



A Comprehensive Analysis of the Physical and Mechanical Responses of Sisal-Epoxy Hybrid Composites to Varied Groundnut Shell Particulate Levels

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ABSTRACT

Sustainable material development has a huge potential for meeting future material demands globally. This research supports such requirements by involving sustainable material sources such as Groundnut shells and sisal to develop the new material by reinforcing them in the epoxy matrix. The waste of groundnut shells was employed in this investigation as filler in the powder form. In the composite, the filler content was increased in the order of 5, 10, 15 and 20 wt. % and the epoxy content was decreased in the order of 55, 50, 45 and 40 wt. %, but the composition percentage remained constant at 40 wt. % for sisal in all composite samples. At 20% concentration of filler, the tensile and flexural strengths are 18% and 14%, respectively. The impact strength for a lower concentration of the filler (up to 10 wt. %) was found to be better than that for the higher concentrations of filler. Through Scanning electron microscopy, the mechanical fluctuations revealed the changes in the composite microstructure. The mechanical and physical properties of sisal and epoxy hybrid composite were found to be complexly influenced by groundnut shell content in the composite.

Keywords: Sisal fiber; Epoxy resin; Groundnut shell; SEM analysis; Mechanical characterization.

1. INTRODUCTION

Natural fiber-reinforced composites have gained significant attention in recent years due to their eco-friendly nature, low cost, and potential for enhancing mechanical properties in polymer matrices (Veerasingam *et al.* 2022). Sisal fibers, derived from the *Agave sisalana* plant, are among the widely studied natural fibers for composite applications due to their high strength-to-weight ratio and biodegradability (Ahmad *et al.* 2022). Epoxy resins are commonly used as matrices in composite materials due to their excellent mechanical properties, adhesion, and chemical resistance. When combined with natural fibers, epoxy matrices can create hybrid composites with enhanced performance characteristics suitable for various engineering applications (Gudayu *et al.* 2022). The incorporation of fillers such as groundnut shells into composite materials has been explored to improve specific properties like impact resistance, thermal stability, and cost-effectiveness (Bekele *et al.* 2022). Groundnut shells, being agricultural waste, offer a sustainable and cost-efficient filler option for composite manufacturing. Previous studies have shown that varying the filler content in composite materials can significantly impact their physical and mechanical properties (Sahoo *et al.* 2022). Higher filler content may increase density and water absorption while potentially enhancing mechanical strength, although an optimal filler concentration is often

preferred for achieving the best balance of properties (Vijayan *et al.* 2020).

Sisal fibers are chosen for their inherent strength and sustainability, while epoxy resin, known for its excellent bonding and mechanical properties, serves as the matrix material. The incorporation of groundnut shell particulates as fillers introduces a sustainable and cost-effective approach to composite manufacturing, utilizing agricultural waste materials (Hu *et al.* 2023). By varying the filler content in the composite formulations, ranging from 5 to 20 wt. %, the study aims to understand how different levels of filler influence the composite's behaviour (Soni *et al.* 2023). Key aspects of interest include the impact of filler content on density, water absorption, tensile strength, flexural strength, and impact resistance of the hybrid composites. The research also employs scanning electron microscopy (SEM) to analyse the microstructure of the composites, providing insights into the mechanisms behind the observed physical and mechanical responses (Patnaik *et al.* 2022). The sisal fibres from the *Agave sisalana* plant possess high tensile strength; in addition, they are biodegradable and are very cheap (Usman *et al.* 2020). Taking into account the virtue of superior desirable qualities, hybrid composites have recently been the preferable material (Ramu *et al.* 2023). Some scientific knowledge is required to fabricate effective hybrid composites through various methods. Adding specific fillers was one potential area that is to

