Evaluation of Mechanical Properties of Jute Fibre Reinforced Epoxy Composites Filled with TiO_2 Nanoparticles

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Abstract- Natural fibre reinforced polymer composites are gaining wide attention due to low density, biodegradability, cost-effectiveness, and acceptable mechanical performance. Among natural fibres, jute is widely preferred because of its good strength characteristics and easy availability; however, its mechanical behaviour can be improved further using nano-fillers. In this study, titanium dioxide (TiO_2) nanoparticles were added to jute fibre reinforced epoxy composites to evaluate their effect on mechanical properties. Composite laminates were fabricated using a vacuum-assisted hand lay-up technique with TiO_2 contents of 0%, 1%, 1.5%, and 2% by weight, using alkali-treated jute fibres for improved fibre–matrix adhesion. Specimens prepared as per ASTM standards were tested under tensile, fatigue, and Brinell hardness conditions. SEM analysis was conducted to observe fracture morphology and fibre–matrix interaction. Finite element analysis (FEA) was carried out in ANSYS Workbench under tensile loading to validate experimental results through stress, strain, and deformation behaviour. Results indicated that TiO_2 content significantly influenced composite performance, The composite containing 1.5% TiO_2 exhibited optimum performance, achieving a maximum tensile strength of 18.50 MPa along with improved fatigue life and interfacial bonding. Excess filler content caused agglomeration and reduced properties. ANSYS results showed good agreement with experimental outcomes, confirming model accuracy.

Keywords: Jute fibre, Epoxy composite, Titanium dioxide (TiO_2), Mechanical properties, ANSYS, SEM

I. INTRODUCTION

Natural fibre reinforced polymer composites have gained considerable attention due to their low density, biodegradability, renewability, and cost-effectiveness, making them suitable for lightweight and eco-friendly engineering applications [3][4][12]. In comparison to conventional synthetic fibre composites such as glass and carbon fibre, natural fibre composites offer improved sustainability with reduced environmental impact.

Among natural fibres, jute is widely available in India and provides good specific mechanical properties, making it a promising reinforcement for polymer composites [1][3]. However, jute fibre composites often exhibit limitations such as moisture sensitivity, weak fibre–matrix bonding, and reduced durability under cyclic loading, which restrict their use in load-bearing applications [2][4].

To overcome these drawbacks, the incorporation of nano-fillers into the polymer matrix is an effective approach to improve mechanical performance [5][6]. Titanium dioxide (TiO_2) is considered a suitable filler due to its high hardness, thermal stability, and compatibility with epoxy matrices, which enhance strength, stiffness, and fatigue resistance [7][8][10][11].

In the present study, jute fibre reinforced epoxy composites filled with TiO_2 nanoparticles (0%, 1%, 1.5%, and 2% by weight) were fabricated using a vacuum-assisted hand lay-up technique. The composites were evaluated through tensile, fatigue, and Brinell hardness testing as per ASTM standards. Fracture morphology was examined using SEM, and tensile behaviour was validated using ANSYS Workbench simulation.

II. LITERATURE REVIEW

Several studies have reported that jute fibre reinforced polymer composites provide moderate mechanical performance with strong potential for lightweight structural applications [1][3][4].

Previous research indicates that alkali treatment of jute fibres improves fibre–matrix adhesion and significantly enhances tensile properties and durability [2].

Recent investigations have explored the use of micro- and nano-fillers to improve composite strength, stiffness, hardness, and fatigue resistance [5][6]. Among various fillers, TiO_2 has shown promising results in enhancing mechanical behaviour due to its hardness, thermal stability, and stable microstructure [7][8][9].

Studies on nano-TiO_2 reinforced epoxy systems have demonstrated improvements in tensile strength, thermal stability, and wear resistance [7][8][11]. Furthermore, hybrid natural fibre composites containing TiO_2 fillers have shown better interfacial bonding and improved mechanical response compared to unfilled composites [10].

