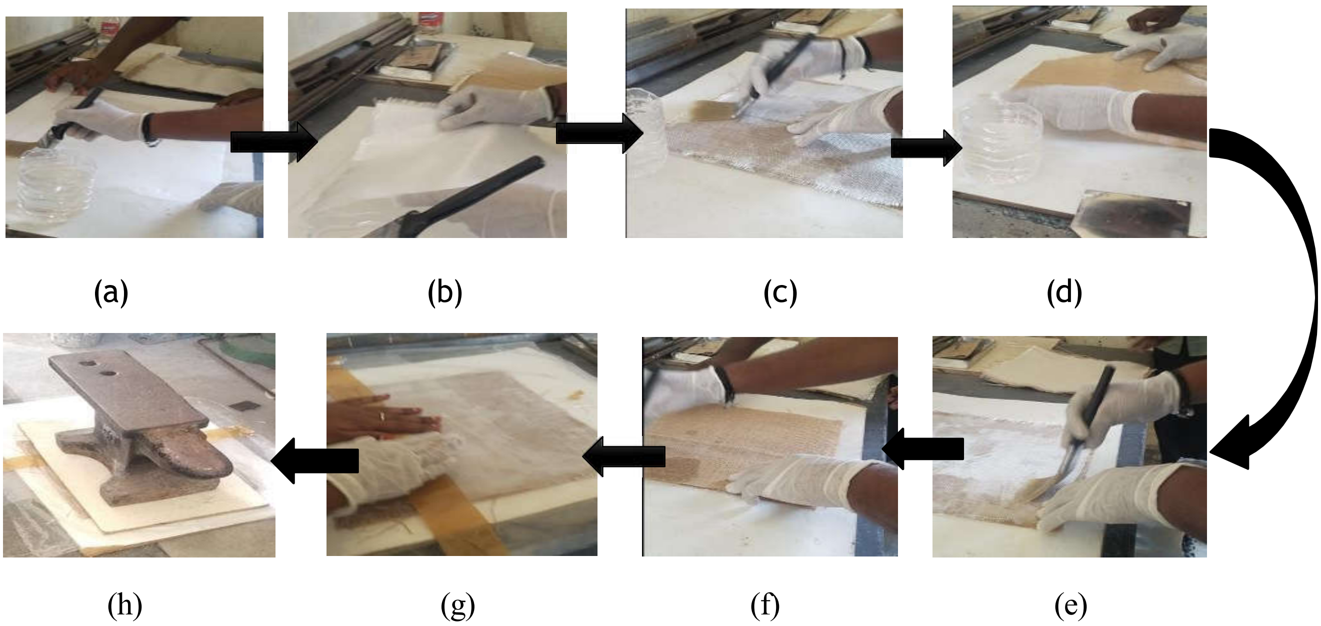


Fig.1. Flow Chart of Fabrication

The fabrication process involved several steps. Fig.1. (a), First, a mylar film was placed over the lower surface plate, and a resin-hardener mixture was poured over it. Fig.1. (b) Next, a layer of glass fibres was carefully positioned on top of the film. Fig.1. (c)The mixture was then

Rolled evenly over the glass layer. Fig.1. (d) a layer of jute fibers was added on top, similarly repeat the process until all the layers are placed layer by layer by following the arrangement as (G + F + G + F + G + F + G + F + G) followed by another application of the resin-hardener mixture, Fig.1. (e) Which was spread uniformly using a brush. Another layer of glass fibers was placed on top, and Fig.1. (f) Shows that the entire assembly was covered with polythene paper. Fig.1. (h) finally, a heavy load was applied to ensure proper bonding and to remove any air pockets and excess resin-hardener mixture. After the composite had set, it was collected and prepared for further processing.