be investigated to obtain the various desirable properties. The peanut shell's lignocellulosic content is readily available and inexpensive. Additionally, they are eco-friendly, making them an excellent option for preparing new materials from such agricultural waste (Annamalai, 2023). The mechanical properties can be improved from the agricultural waste (Kumar *et al.* 2022). Understanding how different levels of groundnut shell fillers impact the physical and mechanical properties of sisal–epoxy composites is crucial for optimizing the performance of these materials. This includes enhancing tensile strength, flexural strength, impact resistance, and other mechanical properties to meet specific application requirements (Girimurugan *et al.* 2022). By using groundnut shell waste as a filler in composite materials, the research aims to explore cost-effective solutions for composite manufacturing. Utilizing agricultural waste materials reduces raw material costs and contributes to sustainable practices in material production (Bobet *et al.* 2020). The use of natural fibers like sisal and waste materials like groundnut shells promotes sustainability in material development. By reducing reliance on non-renewable resources and incorporating biodegradable components, the research contributes to eco-friendly solutions in the composite industry. Agricultural waste, such as groundnut shells, is often disposed of as waste, leading to environmental challenges; incorporating these waste materials into composite formulations, the research explores ways to repurpose waste and reduce its environmental impact. Sisal–epoxy hybrid composites with varied groundnut shell particulate levels can find applications across diverse industries. These include automotive components, aerospace structures, construction materials, and consumer products where lightweight, durable, and sustainable materials are highly valued. Studying the physical and mechanical responses of these hybrid composites provides valuable insights into the behavior of natural fiber-reinforced materials in epoxy matrices. This knowledge can inform future research and development efforts in composite materials engineering. The research on the physical and mechanical responses of sisal–epoxy hybrid composites to varied groundnut shell particulate levels is important for advancing sustainable, cost-effective, and high-performance composite materials with broad applicability across industries.

There may be a lack of comprehensive studies that specifically investigate the influence of varied groundnut shell particulate levels on the physical and mechanical responses of sisal–epoxy hybrid composites. Existing literature may have limited data or focus on other filler materials, highlighting the need for a detailed analysis of groundnut shell effects.

Previous research might not have thoroughly explored the optimal filler content of groundnut shells in sisal–epoxy composites to achieve the best balance of mechanical properties. Identifying the ideal filler

concentration that maximizes strength while considering other factors like cost and sustainability is a key research gap.

The underlying mechanisms behind the observed changes in physical and mechanical properties due to varied groundnut shell content may not be fully understood. This gap calls for investigations into the microstructural changes, interface interactions, and composite bonding that contribute to property fluctuations.

There could be a gap in comparative studies between groundnut shell fillers and other types of fillers commonly used in sisal–epoxy composites. Understanding how groundnut shell particulates perform relative to alternatives such as glass fibers or synthetic fillers would provide valuable insights into their effectiveness and applicability.

While laboratory-scale studies are essential, there may be a gap in translating research findings into practical applications and assessing the industry relevance of sisal–epoxy composites with varied groundnut shell content. Addressing this gap involves considering factors like manufacturability, scalability, and end-use performance in real-world scenarios. By addressing these research gaps, the study aims to contribute significantly to the understanding of sisal–epoxy hybrid composites with groundnut shell fillers, leading to optimized composite formulations with enhanced mechanical and physical properties for various industrial applications.

This study contributes to the ongoing research in sustainable composite materials by exploring the potential of sisal–epoxy hybrid composites with groundnut shell fillers, elucidating the complex relationships between filler content and composite properties.

2. MATERIAL AND METHODS

The material selection is driven by the need to develop sustainable, cost-effective, and high-performance composite materials with tailored properties. The combination of sisal fibers for reinforcement, epoxy resin as the matrix, and groundnut shell particulates as fillers offers a balanced approach to achieving the desired physical and mechanical responses in the hybrid composites. Sisal fibers are chosen as the reinforcing material due to their excellent mechanical properties, including high tensile strength, stiffness, and biodegradability. Sisal fibers are derived from the Agave sisalana plant and are widely used in composite materials for their sustainability and affordability. Epoxy resin is selected as the matrix material for its superior bonding strength, chemical resistance, and versatility in composite applications. Epoxy resins are commonly used

in structural composites where high strength and durability are required. Groundnut shell particulates are used as fillers in the composite formulation. Groundnut shells are agricultural waste materials that offer a sustainable and cost-effective filler option. By incorporating groundnut shell particulates in varying quantities, the study aims to investigate their impact on the physical and mechanical properties of the sisal–epoxy hybrid composites. Additives such as coupling agents, curing agents, and modifiers were purchased for the composite formulations to enhance compatibility, processing, and performance.

