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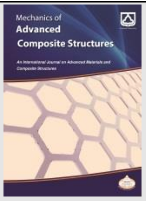

Influence of Graphene Powder on the Physio-Mechanical Properties of Jute Reinforced Epoxy Composites for Automobile Applications

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KEYWORDS

Jute;
Graphene;
Hybrid composite;
Physio-mechanical characterization;
Sustainability.

ABSTRACT

Graphene was employed as filler in various formulations of jute fibers reinforced epoxy composites in this study. Graphene's influence on the physio-mechanical properties of epoxy-based polymer composite reinforced with jute was examined in terms of tensile strength, flexural strength, impact strength, hardness, and water absorption. It was found that the mechanical characteristics significantly improved. Also, a significant decrease in the proportion of water absorption was obtained. The optimal proportion of graphene filler in proposed composites is also discussed in the present study. The optimal concentration filler in the proposed composites was found to be 4%. The findings show that graphene is a promising material and graphene mixed with 36% jute in an epoxy-based composite effectively improves the composites' strength. The findings of this study demonstrate the potential of graphene powder in enhancing the physio-mechanical properties of jute-reinforced epoxy composites for automobile applications. The incorporation of graphene powder offers a promising route for the development of lightweight and sustainable materials that can meet the stringent requirements of the automotive industry in terms of strength, durability

1. Introduction

Sustainable fiber-reinforced polymer (FRP) composites from renewable and biodegradable fibrous materials and polymer matrices are of great interest, as they can potentially reduce environmental impacts. However, the overall properties of such composites are still far from the high-performance conventional glass or carbon FRP composites. Therefore, a balance between composite performance and biodegradability is required with approaches to what one might call an eco-friendly composite [1]. Recent years have seen an increase in environmental awareness, which has led to technicians and scientists emphasizing the use of naturally available materials as reinforcements in composites [2,3]. With environmental considerations in mind, the creation of sustainable composite materials is gaining popularity. A variety of naturally occurring fibers, including sisal (*Agave sisalana*), jute (*Corchorus)*, kenaf (*Hibiscus cannabinus L.)*, coir (*Cocos nucifera*), etc. are widely employed in the production of polymer matrix composites (PMC) for various applications [4-10]. Due to their abundance in nature and the ease and environmental friendliness of their processing, natural fibers are prominently used in the development of composites [11-13].

Due to the high cellulose content of plants, natural fibers' low resistance to water absorption has limited their use[14-17]. Surface leaching might temporarily reduce the cellulose content of fiber and filler after chemical and physical processing [18]. Because of their superior

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strength, biodegradability, affordability, and lightweight, natural fibers are an excellent substitute for man-made fibers. Natural fibers can be used as reinforcing elements in polymer composites for a variety of lightweight applications, including automobile parts, airline seats, and racing sailboats [4,15].

On the fibers of snake grass (Clinacanthus nutans Lindau), several chemical reagents were tested before being employed to create polyester-based composites. The findings demonstrate that treated fiber-reinforced polyester composites outperform untreated fiber composites in their behavior when subjected to mechanical loading [19].

Tribological and mechanical characteristics of blended fabrics reinforced elastomer/epoxy composites in various quantities with tungsten carbide powder were examined. According to the researchers, the composites containing tungsten carbide powder improved significantly in tribo-mechanical characteristics [20]. It was discovered that adding areca nut nanofiller greatly improved the mechanical characteristics of coir-reinforced composites when the areca nut (Areca catechu) nanofiller was successfully employed in coir-reinforced polymer matrix composite [21].

Sathish et al. were able to analyse the water intake behaviour and behaviour under mechanical loading of hybrid epoxy-based composites by utilizing compression moulding techniques to alter the ratio of flax (Linaceae) and bamboo (Poaceae) fibers. The best results are obtained with composites that comprise 40% flax [22]. Sisal, E-glass, and silicon carbide fillers were employed in an epoxy matrix by Arpitha et al. who concluded that composites comprising E-glass showed better behavior under mechanical loading since they produced lesser voids [23]. Jute, combined with eggshell powder and nano clay demonstrated better strength against tensile and flexural loading when the mechanical parameters of treated and untreated samples were compared [24]. Natural fibers such as jute can potentially replace synthetic fibers to manufacture environmentally sustainable, biodegradable, and lightweight composites with improved properties, good thermal and acoustic insulation, and a smaller carbon footprint. However, natural jute fiber-based composites suffer not only from poor mechanical properties but also are inherently electrically insulating, which limits their applications as multifunctional composites [25,26].