Table.1. Composition of Hybrid Composites

Composite type	Arrangement	Thickness(mm)	Weight Fraction, %(fibre)	Weight fraction, %(matrix)
Type1- 0% filler	G+J+G+J+G+J+G+J+G	4.5 ±0.5	42.71	57.28
Type2- 3% filler	G+J+G+J+G+J+G+J+G	4.5±0.5	43.07	56.93

2.2 Evaluation of Mechanical Properties

To evaluate the mechanical properties of the fabricated composites, various tests were conducted following established standards. Tensile properties were assessed using a Tensile Testing Machine (Model-H 80310, 50KN capacity), while flexural properties were examined using a Tenos Meter (ASTM D79 M-86). Compressive properties were evaluated using a Universal Testing Machine (Model UTE-40), and impact properties were tested using an Impact Testing Machine with a capacity of up to 30 kgf-m. Additionally, hardness properties were measured using a Rockwell Hardness Testing Machine (Model RAB.250 & Twin). To ensure accurate and reliable results, specimens were carefully prepared according to the relevant standards. This comprehensive testing protocol provides valuable insights into the composite's mechanical behavior, enabling a thorough analysis of its potential applications.

2.2.1 TENSILE PROPERTIES

A Tensile Testing Machine with a maximum capacity of 50kN was used to perform tensile tests on specimens. The machine applied a gradually increasing tensile load until failure, recording load and displacement data to calculate properties like ultimate tensile strength and elongation at break. A stress-strain curve was generated, providing insight into the material's tensile behaviour. The test results were then analysed and reported, offering valuable information on the material's performance under tension.

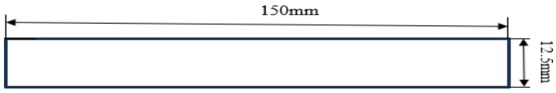


Fig.2. Tensile Test Specimen Dimensions

Fig.3. Tensile Test Specimen

Fig.4. Tenso meter arrangement

The tensile testing machine, model 1.5 G, S. No: 3037, is designed for evaluating the tensile properties of composite materials. With a maximum capacity of 5T (50 KN), it accurately measures the strength and durability of composites under tensile loads. This machine provides reliable data on material properties such as tensile strength, modulus, and strain, making it ideal for research, quality control, and material development in industries working with advanced composites. Its precise control and measurement systems ensure accurate and consistent results.

2.2.2 Flexural Properties

The preparation of specimens for evaluating flexural properties was conducted in accordance with the ASTM standard. To determine these properties, three-point bending tests were performed. Each specimen was prepared to be 20% longer than the support span length, allowing for adequate space and minimizing any potential edge effects. The tests were carried out using a Tenso meter. This setup enabled the collection of accurate and reliable data on the flexural properties of the specimens. The below fig 5.3.1 indicates the instrument setup and the fig5.3.2 shows the specimen dimensions 100mm*25mm.

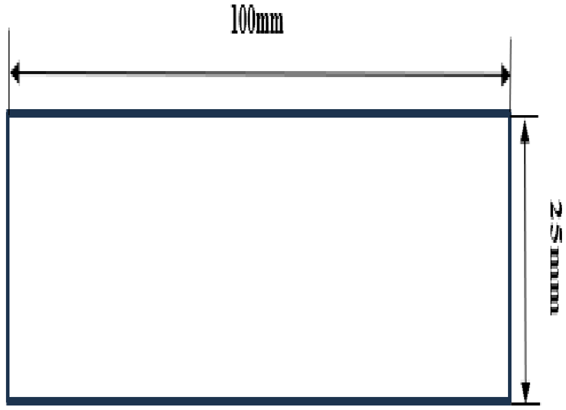


Fig.5. Flexural Test Specimen Dimensions **Fig.6. Flexural Test Arrangements**

A Tenso meter of ASTM D79M-86 is used to perform flexural tests, measuring a material's ability to withstand bending forces. The equipment applies a load to a specimen, typically a beam or rod, supported at two points. The tenso meter records the force and deformation data as the material bends. This data helps engineers understand the material's flexural strength and stiffness. The test provides valuable information for designing structures that are subject to bending loads.