The needy materials such as sisal fiber mate, the hardener for the epoxy resin HY 951 and epoxy Araldite LY 556 were purchased from SAP, Chennai, Tamilnadu, India. They were used in a ratio of 1:10. The groundnut shells were obtained from an oil mill, dried well in the sunlight for a week and ground well to micron-sized particulates. The powder of groundnut shells of the required part, the epoxy resin including the hardener were separated. The powder of Groundnut shells of needed parts was mixed well with the epoxy resin by using an ultrasonicator before adding the hardener. The hand layup technique was employed in the preparation of composite samples. Sisal fiber was 40 wt. % for all composite samples; the epoxy content was decreased in the order of 55, 50, 45 and 40 wt.% and the filler content increased in the order of 5, 10, 15 and 20 wt. %. Hence four kinds of composite samples were prepared for this investigation. Ensure that the specimen thickness is uniform and meets the requirements specified in the standard.

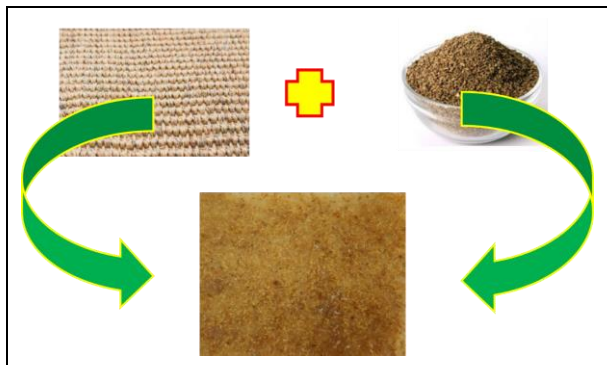


Fig. 1: Composite preparation of Sisal fibre with groundnut shell particles

The picture in Fig. 1 shows a composite made of sisal fibre and peanut shell pieces.

Table 1: Code and representation of the composite

| S. No. | Sample | Sisal | Epoxy | Groundnut shell particles |
|--------|--------|-------|-------|---------------------------|
| 1 | SEG1 | 40% | 55% | 5% |
| 2 | SEG2 | 40% | 50% | 10% |
| 3 | SEG3 | 40% | 45% | 15% |
| 4 | SEG4 | 40% | 40% | 20% |

2.1 Characterization

2.1.1 Tensile Test

As per ASTM D3039, the samples were cut into 25 mm wide, 250 mm long rectangles for tensile testing. Straightened sample edges and removed imperfections that could affect test findings. The Universal Testing Machine grippers grasped the composite specimen ends. Ensured that grip faces were parallel and aligned with specimen longitudinal axis. The opposite end of the specimen was inserted in the UTM's opposing gripper to align it and prevent twisting or bending during testing. The UTM tension speed was 2 mm/min set as per test specifications. Before testing, the UTM was calibrated and the load cell was set to zero to ensure accurate force measurement. Before loading, the specimen's gauge length was noted. At 2 mm/min, the tensile test was started and monitored for elongation, deformation, and failure. The UTM data collection system continually recorded the applied load and displacement measurements throughout the test. Noteworthy occurrences included yield points and UTS.

2.1.2 The 3-point Bending Tests

According to ISO 178, the samples were cut into 135 mm wide, 130 mm long rectangles for 3-point bending testing. ASTM-D-790 standards have been met by ensuring homogeneous specimen thickness. A standard span distance of 100 mm was used to put the composite specimen horizontally on the Universal Testing Machine (UTM) supports for 3-point bending testing. The UTM loaded at 2 mm/min per ISO 178 for 3-point bending testing. Before the test, the UTM was calibrated and the load cell was set to zero to ensure an accurate strength measurement. The specimen was positioned and initial specifications recorded before loading. Then 3-point bending was tested at 2 mm/min. A loading nose (roller) was used to bend the specimen at its centre. The specimen's deflection under stress was evaluated throughout the test. The UTM's data collection system captured load-deflection data constantly throughout the test. The Sisal/Epoxy/Groundnut cell powder composite's bending strength was measured by the specimen's maximum load before failure.