Jeyakumar et al. created a cloisite clay-filled glass-reinforced polymer matrix composite. According to scientists, adding nano clay to glass fiber-reinforced epoxy composites greatly enhanced their mechanical properties [27]. Because of its superior qualities compared to other fibers, jute is the most widely used natural fiber available [28,29].

Researchers have found it very interesting to incorporate fibers and fillers in polymers. According to certain studies, adding filler to PMC results in enhanced modulus, which reduces the cost of the material [30,31]. Hybrid composites are made of a matrix that has reinforcement from both fibers as well as fillers. The strength, stiffness, and ductility of these composites are not shared by single-fiber reinforced composites. They also perform better in terms of fatigue life and fracture toughness than single-fiber reinforced composites. Multifunctional fiber-reinforced polymer (FRP) composites provide an ideal platform for next-generation smart composites applications including structural health monitoring, electrical and thermal conductivity, energy storage and harvesting, and electromagnetic interference shielding without compromising their mechanical properties.

Recent progress in carbon-based nanomaterials such as graphene and carbon nanotubes (CNTs) has enabled the development of many novel multifunctional composites with excellent mechanical, electrical, and thermal properties. However, the effective incorporation of such carbon nanomaterials into FRP composites using scalable, high-speed, and cost-effective manufacturing without compromising their performance is challenging [32]. Graphene, a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice, has garnered considerable attention in the scientific community due to its remarkable properties. Graphene exhibits excellent mechanical strength, high electrical and thermal conductivity, exceptional optical properties, and chemical stability. These attributes have led to extensive research and exploration of graphene-based materials for a wide range of applications [33,34]. The Effect of nanoclay and graphene inclusions on the low-velocity impact resistance of Kevlar-epoxy laminated composites was studied by Rahman et al. [35] where it was found that both nanoclay and graphene inclusions reduced the damaged area and increased the resistance to UV degradation and water absorption. The effect of Graphene Powder on Banyan Aerial Root Fibers Reinforced Epoxy Composites was studied by Ganapathy et al. [36] where it was proved that graphene combined with 40% banyan fiber-reinforced epoxy hybrid composites will efficiently improve the strength of the composites.

While there has been significant research on the development of composite materials for various applications, including the automotive industry, the specific investigation of the influence of graphene powder on the physio-mechanical properties of jute-reinforced epoxy composites for automobile applications is relatively limited. Therefore, there exists a research gap in understanding the synergistic effects and potential benefits of incorporating graphene powder into jute-epoxy composites for automotive applications. The proposed study on the influence of graphene powder on the physio-mechanical properties of jute-reinforced epoxy composites for automobile applications offers several novel aspects that contribute to the existing body of knowledge. The study focuses on the synergistic effect of combining graphene powder with jute fibers as a reinforcement in epoxy composites. While graphene has been extensively studied as a reinforcement in various matrices, its application in combination with jute fibers specifically for automobile applications is relatively unexplored. This unique combination brings together the advantages of graphene's exceptional mechanical and electrical properties with the sustainable and lightweight characteristics of jute fibers.

2. Materials and Methods

The present section describes the selection of materials, manufacturing methods used, and characterization techniques.

2.1. Matrix

The ratio of K6 hardener to Epoxy L12 resin in the current investigation is 10:1. The matrix system was obtained from Bangalore, India's Yuje businesses. The viscosity of the resin used in the present study at 250C ranges between 9000-12000 m Pas.

2.2. Fiber

The jute cloth with 210 GSM was obtained from Go Green Products, Chennai, and was chemically treated using 5% sodium hydroxide solution for a day, acetic solution was used to rinse it, further, it was water washed and then dried in the sun again for a day [18].

2.3. Graphene Powder

Adnano Technologies, Shimoga, Karnataka, India provided the graphene powder, which was 99% pure. Each graphene nanoplatelet had an average 10 nm thickness, 5 μm diameter, 0.4 g/cc bulk density, and a high aspect ratio of around 1000.

2.4. Composite preparation

The viscosity of epoxy resin compositions is quite high. The better the adhesion and performance capabilities, the higher the viscosity. The high viscosity of epoxy results in the non-uniform distribution of graphene in the resin. To overcome the problem, sonication of graphene along with acetone is carried out for half an hour. This ensured the uniform distribution of graphene in epoxy. The kind and content of composites synthesized are listed in Table 1.

