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Effectiveness of Groundnut Shell Powder on Improving the Mechanical Properties of Jute Fiber Mat-Reinforced Epoxy Composites

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ABSTRACT

This research explores the mechanical properties of jute fiber mat-reinforced epoxy composites filled with groundnut shell powder as fillers. The aim is to investigate the effects of filler concentration on the mechanical properties of the composite so that the volume fraction of epoxy in composite is reduced. Using untreated 4-layer jute fiber mats and fine groundnut shell powder (<75 μm), the composites were prepared through a simple hand lay-up process. We examined the tensile and flexural properties of the manufactured composites for comparison with the base jute fiber mat-reinforced epoxy composite. The test results showed improvement in tensile and flexural properties up to a filler content of 6 wt.%. For instance, a 2 wt.% filler provided the best performance with improvements in tensile strength by 8.25 %, in tensile toughness by 25.61 %, in flexural strength by 13.51 %, and in flexural energy absorption by 48.47 %. The tensile modulus of the composite was not significantly affected by the filler addition, but the flexural modulus showed improvement for all filler concentrations. However, when the filler content exceeds 2 wt.%, the properties decline due to filler agglomeration and poor bonding with the matrix indicating the optimum filler content. This research highlights the importance of using agro-waste fillers like groundnut shell powder (GSP), which not only improve performance but also promote sustainability by reducing the use of epoxy in manufacturing jute fiber mat reinforced epoxy composites. This study combines the enhanced material properties with waste management, offering an eco-friendly alternative in improving the strength of composites as well as reducing the plastic utilization in composites.

Keywords: Jute/epoxy Composite, Mechanical Properties, Agro-waste Filler, Eco-friendly Composite, Groundnut Shell Powder

1. Introduction

The synergistic effect of phases present in the composites impart a balance of mechanical properties that make them indispensable for advanced applications like automotive, marine, and construction [1], [2], [3], [4], [5]. The matrix phase of the composites can be made from polymers, metals, or ceramics; each has its own unique set of properties and limitations [5], [6]. Among the different types of composites, polymer matrix composites are the most common, largely because processability and cost effectiveness, making them suitable for both industrial and structural applications. Epoxy resins in particular stand out within this class for their mechanical strength, thermal stability, and chemical resistance, which make them central to modern fiber-reinforced composites [7], [8]. Their balance of lightweight and durability has positioned them as key materials in the automotive and aerospace industries, where efficiency and performance are critical [9]. While conventional epoxies can be brittle, ongoing research incorporating natural fiber and micro-fillers has improved their toughness and sustainability, further broadening their applications. Epoxy resins are widely used in polymer matrix composites. When it is reinforced with fiber, it becomes stronger and tougher. With the concern for the environment, natural fiber reinforced composites come to play an important role as a eco-friendly option. Natural fibers like jute, hemp, flax, sisal, kenaf, etc., are not only for reducing cost but also offer renewability and biodegradability that making them an attractive choice for greener applications [10], [11], [12], [13], [14]. Among these, jute is a renewable bast fiber with low density, good stiffness, and moderate tensile strength, making it a sustainable element for eco-friendly engineering uses. Its properties can be further enhanced through surface treatments that strengthen the fiber-matrix bond and decrease defects in the composite structure[15], [16]. When used to reinforce epoxy resins, jute fibers deliver significant gains in tensile and flexural properties while keeping materials cost-effective and lighter than glass or carbon fiber systems [17], [18]. More recently, Iqbal et al. [19] showed that factors such as how the fibers are arranged, how they are chemically treated, and the way the composites are made all play a important role in the final performance of jute–epoxy composites. Their work suggested that with further improvements, jute-epoxy composites could not only serve as an environment friendly alternative to synthetic fibers but also perform well enough for demanding uses in areas like automotive, construction, and other industries.

However, the problem with the jute-epoxy composite is that it requires a significant amount of epoxy to fill the gaps between the yarns of the fiber mat causing an increased cost. Expanding these insights, the incorporation of agro-waste natural fillers, such as groundnut shell powder may further boost the strength and reduce the utilization of epoxy in jute fiber mat-reinforced epoxy composites without significantly affecting the mechanical performance of jute-epoxy composites.