2.1.3 Izod Impact Test

Izod impact testing followed ASTM D256 and ISO 180 standards. As per ASTM D256 Izod impact testing requirements, the composite samples were cut into 64 mm wide, 12.7 mm long rectangles. Tested specimen thickness to meet established standards. Izod Impact (notched) Machine setup followed ISO 180 process standards; it was calibrated to ensure optimal operation. Each specimen has a V-notch cut at one end using an appropriate notching instrument. The notch depth and angle met ASTM D256 and ISO 180 standards. The specimen's notched end was firmly attached in the

Izod Impact Machine's holder or clamp for impact testing. It was examined the impact pendulum's location. A pre-test calibration or zeroing of the impact pendulum ensured precise impact energy measurement. Before the impact test, the specimen's size and location were documented. ISO 180 standards required the impact pendulum to swing and stroke the specimen's notched end with a predetermined energy level. Make sure the impact is perpendicular to the specimen notch plane. The pendulum swing after impact indicates the specimen's impact energy absorbed during the test.

3. RESULTS AND DISCUSSION

3.1 Tensile Strength

The mechanical strength increased with the decrease of reinforcement quantity of peanut shell. The tensile strength of 56.2 MPa was observed for the composite reinforced with 5% peanut shell. Table 2 shows that the tensile strength continued to decrease by 51.8, 46.6 and 46.1 MPa as the amount of peanut shell increased to 10%, 15% and 20%, respectively.

Table 2: Tensile strength of various content of groundnut shell particles

| S. No. | Sample | Groundnut Shell Content (%) | Tensile Strength (MPa) |
|--------|--------|-----------------------------|------------------------|
| 1 | SEG1 | 5 | 56.2 |
| 2 | SEG2 | 10 | 51.8 |
| 3 | SEG3 | 15 | 46.6 |
| 4 | SEG4 | 20 | 46.1 |

The tensile strength was lowered by the addition of peanut shell pieces, which was caused by a number of variables shown in Fig. 2. The tension inside the matrix was not consistent because of the variations in the strength and stiffness of the sisal fibres and peanut shell pieces (Thomas and Jose, 2022). These differences are highlighted by the fact that the tensile strength falls as the particle load increases (Ahmad *et al.* 2022).

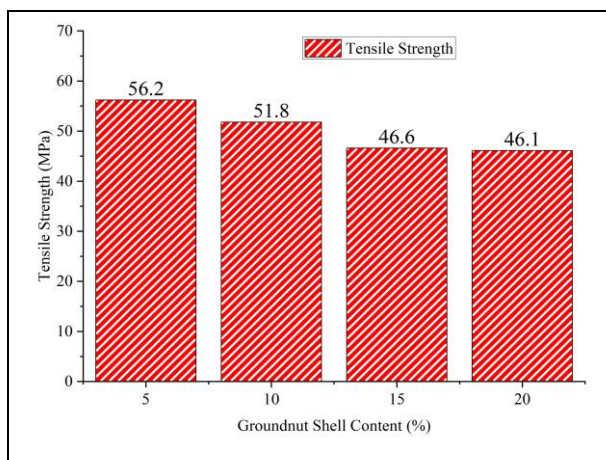


Fig. 2: Influence of Groundnut Shell filler on tensile strength of the composite

The adhesion between the surfaces is principally influenced by presence of peanut shell fragments and epoxy matrix. Tensile strength is important too. Poor bonding happens when the material has weak points that potentially unsettle the structure. A certain form of tensile stress may enhance peanut shell fracture (Soni *et al.* 2023).

3.2 Flexural Strength

In this study, sisal and epoxy were mixed with varying ratios of groundnut shell fragments to test the materials' strength and bending stress resistance. The results indicate that the increase in the concentration of powders of peanut shell particles causes a decrease in flexural strength. The strongest composite for flexural loads was measured as 73.3 MPa; such composite sample (Table 3) was composed of 5% peanut shell. The flexural strengths decreased as the proportion of powders of peanut shells increased. The composites containing 10, 15 and 20% Groundnut Shell Content (%) recorded bending strengths as 66.8, 59.9 and 58.2 MPa, respectively.

