

Mechanical Characterization of Jute -Coconut Shell Hybrid Epoxy Laminates

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Abstract : Natural fiber-reinforced composites are increasingly used due to their sustainability and lightweight characteristics. This study examines jute fiber-reinforced polymer composites with coconut shell powder filler (0–6 wt%) fabricated via the hand lay-up method. Mechanical properties were evaluated using tensile, flexural, and impact tests, while thermal behavior was analyzed through Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC). The control composite (0 wt%) showed the highest mechanical performance, with tensile strength of 152.2 MPa, flexural strength of 186.28 MPa, and impact toughness of 10.83 kJ/m². Thermal analysis indicated variations in glass transition temperature and improved stability at optimized filler content. SEM analysis revealed fiber–matrix interaction and filler dispersion. The results demonstrate the effect of coconut shell powder on composite performance and its potential in eco-friendly applications.

Key Words - Jute Fiber, Coconut Shell Powder, Mechanical Tests, Thermal Analysis(TGA, DSC), SEM

INTRODUCTION

The growing need for sustainable and eco-friendly materials has accelerated the development of natural fiber-reinforced polymer composites as alternatives to conventional synthetic composites. Among natural fibers, jute has gained significant attention due to its low cost, biodegradability, wide availability, and satisfactory mechanical properties. However, the performance of jute-based composites can be further

improved through hybridization and the incorporation of particulate fillers.

Coconut shell powder, an abundant agricultural waste, has emerged as a promising filler material due to its high hardness, good thermal stability, and environmental compatibility. The combination of jute fiber and coconut shell powder in an epoxy matrix offers the potential to enhance mechanical strength, stiffness, and thermal behavior while maintaining sustainability.

In this study, hybrid epoxy laminates reinforced with jute fiber and coconut shell powder were fabricated using the hand lay-up technique. The influence of filler content on mechanical and thermal properties was systematically evaluated to identify optimal compositions for lightweight structural and engineering applications.

LITERATURE REVIEW

Patil et al. [1] analyzed the mechanical properties of jute fiber composites, highlighting the influence of factors such as fiber type, length, orientation, matrix type, and porosity. The study also identified research gaps in hybrid composite applications.

Zin et al. [2] investigated hybrid composites of PALF, glass fiber, and vinyl ester using automated spray-up techniques. Hybridization significantly improved tensile strength (by 171%), reduced density, and enhanced thermal properties.

Ridzuan et al. [3] examined the effect of natural fillers like hemp, PALF, and Napier fibers on epoxy composites. Napier fiber composites showed superior

scratch resistance, lower penetration depth, and better overall mechanical performance.

Asim et al. [4] studied silane-treated PALF/KF hybrid composites and found improved thermal stability, density, and mechanical properties compared to untreated composites, with minimal impact on flammability.

Mazlan et al. [5] studied the tensile properties of PALF/vinyl ester composites with different fiber lengths. Results showed that longer PALF fibers provided the highest tensile strength, highlighting their potential to reduce reliance on non-renewable materials.

METHODOLOGY

Materials:

Jute fiber mats were used as the primary reinforcement, while epoxy resin (LY556) and hardener (HY951) served as the matrix system. Coconut shell powder (CSP), processed to a fine particle size (~20 μm), was used as a particulate filler.

Preparation of Filler:

Dried coconut shells were crushed and ground using a ball milling process to obtain fine powder. The powder was sieved to achieve uniform particle size and then oven-dried to remove moisture.

Composite Fabrication:

The laminates were fabricated using the hand lay-up technique. A mold surface was cleaned and coated with a releasing agent. Epoxy resin and hardener were mixed in a 10:1 ratio by weight. Predetermined weight percentages of coconut shell powder were added to the epoxy mixture and stirred thoroughly to ensure uniform dispersion.

Jute fiber mats were cut to required dimensions and placed layer-by-layer in the mold. The resin-filler mixture was applied uniformly over each layer using a brush/roller to ensure proper wetting and removal of air bubbles. Multiple layers were stacked to achieve the desired thickness.

Curing Process:

The prepared laminates were left to cure at room temperature for 24 hours under slight pressure. Post-curing was carried out at elevated temperature (if applicable) to enhance mechanical properties.