Researchers have found that adding fillers can make fiber-reinforced composites stronger and more versatile. By filling voids and improving bonding between fibers and the matrix, these particles helped the material carry loads more effectively while also boosting the mechanical properties and even resistance to moisture [20]. Among the many natural filler options, groundnut shell powder attracted particular attention because it is low-cost, abundantly available, and sustainable. Studies explored that when groundnut shell powder (GSP) is incorporated into epoxy or hybrid systems, the composites have a clear gain in mechanical properties, especially at moderate loading of about 10-15 wt.% [21], [22]. Groundnut shell fillers have also been reported to improve mechanical strength and thermal resistance in natural fiber reinforced composites, while keeping the material lightweight and eco-friendly [23], [24] .While natural fillers like groundnut shell powder (GSP) have been studied in epoxy composites, most research has focused on single fiber systems, larger particle sizes, or narrow filler ranges. The combined role of fine GSP fillers (<75μm) with 4-layered jute reinforcement, particularly at low-to-moderate loadings (0.5-6 wt.%), has not been systematically studied.

This study is focused on preparing four-layer jute fiber mat-reinforced epoxy composites using untreated jute mats and micro-sized groundnut shell fillers (<75 μm) at various concentrations through a simple hand lay-up process. The main aim is to investigate how varying filler loadings influence the mechanical performance of these laminates. This novel work in combining untreated jute mats with fine agro-waste fillers, offers a cost-effective and eco-friendly route to stronger, sustainable composites by reducing the use of plastic.

2. Materials and Methodology

2.1 Materials

The groundnut shells were collected, cleaned and dried before being crushed into small pieces. The sun-dried small pieces were blended to make fine powders. To ensure uniformity, the powder was then sieved through a mesh with openings smaller than 75 microns (see Figure 1(a)). Then the powders were again dried in an oven at 80°C for 24 hours to remove excess moisture and to improve the ability to bond with the matrix. After drying, the powder was stored in airtight containers.

The fine-staple jute fiber mats (see Fig. 1(b)), collected from local market. The mat was cleaned and dried then cut into the required mold size. The mat was dried in an oven at 80 °C for 24 hours to remove moisture.

For preparing the composite, Lapox epoxy resin (LAPOX® L-12) with its hardener (LAPOX® K-6) is used with a 2:1 weight ratio. Silicon spray was used to ensure easy removal of the composite from the mold without any damage.

2.2 Fabrication Process

The composite material was fabricated using the conventional hand layup technique at room temperature. Silicon mold (200 × 150 × 13 mm) was used and silicon spray was applied to the mold to prevent sticking and to ease the release of the cured composites. The mix proportion of GSP and Epoxy is shown in Table 1.

The optimal 2 wt.% GSP filler is in line with previous studies, which found that moderate filler levels enhance mechanical properties, while higher amounts lead to agglomeration and reduced performance [21],[22].

(a) (b)

Fig.1: (a) Groundnut Shell Powder and (b) Jute Fiber Mat

Table 1: Mix proportion of GSP and Epoxy

Composites	GSP, %	GSP, g	Epoxy, g
Base	0	0.00	210
0.5G	0.5	1.05	
1G	1	2.10	
2G	2	4.20	
4G	4	8.40	
6G	6	12.60	

To ensure the fillers were evenly distributed within the epoxy, an ultrasonic probe sonication process was used for 6 minutes. After sonication, the mixture was rested for 10 minutes to reach at room temperature. Then, the hardener was added at a 2:1 weight ratio and gently stirred for 5 minutes. The mixture was then used to manufacture jute mat-reinforced epoxy composites using four layers of jute mat. Each layer was rolled with a hand roller (grooved) to remove air bubbles and ensure the filler-epoxy mixture was evenly distributed. A plastic sheet was placed on top of the layup and then a glass plate with a load of 10 kg to create a smooth surface. After 48 hours of curing, the composite was removed from the mold and cut into the required dimensions. A flow diagram of the fabrication process is given in Fig. 2.

2.3 Mechanical Testing

The tensile and flexural properties were tested using a Shimadzu Universal Testing Machine (Shimadzu AGX 300kNV, Japan) with a load capacity of 300 kN. The composite specimens were prepared according to ASTM D3039 standard [25], with dimensions of 100 mm for the gauge length, 13 mm in width and approximately 5 mm in thickness. These specimens were carefully clamped and tested in tension at a constant speed of 2 mm/min until they failed. The tensile tenting setup is shown in Fig. 3(a). The flexural test used was the three-point bending method and the standard ASTM D790 [26] was followed. The span length was 70 mm for flexural testing. Each specimen was placed on two supports and loaded at the midpoint until failure. The rectangular specimens measured 90mm in length, 13 mm in width, and had a 70 mm in span length. The flexural testing set up is shown in Fig. 3(b). At least three specimens of all composite types were tested at room temperature to ensure reproducibility.