Table 3: Flexural strength of various content of groundnut shell particles

| S. No. | Sample | Groundnut Shell Content (%) | Flexural Strength (MPa) |
|--------|--------|-----------------------------|-------------------------|
| 1 | SEG1 | 5 | 73.3 |
| 2 | SEG2 | 10 | 66.8 |
| 3 | SEG3 | 15 | 59.9 |
| 4 | SEG4 | 20 | 58.2 |

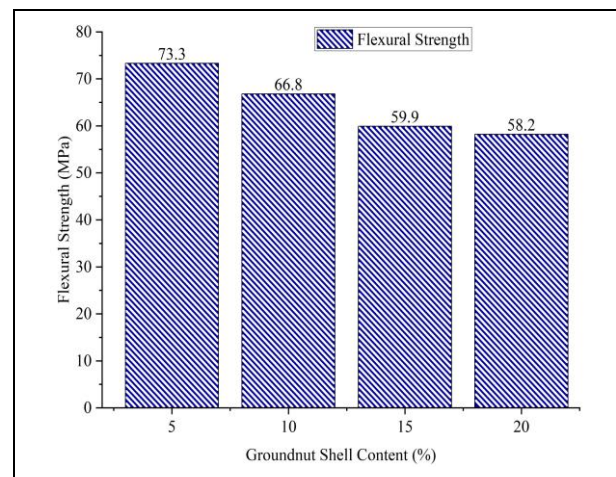


Fig. 3: Effect of Groundnut shell particles on flexural strength

Impact affects the reinforcement in composite because groundnut shell particles absorb into the matrix (Ramu *et al.* 2023). Many reasons cause flexural weakness. These localised non-uniformities may make the composite bendable. The stiffness and strength of sisal fibres may vary when flexural strength rises and

groundnut shell particles decrease (Patnaik *et al.* 2022). The observed values are depicted in Fig. 3. Its resistance to bending deformation indicates how well the composite controls the synergistic connection between the matrix and reinforcing fibres.

3.3 Impact Strength

The sisal and epoxy hybrid composites with varying proportions of peanut shell fragments need to be tweaked for the best possible results. In these circumstances, performance metrics were essential, and impact resistance was among the most significant ones. The findings indicate that the impact strength of the composites comprised of 10% groundnut shell particles was 14.2 kJ/m². Conversely, the impact strengths of composites incorporating groundnut shell particles at weight percentages of 15 and 20% were observed to be 13.8 and 12.5 kJ/m², respectively. As shown in Table 4, the composite consists of 5 wt. % groundnut shell particles and has a high impact strength of 16.7 kJ/m².

Table 4: Impact strength of various content of groundnut shell particles

| S. No. | Sample | Groundnut Shell Content (%) | Impact Strength (kJ/m ²) |
|--------|--------|-----------------------------|--------------------------------------|
| 1 | SEG1 | 5 | 16.7 |
| 2 | SEG2 | 10 | 14.2 |
| 3 | SEG3 | 15 | 13.8 |
| 4 | SEG4 | 20 | 12.5 |

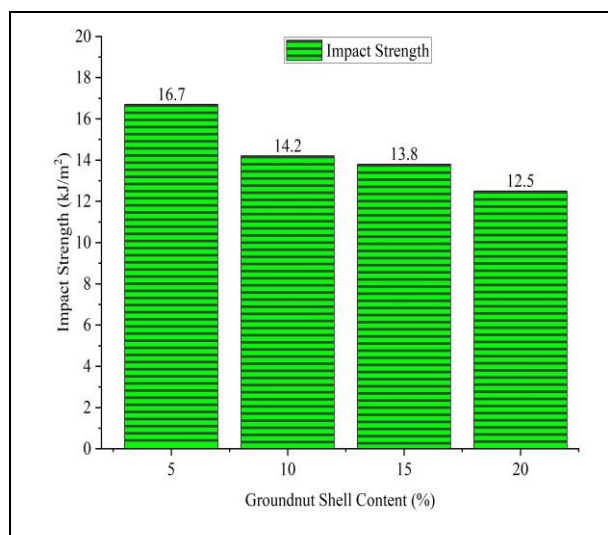


Fig. 4: Effect of Groundnut shell particles on impact strength

The variations in adhesive strength show how the matrix and peanut shell particles work together to strengthen the contact. In settings where there are unpredictable forces or sudden loads, like on sports equipment and car components, impact resistance must be met [14]. Impact resistance can be increased by adding

10% peanut shell to the material, according to the energy absorbed during hits. This characteristic could help the material's ability to hold onto a certain amount of particles. It was shown that adding peanut shell (15 or 20 weight percent) reduced the impact severity. This may have happened as a result of a change in the material's structure or particle aggregation (Bobet *et al.* 2020).