However, limited literature is available on combined experimental evaluation of tensile–fatigue behaviour along with ANSYS validation for TiO_2-filled jute epoxy composites. Therefore, the present study focuses on evaluating and comparing the mechanical properties of jute epoxy composites with varying TiO_2 content through experimental testing, SEM analysis, and numerical simulation.

Objectives

- To fabricate jute fibre reinforced epoxy composites with TiO_2 filler.
- To evaluate tensile, fatigue and hardness properties as per ASTM standards.
- To examine fracture morphology using SEM.
- To validate tensile response using ANSYS Workbench.

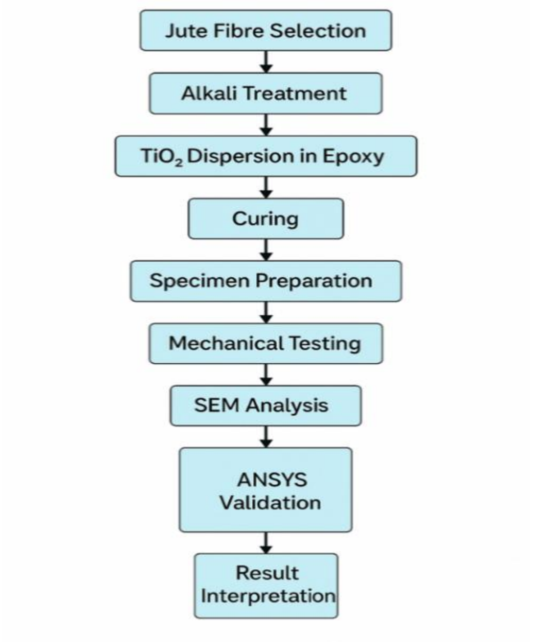
Scope of the Work

The scope of the present work is limited to the evaluation of mechanical properties of jute fibre based polymer composite reinforced with Titanium Oxide. The work includes:

- Fabrication of jute fibre reinforced polymer composite specimens
- Incorporation of Titanium Oxide in varying weight percentages
- Conducting Tensile Test, Fatigue Test, and Brinell Hardness Test
- Performing SEM analysis for microstructural examination
- FE analysis of specimens using ANSYS Workbench
- Comparative study of experimental and numerical results

The study is confined to limited filler percentages and specific testing conditions, which helps in obtaining consistent and reliable results.

III. MATERIALS AND METHODOLOGY



Alkali-treated jute fibres were used as reinforcement, epoxy resin as the matrix material, and Titanium Oxide (TiO_2) nano-particles as filler. Composite laminates were fabricated using the vacuum assisted hand lay-up technique to reduce void formation and ensure uniform resin distribution. TiO_2 content was varied as 0%, 1%, 1.5%, and 2% by weight.

Tensile tests were conducted as per ASTM D638, fatigue tests were carried out under tension–tension loading according to ASTM D3479, and Brinell hardness tests were performed following ASTM E10. Fracture morphology was examined using Scanning Electron Microscopy (SEM). Finite element simulations were performed using ANSYS Workbench to validate experimental results.

Materials

Alkali-treated jute fibres were used as reinforcement, epoxy resin as matrix and TiO_2 nanoparticles as filler. Composite laminates were fabricated by vacuum assisted hand lay-up technique. TiO_2 content was varied as 0%, 1%, 1.5% and 2% by weight.

Jute Fibre and Alkali Treatment

Jute fibres were treated using 5% NaOH solution for 4–6 hours, washed to neutral pH and dried at room temperature. This treatment improves surface roughness and interfacial bonding with epoxy resin.

Fig. Alkali Treated jute fibres

Table 1: Physical and Mechanical Properties of Jute Fibre

Property	Typical Value	Unit
Density	1.3 – 1.5	g/cm³
Tensile Strength	300 – 800	MPa
Young's Modulus	20 – 30	GPa
Moisture Absorption	10 – 12	%

Epoxy Resin

Epoxy resin and hardener were mixed in 10:1 ratio by weight to ensure proper curing and uniform properties.