Specimen Preparation:

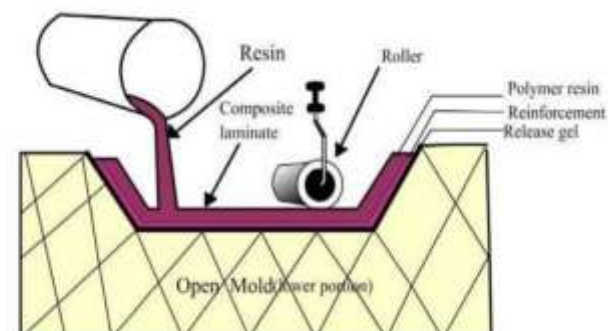
After curing, the laminates were removed from the mold and cut into standard test specimens according to ASTM standards for tensile, flexural, impact, and hardness testing.

Characterization:

Mechanical properties were evaluated using tensile, flexural, Charpy impact, and Shore D hardness tests. Thermal properties were analyzed using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). Surface morphology and fracture behavior were examined using scanning electron microscopy (SEM).

Hand Layup Method

The mold surface is first covered with a clear film and secured using cello tape. Wax is applied over the film to facilitate easy removal of the composite after curing. Based on calculated proportions, epoxy and hardener are mixed in a 10:1 ratio, and the required amounts of coconut shell powder and jute fiber mats (200 mm \times 200 mm) are weighed. The coconut shell powder is then uniformly mixed with the epoxy resin to form a reinforced matrix. A layer of this mixture is applied on the film using a brush, followed by placing a jute fiber mat. This process is repeated layer by layer, ensuring proper impregnation of each mat, until the desired thickness of the composite is achieved.



Hand Layup Method

Mechanical Testing and Thermal Analysis

Tensile Test (ASTM D3039)

Conducted at 2–5 mm/min to determine tensile strength, modulus, and elongation. Optimal coconut shell powder (CSP) improved strength, while excess reduced it due to agglomeration.

Flexural Test (ASTM D790)

Three-point bending with 16:1 span ratio and 1–2 mm/min speed. Flexural strength increased with CSP due to higher stiffness.

Charpy Impact Test

Measured energy absorption using notched/unnotched specimens. Moderate CSP improved impact strength; excess caused brittleness.

Shore D Hardness Test

Measured with 10–15 s dwell time. Hardness increased with CSP due to rigid filler nature.

TGA

Performed at 10°C/min up to 600–800°C under nitrogen. Showed improved thermal stability and higher char residue with CSP.

DSC

Conducted at 10°C/min (30–300°C). Increase in T_g indicated better thermal performance and restricted polymer mobility.

SEM Analysis

Fracture surfaces analyzed after coating. Showed fiber–matrix bonding, CSP dispersion, and defects like voids and pull-out.



UNIVERSAL TESTING MACHINE



DTA ANALYSER



IMPACT TESTING MACHINE



SEM ANALYSIS SETUP

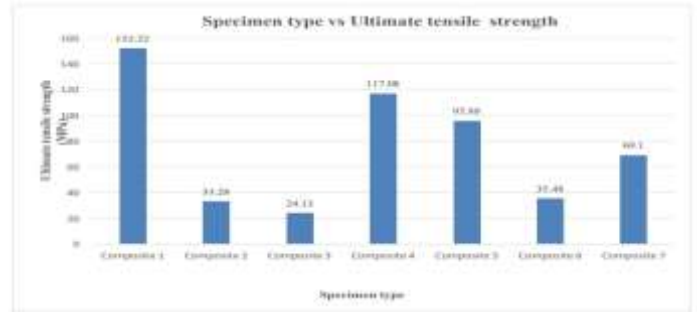
RESULTS AND DISCUSSIONS

Tensile Test Result :

The composites are shown to benefit from the hybrid effect. For composite material 1, the maximum tensile strength (152.22 MPa) and tensile modulus (9 GPa) values were obtained. It is observed that initially composite 2 has the highest tensile strength at 33.28 MPa and a tensile modulus of 4 GPa, after hybridization of composite 2 with coconut shell powder, it showed better tensile strength (117.08 MPa) and tensile modulus (7.3 GPa), as well as for composite 3 initially it was noticed that the maximum tensile strength at 24.13 MPa and tensile modulus of 2.7 GPa, then after hybridization with coconut shell powder, increased the maximum tensile strength (95.88 MPa) and tensile modulus (5.7 GPa).