The results are depicted in Fig. 4. The sisal and epoxy hybrid composites with varying proportions of peanut shell fragments need to be optimised for the best possible results. In these circumstances, performance metrics were essential, and impact resistance was among the most significant ones (Usman *et al.* 2020).

3.4 SEM Analysis

Scanning electron microscopy (SEM) was used to examine the surface and substructure characteristics of hybrid composites composed of ground shell particles, sisal and epoxy in different quantities. When the epoxy concentration is minimal, between 5 and 10%, the sisal fibers are evenly distributed throughout the matrix, as shown in Figures 5 and 6. As illustrated in Figure 7 and Figure 8, the microstructure underwent a significant transformation when the concentrations increased to 15 and 20%. Certain areas are subject to elevated levels of tension, which may result in the composition becoming deficient in certain regions.

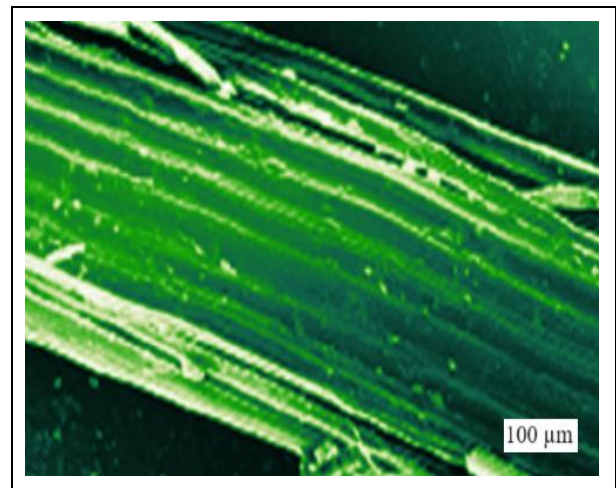


Fig. 5: SEM image of 5% groundnut shell particles

Effective load transfer occurs at lower content levels; the reinforcing fibers adhere well to one another to maintain clear and continuous contact. The cohesive interaction between the epoxy binder and the sisal fibers was evident in the scanning electron microscope images. Indications of diminished matrix binding and fiber presence were detected at elevated concentrations, potentially indicative of areas of weakness (Gudayu *et al.* 2022).

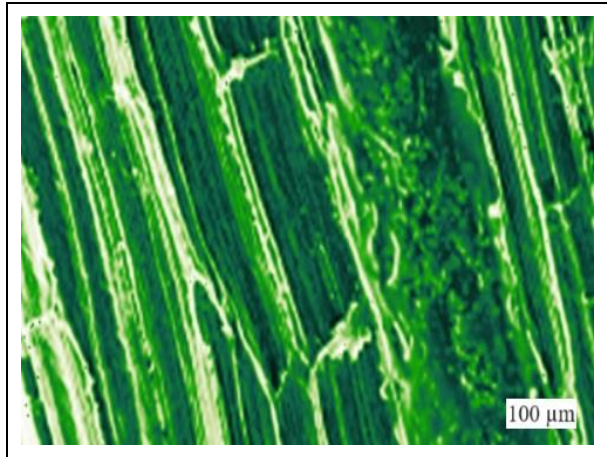


Fig. 6: SEM image of 10% groundnut shell particles

Lower concentrations resulted in uniform particle dispersion; however, higher concentrations presented challenges in achieving even particle dispersion due to aggregation and agglomeration (Sahoo *et al.* 2022). Performance differences resulted in a distribution of stress, which changed the unequal distribution of particles and may be related to changes in the mechanical characteristics (Veerasingam *et al.* 2022).