Table 1. Suggested composites and their composition

Designation	Composition
C1	60% epoxy + 40% fiber
C2	60% epoxy + 38% fiber + 2% Graphene Powder
C3	60% epoxy + 36% fiber + 4% Graphene Powder
C4	60% epoxy + 34% fiber + 6% Graphene Powder
C5	60% epoxy + 32% fiber + 8% Graphene Powder
C6	60% epoxy + 30% fiber + 10% Graphene Powder

The chopped jute fibers were inserted into the mould cavity and the required amount of epoxy was poured into it to make composites. The C1 jute fiber-reinforced composite was made by combining 40% jute fiber with 60% epoxy resin. The weighted epoxy resin was poured over the weighted fiber after it had been put into the mould die and by using the compression moulding method, laminate was prepared by curing it for 24 hours. The samples were released from the mould using wax. The composite laminates were 300 x 300 x 3 mm3 in size. Hybrid composites including graphene powder were also created in the same way. C2, C3, C4, C5 and C6 are graphene-based composites with 2, 4, 6, 8, and 10% graphene content respectively.

2.5. Physio-mechanical Characterization

A universal testing device was used to conduct the tensile and flexural test according to ASTM D3039 and ASTM D790 respectively at 2 mm/min speed of cross-head movement. According to ASTM D6110-18, a Charpy impact testing was executed.

The composites' resistance to the conical indentation was evaluated according to ASTM 2240-15 by making use of a Shore D meter. The ASTM D570 standard was followed when conducting the water intake test. The water intake behaviour of the composites was investigated using distilled water. Eq. 1 is used to compute the percentage of water absorption. For each of the composite compositions under study, all the tests were repeated five times as suggested in ASTM standards and their average is reported as the result.

$$\mathit{Water\ absorption(\%)}=\left(\frac{w_{final}-w_{initial}}{w_{initial}}\right)*100 \quad (1)$$

Prepared composites are their mechanical testing arrangement are presented in Figure 1.

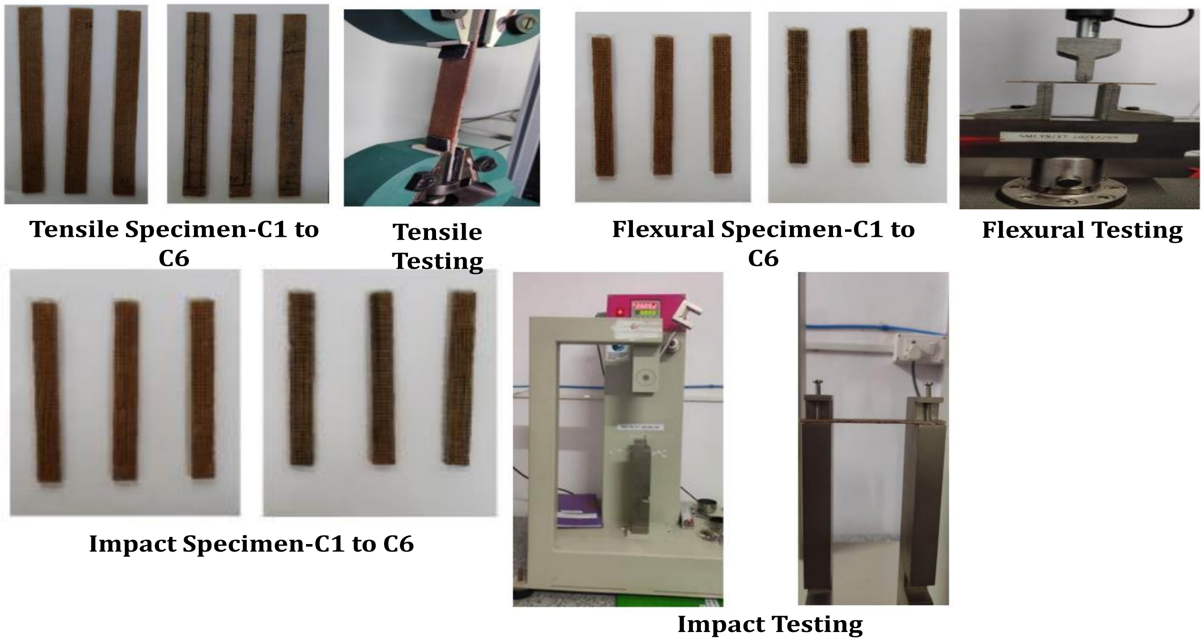

Figure 1. Samples prepared and their testing arrangement

3. Results and Discussion

3.1. Physio-mechanical Characterization

Figure 2 shows that the addition of 4% graphene powder results in a considerable increase in tensile strength, which is 90.08 percent and 22.88 percent greater than the C1 and C2 samples, respectively.