2.2.3 Impact properties

The Izod impact test was conducted using an impact testing machine to evaluate the material's resistance to impact. Specimens with dimensions of 75mm x 10mm were prepared and securely mounted in the machine. The pendulum struck the notched specimen, measuring the energy absorbed during impact. The test results provided valuable insights into the material's toughness and resistance to cracking, helping engineers determine its suitability for applications where impact resistance is crucial.

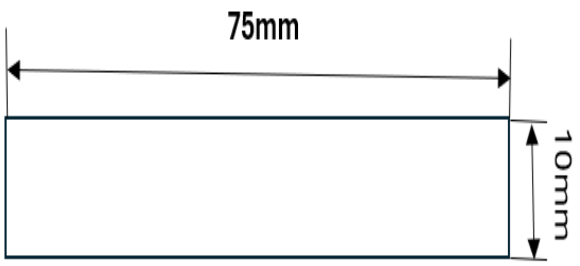


Fig.7. Impact Test Specimen **Fig.8. Impact Test Specimen Dimensions**

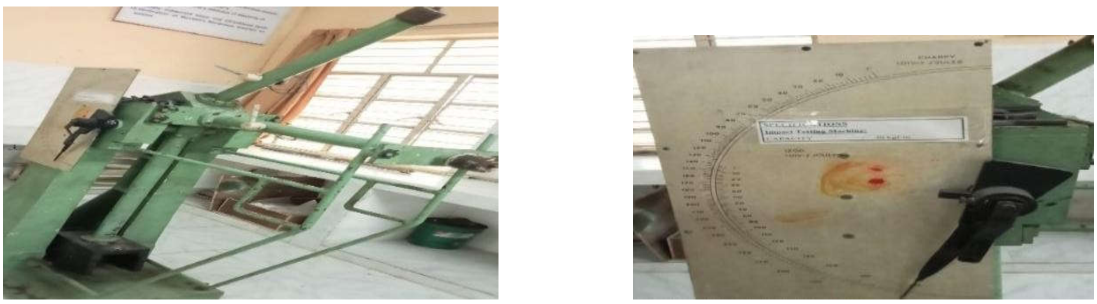


Fig.9. Impact Testing Machine

The Izod impact test is a widely used method to evaluate a material's resistance to impact. To perform the test, a rectangular bar specimen with a notch is carefully prepared to ensure a smooth surface finish. The specimen is then securely mounted in the impact testing machine, aligning it with the pendulum's striking edge. When the pendulum is released, it strikes and breaks the specimen, absorbing a certain amount of energy in the process. The energy absorbed during impact, measured in joules, indicates the material's toughness and resistance to cracking. by calculating the Izod impact strength, engineers can determine a material's suitability for applications where impact resistance is critical, providing valuable insights into its ability to withstand sudden impacts.

2.2.4 Hardness Properties

A Rockwell hardness test was conducted to evaluate the material's hardness. The specimen was placed on a testing machine, and a specific load was applied using a diamond or ball indenter. The indenter created an indentation, and the hardness value was determined by measuring the depth of penetration. The Rockwell hardness number (HR) was then calculated and reported, providing a quantitative measure of the material's resistance to indentation and hardness. This test offers valuable insights into the material's mechanical properties and performance.

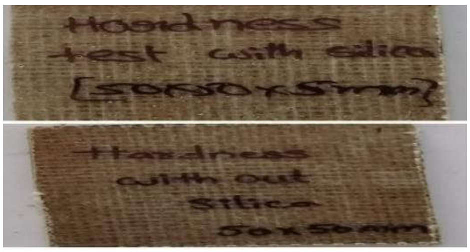


Fig.10. Hardness Specimen

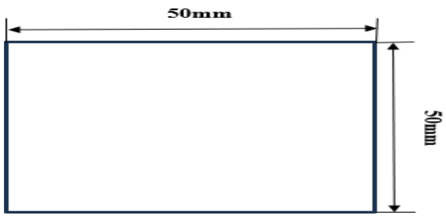


Fig.11. Hardness Specimen Dimensions

The Rockwell Hardness Testing Machine is used to measure the hardness of the specimen, here we have used the ball indenter of size 1/16 inches. The Rockwell hardness test uses a 1/16” ball indenter to measure the hardness of materials. This test is commonly used for softer materials like aluminium, copper, and mild steel. The test applies a minor load followed by a major load, and the hardness is determined by measuring the depth of indentation. The Rockwell B scale (HRB) typically uses a 1/16” ball indenter. The test is relatively quick and easy to perform, providing a numerical hardness value. The results are useful for evaluating material properties and ensuring consistency in production. The 1/16” ball indenter is suitable for materials with a moderate level of hardness.