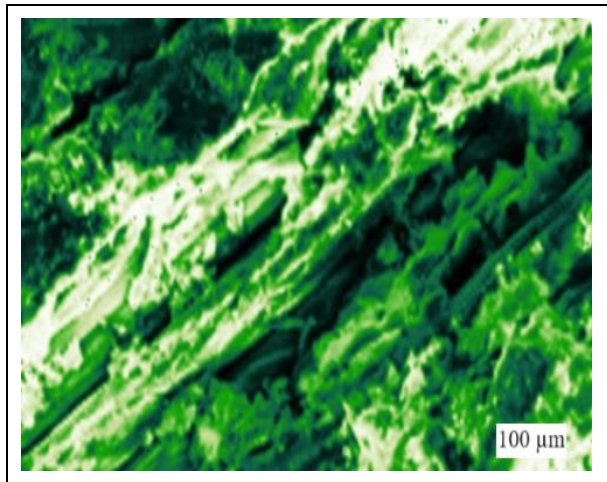


Fig. 7: SEM image of 15% groundnut shell particles

Effectiveness predominantly depends upon accurate load transfer and lower-level reinforcement between the epoxy matrix and the particulates. The significance of the ground nut shell particle and epoxy matrix interaction was demonstrated by SEM investigation in Fig. 7. It was observed that the mechanical properties of the interfaces deteriorated as the groundnut shell content increased, potentially resulting in insufficient adhesion (Annamalai, 2023).

The SEM image of the composite matrix with 20% groundnut shell particles is depicted in Fig. 8. The epoxy matrix and sisal fibres in the composite may be

modified to improve the groundnut shell particles' interfacial adhesion.

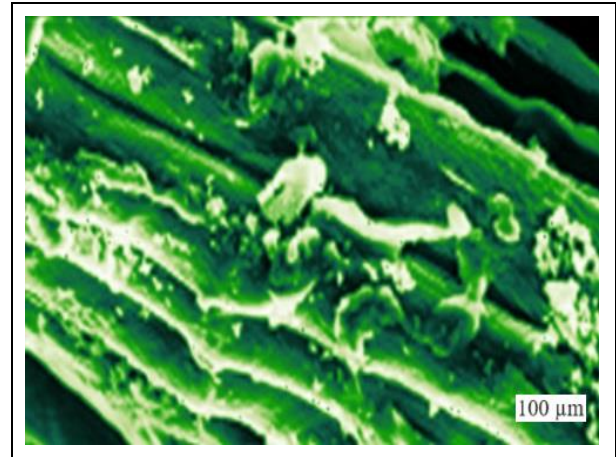


Fig. 8: SEM image of 20% groundnut shell particles

4. CONCLUSION

The study investigated the utilization of the waste groundnut shell as a filler in composite materials, and by varying the filler content from 5 to 20 wt. % and varying epoxy content, while keeping the sisal content constant at 40 wt. %. Tensile and flexural strength registered an increase at 20% filler concentration by 18 and 14% respectively, highlighting the potential for strength enhancement in these composites. Interestingly, lower filler concentrations (up to 10 wt. %) resulted in better impact strength compared to higher concentrations. SEM revealed microstructural changes corresponding to mechanical fluctuations in the composite. In a nutshell, the mechanical and physical properties of sisal and epoxy hybrid composites are intricately influenced by the presence of groundnut shell content, showcasing the complexity of material behavior in composite systems.

- ✓ Sisal and epoxy hybrid composites were investigated by examining the influence of groundnut shell filler with different quantities in the physical, mechanical, and microstructural characteristics.
- ✓ The results of the Scanning electron microscopy examination clearly show that when the epoxy concentration is minimal (5 to 10%), the sisal fibers are evenly distributed throughout the matrix.
- ✓ Composite mechanical qualities such as tensile, flexural and impact strengths declined with the increase in filler content.
- ✓ However, as the content increased, agglomeration and weaker fibre-matrix and particle-matrix contacts were apparent.

- ✓ By varying the groundnut shell filler content ratio, one can vary the strength of sisal and epoxy hybrid composites. The variation shall be fine-tuned to meet the application requirements of various sectors or structural specifications.
- ✓ Many optimization strategies shall be tried and tested in future research for increasing particle dispersion uniformity and dealing with agglomeration.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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