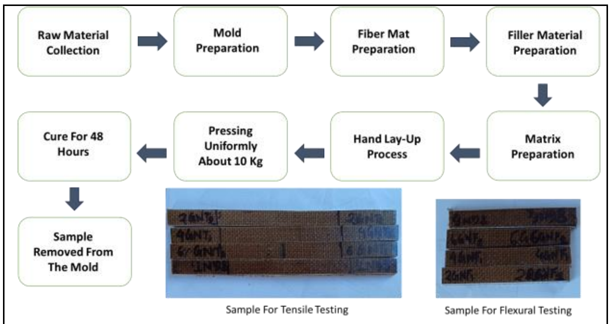
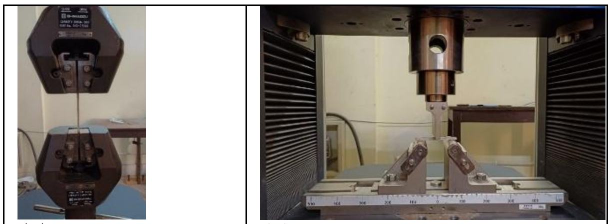


Fig. 2: Flow Chart of Composite Fabrication



(a) (b)

Fig. 3: (a) Tensile Test Setup and (b) Flexural Test Setup

3. Result and Discussion

3.1 Density

The density of the composites for various weight percentages of groundnut shell micro-fillers is plotted in Fig. 4. The results revealed a consistent increase in density with the increase in filler loading. The control sample showed a density of 1.15 g/cc and with the addition of 6 wt.% of GSP filler the density increased to 1.22 g/cc showing an insignificant 6.09 % increment. This gradual increase in density suggests that the groundnut shell micro-fillers have contributed to the overall weight of the composite replacing epoxy which has a density lower than the GSP particles.

3.2 Tensile Properties

The tensile strength and specific tensile strength of the composites are given in Fig. 5 for various GSP filler contents. The addition of GSP to jute fiber mat-reinforced epoxy composites results in a noticeable increase in tensile strength and specific tensile strength up to 2 wt.% of filler loading, as shown in Fig. 5. The control sample had a tensile strength of 49.12 MPa, which increases to 53.17 MPa at a 2 wt.% filler loading, showing 8.25 % improvement. The improvement indicated that GSP serves as an effective reinforcement. Beyond 2 wt.% filler loading, the tensile strength decreased. This decline is likely been caused by the agglomeration of filler particles, which has interfered with their bonding to the epoxy matrix, ultimately reducing the overall strength of the composite.

From Çetin's (2024) study which highlighted a 48.2% increase in tensile strength with almond shell filler, our findings show a similar improvement with ground nut shell micro-filler (GSP). At optimal filler loading, we observed about 8,25% increase in tensile strength in jute fiber reinforced composites [27].

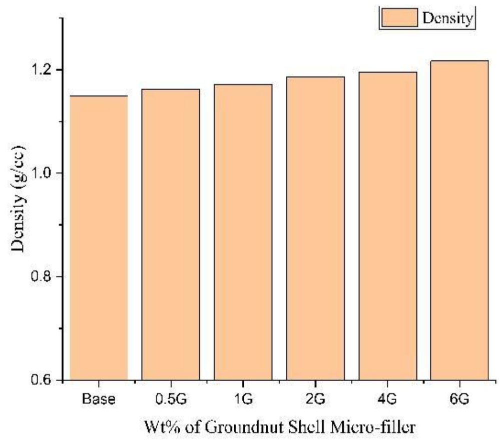


Fig. 4: Density of the composites for various Groundnut Shell micro-filler content

The tensile modulus and specific tensile modulus are given in Fig. 6 for various GSP contents. It is seen that the tensile modulus and specific tensile modulus decrease gradually up to a GSP filler content of 1 % followed by an increase at 2 % GSP filler content. At 4 % and 6 % GSP filler content, the composites show even greater modulus compared to the base composite.

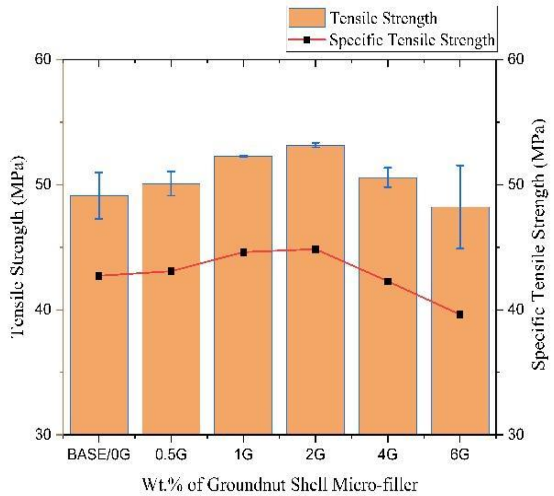


Fig. 5: Tensile strength and specific tensile strength of the composites for various GSP content

However, the drop in modulus at 0.5 % and 1 % filler content and the increase in modulus at 2 %, 4 %, and 6 % are insignificant. This observation indicates that the effect of GSP filler on the tensile modulus is negligible because the jute fiber mat is the most responsible element in the jute fiber mat-reinforced epoxy composite which controls the modulus of the composite.