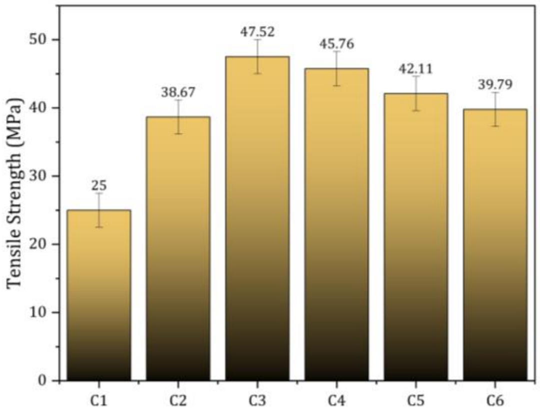

Figure 2. Tensile strength variations in suggested composites

Due to the increasing content of filler, at higher loading of filler, there will be agglomeration leading to reduced strength during tensile loading when loading of graphene is beyond 4% which is evident from the optical image of the composite shown in Figure 3 [37].

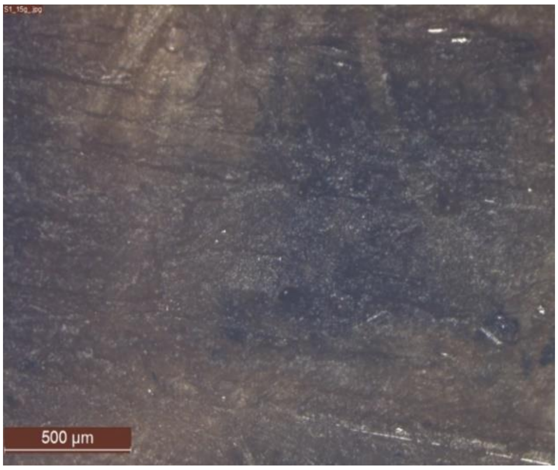

Figure 3. Optical image showing agglomeration of graphene particles in the composite

It should be mentioned that the jute fiber may also play a key part in the composite material's excellent performance, resulting in a synergetic rise in tensile strength. The addition of up to 4% graphene to the composite results in filling the voids, aiding the proper transfer of load. The clustering of graphene might occur if its content is increased by over 4%. As a result, the matrix and filler have a weak interfacial interaction. Because of this, the rate of transfer of tensile stress between them is incredibly sluggish, leading to early specimen failure. This pattern resembles that seen in the literature [29].

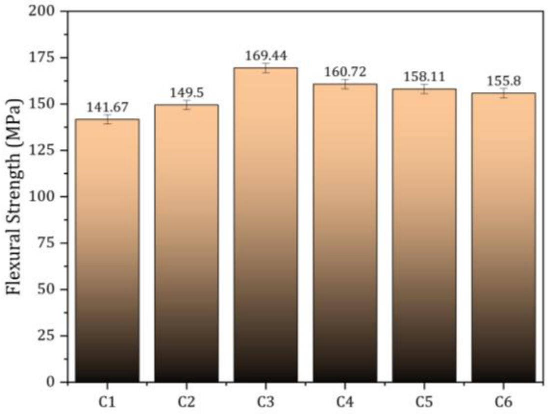

Figure 4. Flexural strength variations in suggested composites

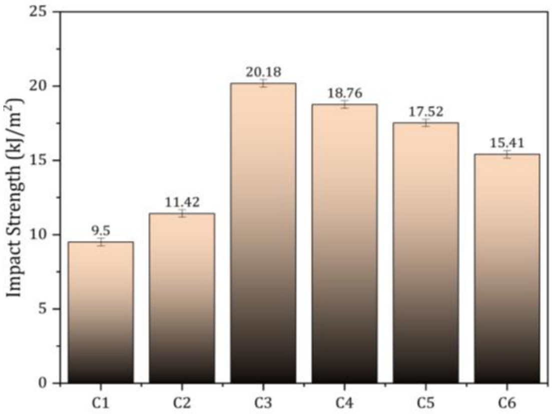

Figure 5. Impact strength of certain suggested composites

The strength of the composites when subjected to flexural loading is presented in Figure 4. Flexural strength is improved mostly because of the interlocking connection of reinforcement with epoxy [30].

With a maximum filler percentage of 4 wt percent, the hybrid composites exhibit an appreciable enhancement in flexural strength, followed by a loss of flexural strength as the graphene level increases.