Fig.1.2 Rockwell Hardness Testing Machine

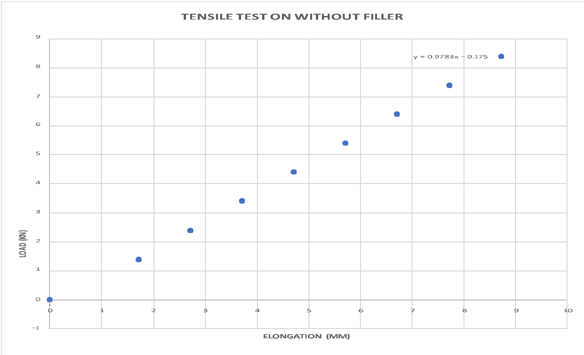
3. Results and Discussion

3.1 TENSILE TEST

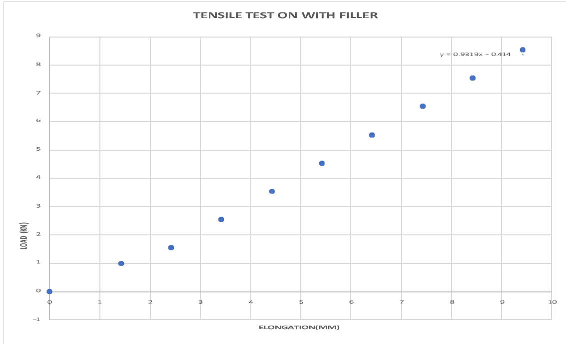
The tensile properties of the specimen were determined using the. The obtained data is presented in Table-2. It is observed that from the below table-2 the hybrid composite material with 3% of nano silica obtained the high tensile strength and young's modulus than the other composite with 0% of nano silica. That load carrying capacity of hybrid composite with 3% of nano silica is more than the other one.

Table-2 Results of Tensile Test

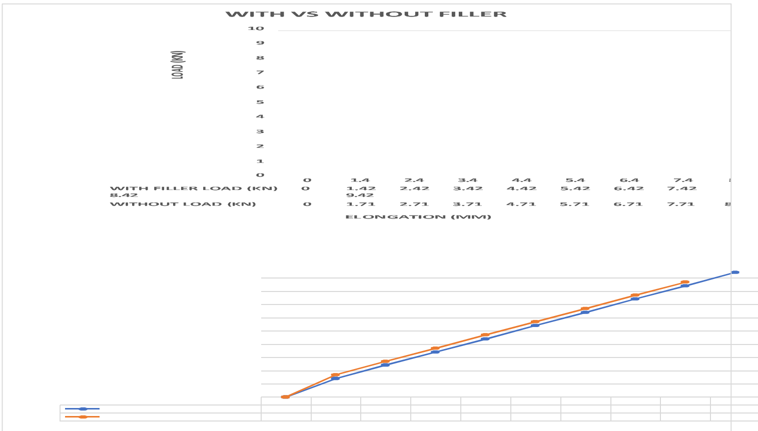
Nano Silica (%)	Load(N)	Elongation(mm)	Strength (N/mm^2)	Strain	Young's Modulus (N/mm^2)
0	8710	8.40	139.36	1.057	131.844
3	9420	8.54	150.72	1.056	142.728