The toughness and the specific toughness of the composites for various GSP filler contents is given in Fig. 7. It is seen that the toughness and specific toughness increases gradually up to a GSP filler content of 2 %. Further addition of GSP filler causes the toughness to decrease even below the base composite.

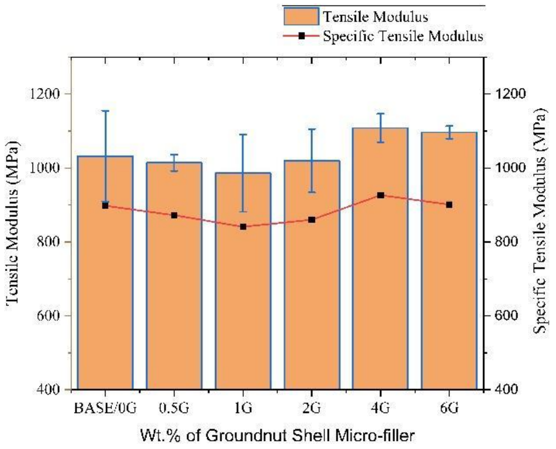


Fig. 6: Tensile modulus and specific tensile modulus of the composites for various GSP content

The agglomeration of particles and formation of voids in the matrix may be the reason for the decline in the toughness. The toughness has increased from 1.64 MJ/m³ in the base composite to 2.06 MJ/m³ at 2 wt.% due to proper dispersion of particles in the matrix, showing a significant enhancement of 25.61 %.

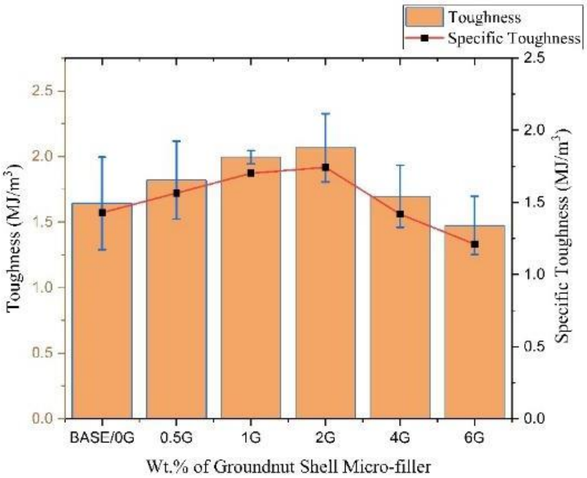


Fig. 7: Toughness and specific toughness of the composites for various GSP content

3.3 Flexural Properties

The flexural strength and specific flexural strength of the composites are plotted for various GSP content as filler in Fig. 8. The flexural strength and specific flexural strength increase with increasing GSP filler content up to a GSP filler content of 2 wt.%.

This enhancement indicates proper dispersion of fillers and bonding between the matrix and the fillers. The base sample has showed a flexural strength of 86.88 MPa and the maximum flexural strength achieved at 2 wt.% GSP filler loading, which is 98.62 MPa, representing an increase of approximately 13.51 %. However, beyond 2 wt.% of GSP filler content the flexural strength decreases gradually. Nonetheless, at 6 wt.% of GSP filler content the flexural strength is still greater than the base composite.

The flexural modulus and specific flexural modulus are plotted in Fig. 9 for various GSP filler content. It can be observed that the flexural modulus and specific flexural modulus increased by 21.20 % at 0.5 wt.% of GSP filler.

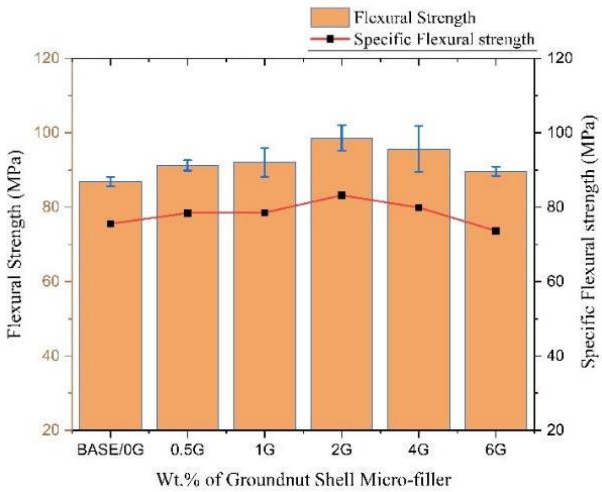


Fig. 8: Flexural strength and specific flexural strength of the composites for GSP content