Table 2: Properties of Epoxy Resin

Property	Value	Unit
Density	1.15 – 1.20	g/cm³
Tensile Strength	70 – 90	MPa
Elastic Modulus	2.5 – 3.5	GPa
Curing Time	24	hours

Titanium Oxide (TiO_2) Nanoparticles

TiO_2 nanoparticles were incorporated to improve stiffness, hardness and fatigue resistance. TiO_2 content was varied as shown in Table 3.

Table 3: Composite Sample Designation

Sample Code	TiO_2 Content (wt%)
S1	0
S2	1
S3	1.5
S4	2

Table 4: Properties of TiO_2 Nanoparticles

Property	Value	Unit
Particle Size	40 – 60	nm
Density	4.23	g/cm³
Thermal Stability	1843	°C

Fig. TiO_2 nano powder

Table 5: Material Composition and Total Weight of Jute Fibre–Epoxy–TiO_2 Composites

Sample ID	TiO_2 Content (wt%)	Jute Fibre (g)	Epoxy Resin (g)	Hardener (g)	Total Matrix (g)	TiO_2 (g)	Total Composite Weight (g)
S1	0	44	176.0	17.6	193.6	0.000	237.6
S2	1.0	44	176.0	17.6	193.6	1.936	239.536
S3	1.5	44	176.0	17.6	193.6	2.904	240.504
S4	2.0	44	176.0	17.6	193.6	3.872	241.472

The material requirements for the jute fibre–epoxy composite were calculated on a weight basis. An epoxy resin to hardener ratio of 10:1 was maintained. Four layers of jute fibre were used, each weighing 11 g, giving a total fibre weight of 44 g. The total epoxy resin required was 176 g, and the corresponding hardener weight was 17.6 g. Thus, the total matrix weight was 193.6 g. Titanium dioxide (TiO_2) nanoparticles were added as a weight percentage of the total matrix. Accordingly, TiO_2 contents of 0%, 1%, 1.5%, and 2% correspond to 0 g, 1.936 g, 2.904 g, and 3.872 g, respectively.

Specimen Preparation

Composite laminates were cured for 24 hours and cut as per ASTM standards. Specimen dimensions are listed in Table 5.

Fig. Vacuum-assisted Hand lay-up Process

The fabrication procedure of the TiO_2-filled epoxy composite using a vacuum-assisted method is illustrated in the figure series. Initially, the mold surface is cleaned and prepared as shown in Fig. 1(a). Epoxy resin and TiO_2 nanoparticles are accurately weighed (Fig. 1(b)) and mixed thoroughly to achieve uniform dispersion (Fig. 1(c–d)). The prepared resin mixture is then poured onto the reinforcement placed in the mold (Fig. 1(e–f)). After lay-up, the assembly is covered with vacuum bagging materials (Fig. 1(g–h)) and sealed. Vacuum pressure is applied (Fig. 1(i)) to remove entrapped air and excess resin, ensuring proper impregnation and reduced void content before curing (Fig. 1(j)).

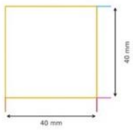
Table 6: Specimen Dimensions as per ASTM Standards

Test	ASTM Standard	Length (mm)	Width (mm)	Thickness (mm)
Tensile	D638	150	25	3.5
Fatigue	D3479	125	12.7	3.5
Hardness	E10	40	40	3.5
SEM	—	10	10	3.5

1. Tensile Test Specimen
Dimensions: 150 mm × 25 mm × 3.5mm
Shape: Rectangular

2. Fatigue Test Specimen
Dimensions: 125 mm × 12.7 mm × 3.5mm
Shape: Rectangular

3. BHN Hardness Test Specimen
Dimensions: 40 mm × 40 mm × 3.5mm
Shape: Square



4. SEM Analysis Specimen
Dimensions: 10 mm × 10 mm × 3.5mm
Shape: Square

Experimental Testing

Tensile, fatigue and hardness tests were carried out as per respective ASTM standards. SEM and ANSYS validation were performed.