Graph.1. Load vs Elongation of without Nano silica for tensile test

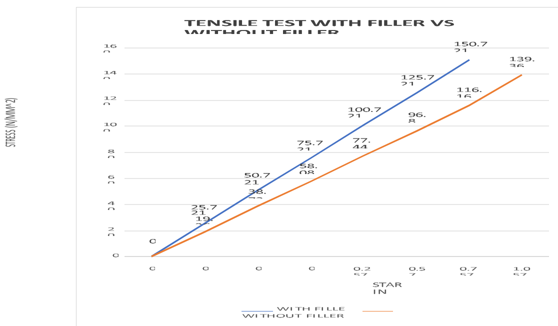


Graph.2. Load vs Elongation of With Nano-silica for tensile test



Graph.3. Load vs Elongation Comparison of With and Without Nano Silica for Tensile Test

The load vs displacement curve (Graph-1,2,3,) shows that, the hybrid composite with nano silica could take more load than other composite for a definite displacement. The hybrid composite with nano silica displaced more than the hybrid composite without nano silica prior to tensile loads because of the presence of 3% filler material. The results presented in this study are significantly higher than previous studies. The improvement of tensile properties is attributed to addition of nano silica.



Graph.4. Stress vs Strain for tensile test

The Graph-4 Shows stress-strain curves plotted above for all the hybrids. It is observed that, the hybrid composite with nano silica and without nano silica followed almost the same strain properties. But the composite with nano silica has more tensile strength, and load carrying capacity than the composite without nano silica, so it could take more tensile stress. Due to no filler material, the composite without filler material could take less tensile stress than other.

Fig.1.3 Tensile Specimen after Testing

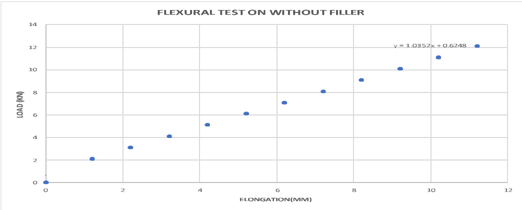
Under tensile load, hybrid composite specimens with and without silica exhibited similar failure modes, characterized by jute fiber breakage. The failure process began with matrix failure between the jute and glass fiber layers. As the load increased, the jute fibers eventually broke, leading to specimen failure. The hybrid composite with silica showed superior tensile properties, but both types ultimately failed due to fiber breakage. The failure mechanism involved delamination and fiber breakage, as evident in the images.

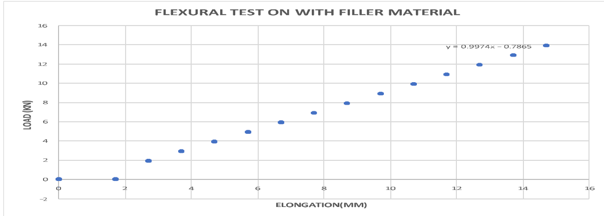
3.2 Flexural Test

A 3-point bending test was conducted to evaluate the flexural properties of hybrid composites. The results showed that the hybrid composite with nano silica outperformed the one without, exhibiting a flexural strength of 634.532 N/mm² and flexural Young's modulus of 1.9948 kN/mm². In contrast, the composite without nano silica had a flexural strength of 555.371 N/mm² and Young's modulus of 2.07 KN/mm². The addition of nano silica enhanced the material's flexural properties, making it more suitable for applications with bending load.

Table-3 Results of Flexural Test

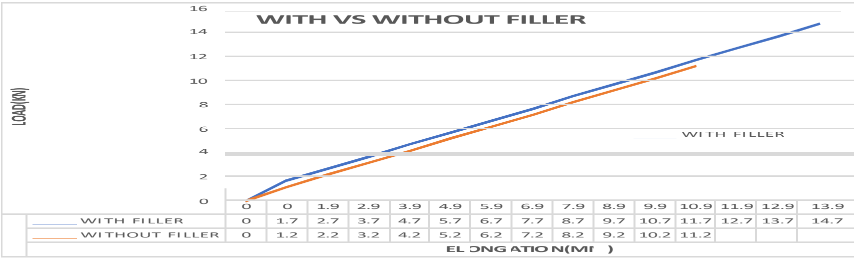
Nano Silica (%)	Load(N)	Elongation (mm)	Strength(N/mm²)	Strain	Young's modulus(N/mm²)
0	1120	12.10	555.371	0.268	2070.4
3	1470	13.9	634.532	0.318	1994.8