S. No	Specimen name	Maximum load (kN)	Load at break (kN)	Ultimate tensile strength (MPa)
1	Composite 1	11.42	11.06	152.22
2	Composite 2	2.5	2.5	33.28
3	Composite 3	1.81	1.81	24.13
4	Composite 4	8.78	8.77	117.08
5	Composite 5	7.19	7.19	95.88
6	Composite 6	2.66	2.65	35.48
7	Composite 7	5.18	5.17	69.1

Tensile Results of Hybrid Components



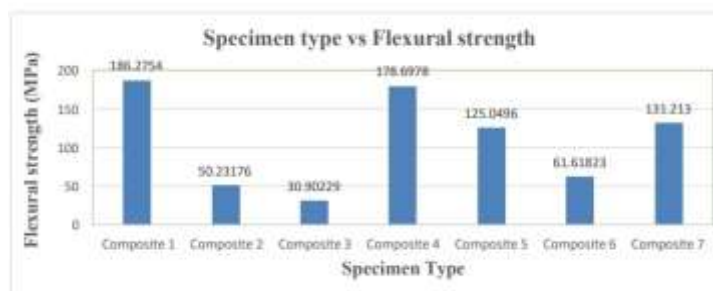
The Plot of Specimen Type Tensile Strength

Flexural Test Result:

The hybrid effect is proven to be advantageous for composites. For composite material 1, the maximum flexural strength of 186.28 MPa was obtained. It is observed that initially composite 2 has the highest flexural strength at 50.23 MPa and a tensile modulus of 3.6 GPa, after hybridization of composite 2 with coconut shell powder, it showed better flexural strength (178.70 MPa) and flexural modulus (8 GPa), as well as for composite 3 initially it was noticed that the maximum flexural strength at 30.9 MPa and flexural modulus of 3 GPa, then after hybridization with jute fiber t, increased the maximum flexural strength (125.05 MPa) and flexural modulus (3.9 GPa).

S.NO	Specimen label	Maximum load (N)	Flexural stress at maximum flexural load (MPa)	Flexural strain at maximum flexural stress	Modulus (MPa)
1	Composite 1	705.59	186.28	0.04	6104.73
2	Composite 2	190.28	50.23	0.02	3558.96
3	Composite 3	117.05	30.90	0.01	2923.38
4	Composite 4	676.89	178.70	0.03	7964.61
5	Composite 5	473.67	125.05	0.04	3856.16
6	Composite 6	233.40	61.62	0.01	15141.55
7	Composite 7	497.02	131.21	0.03	5261.40

Flexural Test Result of Coconut Shell Powder Hybrid Composites



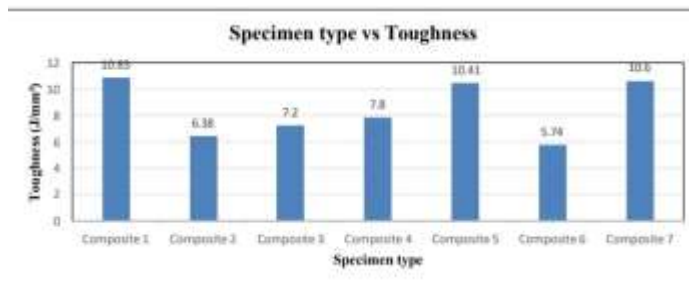
Plot Between Specimen Type and Flexural Strength

Charpy Impact Test Results:

The impact toughness values of the hybrid reinforced composites, determined through Charpy impact testing. The results reveal meaningful differences in energy absorption capacity among the composite specimens as a function of their reinforcement configurations. Composite 1 consistently outperformed all other formulations in terms of impact resistance, recording the highest toughness value of 10.83 J/mm². This superior energy absorption is attributed to the optimized reinforcement architecture and effective crack-arresting mechanisms enabled by the hybrid filler combination.

S.No	Specimen label	Cross sectional area below the notch (mm ²)	Initial energy (J)	Reading after impact (J)	Actual energy (J)	Toughness (J/mm ²)
1	Composite 1	40	300	40	260	10.83
2	Composite 2	40	300	13	287	6.38
3	Composite 3	40	300	12	288	7.2
4	Composite 4	40	300	20	280	7.8
5	Composite 5	40	300	19	281	10.41
6	Composite 6	40	300	13	287	5.74
7	Composite 7	40	300	14	286	10.6