Table 7: Tensile Test Conditions

Parameter	Value
Crosshead Speed	2 mm/min
Load Capacity	25 kN
Temperature	27°C

Table 8: Fatigue Test Parameters

Parameter	Value
Stress Ratio (R)	0.1
Frequency	5 Hz
Maximum Cycles	10^6

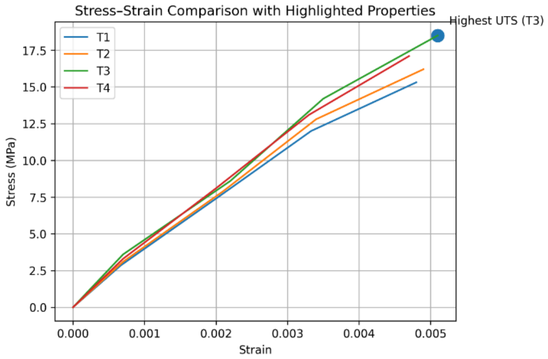
Table 9: Brinell Hardness Test Conditions

Parameter	Value
Load	500 kgf
Indenter Diameter	10 mm
Dwell Time	15 sec

RESULTS AND DISCUSSION

Tensile Behaviour

The tensile properties of the composites improved with the addition of TiO_2 up to 1.5%. The neat composite (0% TiO_2) exhibited an ultimate tensile strength of 15.31 MPa, whereas the composite containing 1.5% TiO_2 achieved a maximum tensile strength of 18.50 MPa, representing a significant improvement. A reduction in tensile strength was observed for the 2% TiO_2 composite due to particle agglomeration and stress concentration effects.



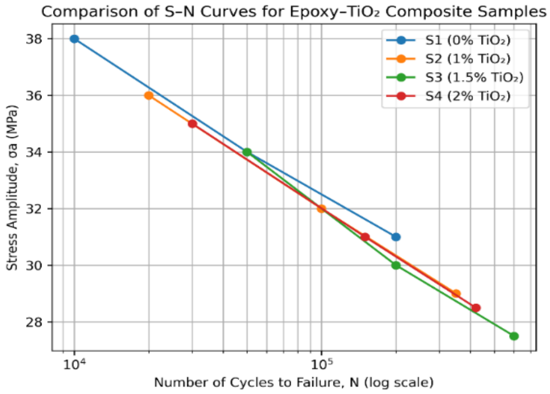
Graph 1. Stress–strain curves of jute fibre epoxy composites with varying TiO_2 content.

Table 10. Tensile properties of jute fibre epoxy composites

Sample	TiO_2 (%)	Young's Modulus (GPa)	UTS (MPa)
S1	0	3.43	15.31
S2	1	3.70	16.20
S3	1.5	4.10	18.50
S4	2	3.80	17.10

Fatigue Behaviour

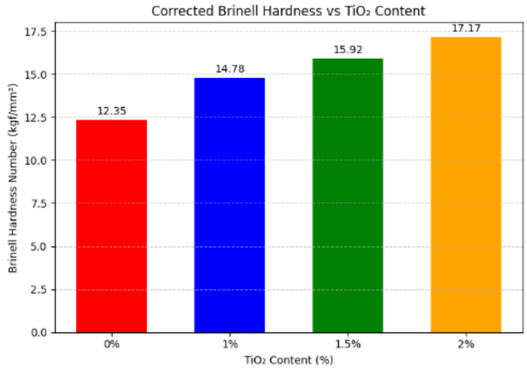
Fatigue test results showed a substantial improvement in fatigue life with TiO_2 addition. The neat composite exhibited a fatigue life of approximately 2×10^5 cycles, while the composite containing 1.5% TiO_2 showed the highest fatigue life of about 6×10^5 cycles. Improved fibre–matrix bonding and increased stiffness contributed to delayed crack initiation and propagation.



Graph 2. S–N curves showing fatigue performance of jute fibre epoxy composites.