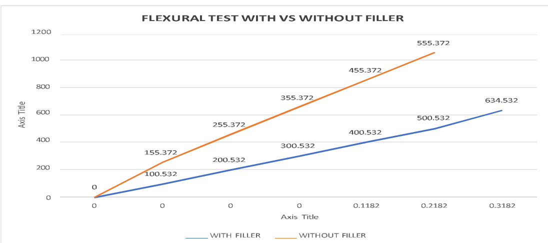
Graph.5 .Load vs Elongation of Without Nano Silica for Flexural Test

Graph.6 .Load vs Elongation of with Nano Silica for Flexural Test



Graph.7. Load vs Elongation Comparison of with and without Nano Silica for flexural test

The Gaphs-5,6and 7 presents the load and displacement curve under flexural load. The Graph -5 and 6 shows that the hybrid composites individual graphs of load and displacement. Whereas, the Graph-7 shows the comparison of both the hybrid composites with and without nano silica. The hybrid composite with nano silica possessed maximum strain, whereas the hybrid composite without nano silica obtained maximum Young’s modulus than the composite with nano silica. From the stress-strain curves of the composites (Graph-8), it is clear that the hybrid composite with nano silica showed the best stress vs strain properties.



Graph.8. Stress vs Strain for Flexural Test

Fig.1.4 Flexural Specimen after Testing

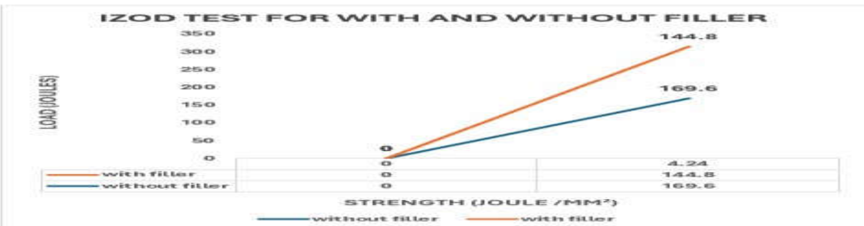
From the above-fractured pictures of specimens, as shown in Fig.30, it is clear that due to 3-point bending, the upper surfaces of the specimen faced contraction, and the lower surfaces faced expansion. When the downward forces reached the capacities of the specimens, they failed. It can be seen that the glass-fibre layer didn't fail at all, as the upper surface and the lower surface are made of glass fibre.

3.3 Impact Test

The Izod testing method is taken to calculate the impact strength of the hybrid composites. An impact Izod test determined the impact strength of hybrid composites. The impact test results are presented in Table-5. The hybrid composite with nano silica exhibited an impact load of 169.6 J and an impact strength of 4.24 J/mm². In contrast, the composite without nano silica had an impact load of 144.8 J and an impact strength of 3.62 J/mm². The results indicate that the addition of nano silica improved the material's impact resistance, resulting in higher impact load and strength values.