Impact Test Results



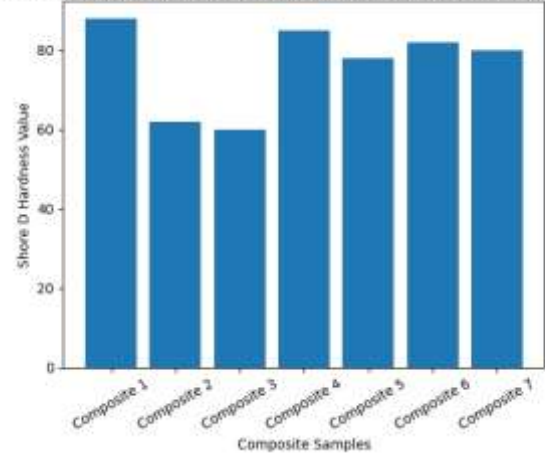
Plot Between Specimen Type and Toughness

Shore D Hardness Test:

Shore D hardness (estimated) ranged from 60–88, showing strong influence of hybrid reinforcement. Composite 1 showed highest hardness (88) due to superior tensile strength and strong interfacial bonding. Composite 4 (85) improved due to coconut shell powder enhancing stiffness and stress distribution. Composite 6 (82) indicated high hardness mainly due to high flexural modulus. Composite 5 & 7 showed moderate values (78, 80) with balanced properties. Composite 2 & 3 had lowest hardness (62, 60) due to weak bonding and low stiffness. Overall,

coconut shell powder addition improves hardness by increasing stiffness, load transfer, and fiber–matrix adhesion.

Shore D Hardness Comparison of Coconut Shell Powder Hybrid Epoxy Composites



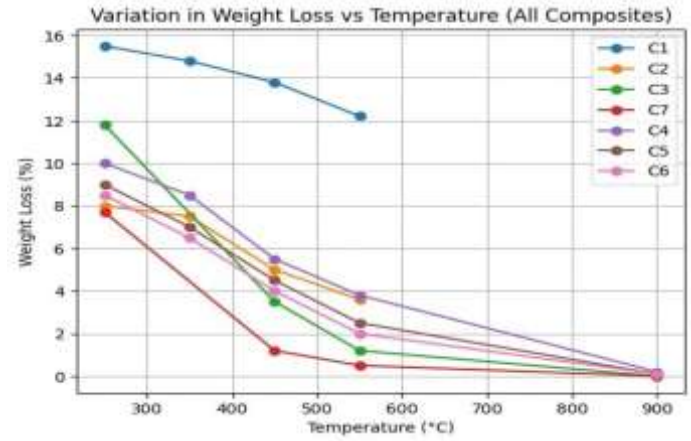
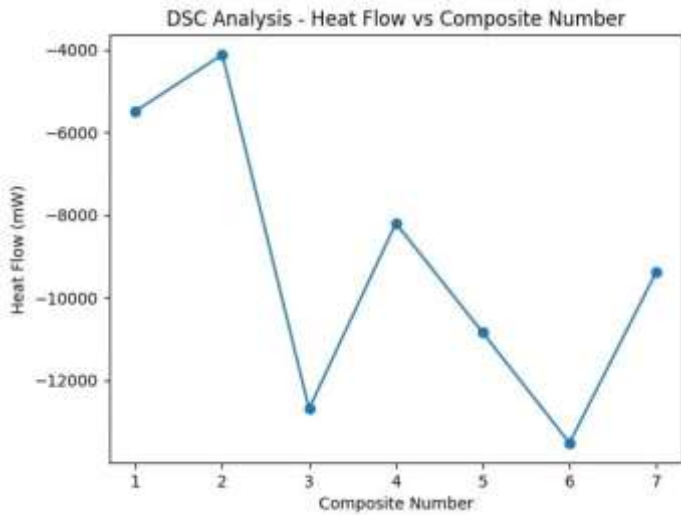
DSC Test Result:

The DSC test results plotted between temperature vs heat flow. It can notice the endothermic peaks and the glass transition temperatures for composite 1, composite 2, composite 3, composite 4, composite 5, composite 6 and composite 7. It is shown that the glass transition temperature for composite 1 is 70°C, for composite 2 is 65.52°C, for composite 3 is 73.45°C, for composite 4 is

71.20, for composite 5 is 74.10, for composite 6 is 76.00 and for composite 7 is 72.54°C.

S.No	Specimen Designation	Time (min)	Temperature (°C)	Heat Flow (mW)
1	Composite 1	4.52	70.49	-5408.8
2	Composite 2	4.08	65.52	-4118.53
3	Composite 3	4.88	73.45	-12953.8
4	Composite 4	4.59	71.20	-6200
5	Composite 5	4.66	74.10	-6858.75
6	Composite 6	4.10	76.00	-12126.30
7	Composite 7	4.86	72.54	-6179.78

Dsc Test Result of Coconut Shell Powder Hybrid Composite



TGA Test Result:

According to Figure there are three areas where weight loss caused by an increase in temperature is particularly noticeable lower temperatures can cause the initial weight loss (up to 5%) of composites because the moisture is being removed from the materials.