Hardness Behaviour

Brinell hardness values increased with increasing TiO_2 content. The neat composite exhibited a hardness value of 12.35 BHN, while the 2% TiO_2 composite showed the highest hardness of 17.17 BHN, owing to the presence of hard ceramic particles that resisted surface deformation.



Graph 3. Variation of Brinell hardness number with TiO_2 content.

SEM Analysis

The low-magnification SEM image of Sample S1 reveals non-uniform fibre distribution within the epoxy matrix, along with the presence of visible voids and porosity. These voids (marked A) indicate incomplete resin impregnation during fabrication, while the fibre bundles (marked B) appear loosely packed. The absence of TiO_2 nanoparticles results in poor matrix flow and inadequate filling of inter-fibre spaces. Such defects act as stress concentration sites and significantly reduce the load transfer efficiency, leading to early damage initiation under mechanical loading.

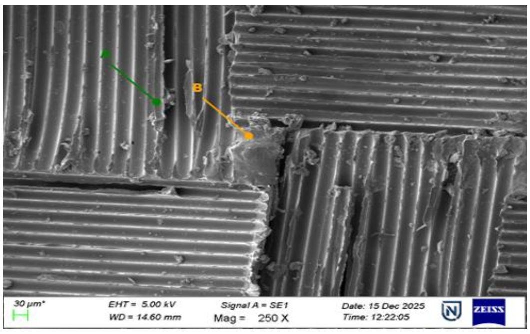
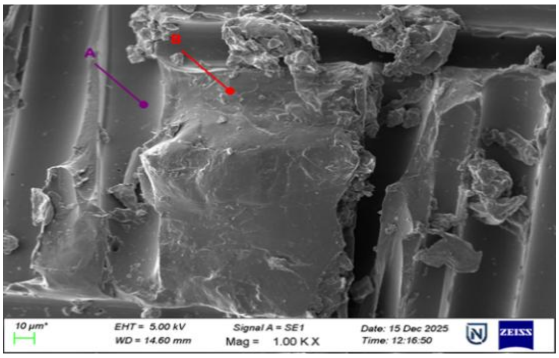


Fig. Medium Magnification of Sample 1

ii)Observation (Figure–MediumMagnification):

The medium-magnification SEM image clearly shows extensive fibre pull-out (marked A) and fibre–matrix interfacial debonding (marked B). The pulled-out fibres exhibit smooth surfaces, confirming weak interfacial adhesion between the jute fibres and epoxy matrix. This weak bonding is primarily due to the absence of nanoparticle reinforcement, which normally enhances interfacial strength. As a result, load transfer from matrix to fibre is inefficient, contributing to lower tensile strength and reduced fatigue resistance of Sample S1.



Fig, High Magnification of Sample

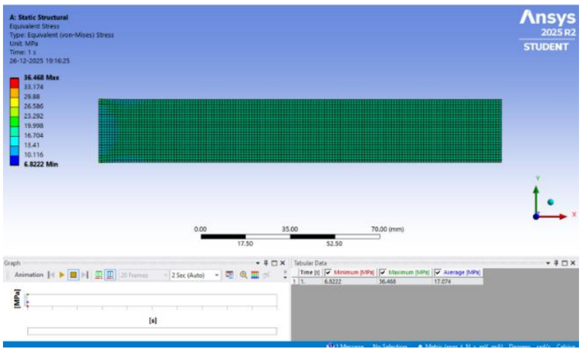
iii)Observation(Figure–HighMagnification):

The high-magnification SEM image highlights matrix cracking (marked A) and micro-void formation (marked B) within the epoxy phase. Crack initiation and propagation are predominantly observed along the fibre–matrix interface, indicating interfacial weakness. The micro-voids further accelerate crack growth by acting as local stress raisers. These microstructural features explain the brittle fracture behaviour, minimum hardness, and inferior mechanical performance of Sample S1 compared to TiO_2-filled composites

ANSYS Validation

ANSYS simulation results for stress and deformation were in good agreement with experimental observations. The numerical analysis confirmed that the composite containing 1.5% TiO_2

experienced lower stress concentration and deformation compared to other compositions.