Table-4 Results of Impact test

Nano Silica (%)	Energy (J)	Impact Strength(J/mm²)
0	144.8	3.62
3	169.6	4.24



Graph. .9 Load vs Impact Strength comparison of with and without Nano Silica

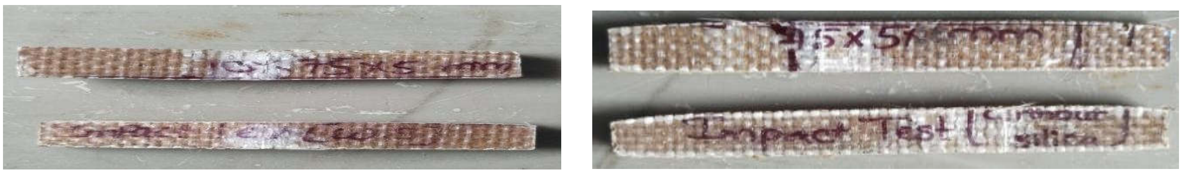


Fig.15. Impact Specimen after Testing

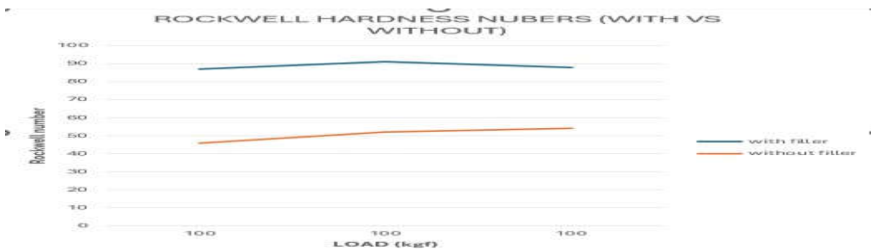
The addition of nano silica significantly enhanced the composite's impact resistance, enabling it to absorb more energy and withstand higher impact forces. This makes the hybrid composite with nano silica a better choice for applications where impact resistance is critical. The nano silica reinforcement played a crucial role in improving the composite's impact properties.

3.4 Hardness Test

The hardness of the specimens was evaluated using a Rockwell hardness tester with ball indenter of size 1/16 inch, and the results are presented in Table-4. According to the data, the hybrid composite material with 3% nano silica demonstrated higher hardness values compared to the composite without nano silica (0%). This suggests that the incorporation of 3% nano silica enhances the material's resistance to surface deformation and indentation, resulting in improved hardness properties. The increased hardness of the 3% nano silica composite indicates its potential for better performance in applications where surface durability is crucial.

Table-5 Results of hardness test

Nano silica (%)	Hardness number (BHN)	Average hardness number (BHN)
0	46	51
	52	
	54	
3	87	89
	91	
	88	



Graph.10. RHN vs Load Comparison of with and without Nano Silica

The hardness test results are presented in Graph-9. From the Rockwell hardness test results, it is evident that the hybrid composite with nano silica demonstrated superior hardness compared to the composite without nano silica. The incorporation of nano silica led to increased resistance to surface deformation, resulting in higher hardness values. This suggests that the hybrid composite with nano silica possesses improved surface properties, making it more suitable for applications where hardness and durability are essential. The test results clearly show the positive impact of nano silica on the hardness characteristics of the hybrid composite.

Fig.1.6 Hardness Specimen After Testing

4. Conclusion Future Scope

From the obtained numerical and experimental result it was found that the well laminated Glass Fiber Reinforced with Epoxy, Jute Fiber and Nano Silica (GFEJNS) having more strength also lesser weight when compared to that of other laminate Glass Fiber Reinforced with Epoxy and Jute Fiber (GFEJ). This project, "Characterization of Glass Fiber Reinforced with Epoxy, Jute Fiber, and Nano Silica/With Epoxy and Jute Fiber," aimed to investigate the mechanical properties of hybrid composites with and without nano silica. The results revealed that the composite with nano silica exhibited improved strengths and properties, including: Enhanced tensile strength, increased impact strength, improved hardness, higher flexural strength and Increased Young's modulus. However, the composite with nano silica showed slightly lower compressive strength compared to the composite without nano silica. The addition of nano silica significantly enhanced the load-carrying capacity of the hybrid composite. Based on the findings, it can be concluded that the glass fiber reinforced with epoxy, jute fiber, and nano silica composite is a suitable material for various applications. The improved properties of the composite with nano silica make it an attractive option for industries such as automotive, aerospace, and construction. The results of this study can be used to inform the design and development of composite materials with properties for specific applications, highlighting the benefits of adding the nano silica in hybrid composites. Future research directions include optimizing nano silica content, exploring other nano materials, and scaling up to industrial applications. Investigating the sustainability and recyclability of these composites will also be crucial. Theoretical modelling can help predict material behavior, enabling more efficient design. Additionally, testing in real-world conditions will validate the performance of hybrid composites. This study's findings can pave the way for developing advanced materials. Further exploration of multi-functional composites can also unlock new applications.

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