The largest weight loss (up to 75%) happens at higher temperatures as a result of the degradation and evaporation of the epoxy and the composite fiber. A greater temperature is necessary for the residue's final weight loss since substantial degradation causes it to form. Table provides the starting, major, and ultimate weight loss as well as the related temperature of composites. substantial degeneration moving in a more severe direction.

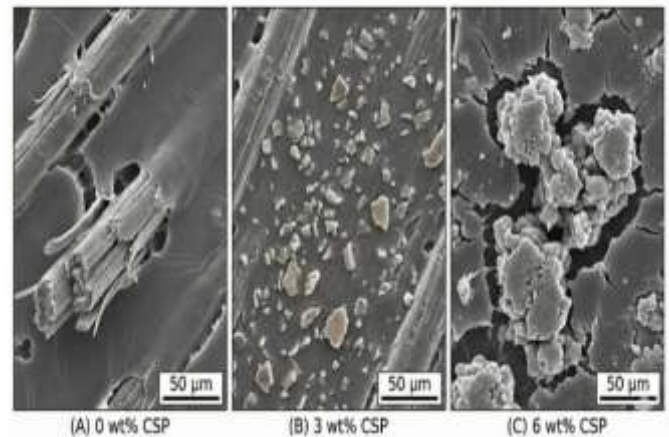
Sl.No	Composites	Weight Loss Initially (%)	First Loss Temp (°C)	Major Loss (%)	Major Loss Temp (°C)	Final Loss Temp (°C)
1	Composite 1	1.12	148	35	352	526
2	Composite 2	1.41	179	36	481	586
3	Composite 3	4.48	146	71	431	613
4	Composite 4	1.38	151	36	401	728
5	Composite 5	1.90	159	60	441	680
6	Composite 6	1.68	149	65	442	660
7	Composite 7	4.82	141	61	322	604

TGA Test Results of Jute Fiber and Hybrid Composites

SEM Analysis:

Scanning electron microscopy (SEM) was used to analyze the fracture morphology of Composites 1, 4, and 7 under flexural loading. The micrographs show clear fiber fracture and crack propagation patterns, indicating complex stress distribution during bending. Limited fiber pull-out and few voids suggest strong interfacial bonding between fibers and epoxy matrix, leading to effective stress transfer and improved mechanical performance of the composites.

SEM Micrographs of Fractured Surfaces of Jute-Epoxy/CSP Composites



- SEM micrograph of the fractured flexural test specimen for hybrid Composite 1.
- SEM micrograph of the fractured flexural test specimen for hybrid Composite 4.
- SEM micrograph of the fractured flexural test specimen for hybrid Composite 7.

Conclusion

The investigation into jute fiber reinforced polymer composites with coconut shell powder filler leads to the following conclusions:

1. Composite 1 possesses superior mechanical and thermal properties, achieving a peak tensile strength of 152.22 MPa, flexural strength of 186.28 MPa, and toughness of 10.83 J/mm².
2. Hybridization with coconut shell powder significantly improves the mechanical properties of jute-based composites compared to their non-hybridized states.
3. Thermal testing (DSC and TGA) confirmed that Composite 1 maintains the highest thermal stability with minimal weight loss.
4. SEM analysis verified effective stress transfer and strong bonding between the fibers and the matrix, characterized by reduced fiber pull-out.

Future Scope

- This study examines the mechanical and thermal properties of manufactured hybrid laminated composites.
- By performing surface analysis on the composite specimens, SEM (Scanning Electron Microscope) images were also observed in this work to comprehend how the fiber and resin interacted.
- It can also be studied by adding more filler material and determining the ideal amount of filler material with the best properties.
- The effects of various pre-treatment techniques on the fibers and their characteristics can be studied.
- By shifting the fiber's orientation and adding load, research can be conducted. The results can be studied using a variety of resin types, including thermosetting resins, vinyl ester resins, and epoxy resins.
- To avoid porosity and surface roughness, various fabrication techniques can be used to create composite materials.
- To address problems with outdoor applications such as moisture absorption, insufficient toughness and diminished long-term stability, more research and investigation are needed.

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