A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
26-12-2025 19:16:25

	Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1	1.	6.8222	36.468	17.074

Fig 5. ANSYS-predicted von Mises stress distribution for 1.5% TiO_2 composite.

CONCLUSIONS

The mechanical behaviour of jute fibre reinforced epoxy composites filled with TiO_2 nanoparticles was investigated through tensile, fatigue, Brinell hardness and SEM analysis along with ANSYS validation. The following conclusions are drawn:

1. The neat composite (S1: 0% TiO_2) exhibited the lowest tensile strength (15.31 MPa), fatigue life (~2×10^5 cycles) and hardness (12.35 BHN) due to weaker fibre–matrix bonding and higher void content.
2. The addition of TiO_2 improved tensile strength, Young's modulus, fatigue resistance and hardness due to enhanced interfacial adhesion and restricted matrix deformation.
3. Sample S3 (1.5% TiO_2) showed the best overall performance with maximum tensile strength of 18.50 MPa and Young's modulus of 4.10 GPa.
4. Experimentally, S3 exhibited the highest fatigue life of approximately 6×10^5 cycles, indicating delayed crack initiation and improved durability.
5. Sample S4 (2% TiO_2) showed the maximum hardness value; however, a slight reduction in tensile and fatigue behaviour was observed due to nanoparticle agglomeration.
6. SEM observations confirmed improved fibre–matrix interaction for S3, while S4 showed filler clustering and microstructural non-uniformity.
7. ANSYS Workbench simulation results showed good agreement with experimental tensile behaviour, validating the numerical model for predicting composite response.

REFERENCES

[1] Sathishkumar, T. P., Naveen, J., & Satheeshkumar, S. (2022). Mechanical characterization of woven jute fibre reinforced epoxy composites with filler addition. E3S Web of Conferences, 309, 01045.

[2] Suthenthiraveerappa, M., Prakash, R., & Ramesh, M. (2024). Tensile behaviour of basalt/jute hybrid composites and effect of alkali treatment. Journal of Natural Fibers, Taylor & Francis.

[3] Iqbal, M., Rahman, M. M., & Hasan, M. (2024). Manufacturing methods and mechanical properties of jute fibre reinforced polymer composites. Preprints.

[4] Shakir, A., Jawaid, M., & Sultan, M. T. H. (2024). A review on jute fibre and hybrid jute composites: Mechanical performance and applications. Journal of Reinforced Plastics and Composites, Wiley.

[5] Ramasamy, D., Karthikeyan, R., & Kumar, P. (2024). Effect of SiC and Al2O3 fillers on mechanical behaviour of ramie/jute epoxy composites. Journal of Composite Materials, SAGE Publications.

[6] Ben Samuel, O., et al. (2023). Mechanical, wear and fatigue behaviour of nanosilica reinforced areca fibre epoxy composites. Journal of Materials Research and Technology, Springer.

[7] Sagar, R., Kumar, A., & Singh, S. (2022). Mechanical and thermal properties of nano-TiO2 filled epoxy composites. Materials Today: Proceedings.

[8] Madhu, K., Reddy, P. R., & Rao, V. S. (2022). Influence of nano-TiO2 on mechanical and thermal behaviour of epoxy composites. Materials Today: Proceedings.

[9] Natrayan, L., et al. (2023). Cryogenic mechanical behaviour of nano-TiO2 filled Kevlar/epoxy composites. Frontiers in Materials, 10, 1178452.

[10] Arunachalam, R., & Saravanan, S. (2024). Effect of nano-TiO2 on mechanical properties of jute/kenaf/glass hybrid composites. SRS Journal of Materials Science.

[11] Maloth, R., et al. (2025). Mechanical and tribological performance of Al2O3 and TiO2 reinforced epoxy composites. Tribology International, Elsevier.

[12] Habib, F., Jawaid, M., & Thariq, M. (2025). Fabrication and tensile behaviour of natural fibre reinforced polymer composites – A review. Polymer Composites, Springer