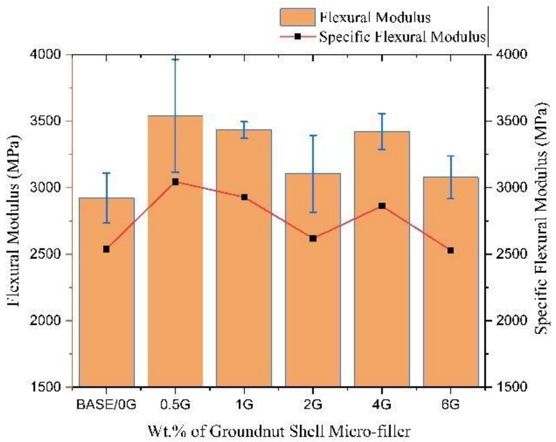


Fig. 9: Flexural modulus and specific flexural modulus of the composites for various GSP content

The modulus does not show any specific trend unlike the flexural strength but up to 6 wt.% of GSP filler content the modulus consistently remained greater than the base composite.

The energy absorption and specific energy absorption during bending are plotted for various GSP filler content in Fig. 10. The energy absorption and the specific energy absorption are found to be decreased (although insignificant compared to the base composite) for all composites with GSP filler except the composite with 2 wt.% of GSP filler which showed the maximum energy absorption capability during bending, showing an enhancement of 48.47 % compared to the base. Note that the tensile and flexural strength of the composite with 2 wt.% of GSP filler is found to be the maximum among all composites. These observations further indicate the proper dispersion of particles and bonding between particles and matrix in the composite with 2 wt.% of GSP filler.Çetin (2024) showed a notable 63.5% increase in flexural strength with the incorporation of almond shell filler into jute composites. In a similar passion, our study highlighted that groundnut shell powder (GSP) also improves the flexural properties of jute fiber reinforced composites. These findings further highlighted the potential of agro-waste fillers to enhance the flexural properties and overall mechanical performance in mechanical performance of natural fiber composites[27].

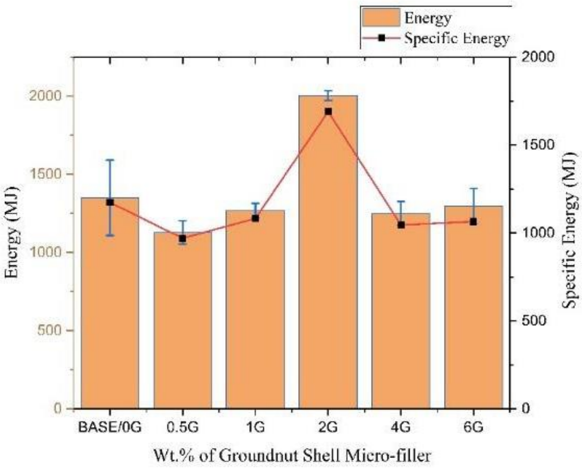


Fig. 10: Energy absorption and specific energy absorption of the composites for various GSP content

4. CONCLUSION

The study examined the effect of groundnut shell powder (GSP) micro-fillers on jute fiber mat-reinforced epoxy composites. The study showed that adding 2 wt.% groundnut shell powder (GSP) to jute fiber-reinforced epoxy composites delivered the best results, boosting density, tensile and flexural strength, toughness, and energy absorption, while keeping the stiffness mostly unchanged and only a slight drop in performance with more filler. The findings are summarized below:

- Density increased slightly with filler loading due to the higher density of GSP.
- Tensile and flexural strengths, toughness, and energy absorption improved notably at 2 wt.% filler, showing optimal reinforcement and good filler dispersion.
- Beyond 2 wt.% filler, agglomeration and void formation reduced performance, though properties remained comparable to or slightly above the base composite.
- The tensile and flexural modulus showed minor variations, suggesting limited influence of GSP on stiffness, as jute fibers dominated modulus behavior.
- Overall, 2 wt.% GSP yielded the best balance of properties.

It can be concluded that incorporating GSP fillers offers a sustainable and cost-effective means of reducing epoxy content in jute fiber mat-reinforced epoxy composite while enhancing the mechanical properties which makes these composites attractive and eco-friendly for applications in automotive, construction, and related industries.

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