As previously stated, the graphene filler tends to agglomerate as its percentage increases resulting in failure.

The addition of graphene to the suggested composites fills in the voids and improves their bending performance.

Agglomeration occurs when graphene is added more than 4%, resulting in a reduction in flexural strength.

The strength of the composites when subjected to impact loading is presented in Figure 5. When compared to its competitors, it is clear that the composite C3 has superior strength against impact loading. The strength of composite C1 when subjected to impact loading is 9.5 kJ/m^2. This is 112.42% less as opposed to the impact strength of the C3 composite. The suggested composites' impact strength is decreased if graphene is added more than 4% graphene powder. The suggested composites' use of graphene as a filler fills in the gaps in the composites. This is evident from the scanning electron microscope study of the fractured specimen shown in Figure 6. Because of this, graphene-filled composites are better at absorbing impact energy than those that aren't. Due to graphene's role as a stress concentrator and matrix shear yielding, the strength to impact loading has been improved [29].

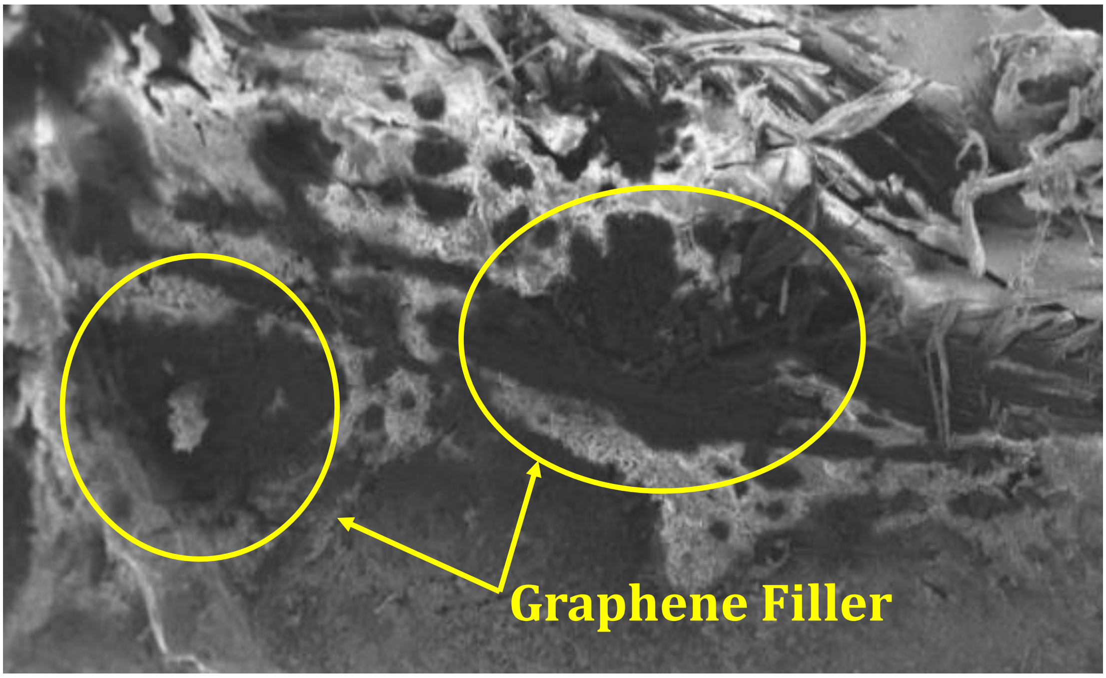

Figure 6. Scanning electron microscope showing filling up of void by the graphene filler

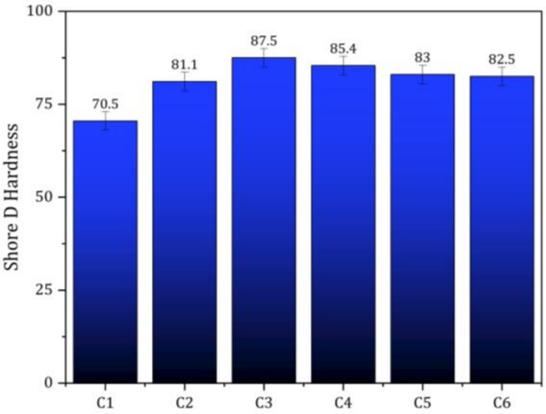

Figure 7. Variation of shored D hardness of proposed composites

Unfilled and filled graphene composites are evaluated for their hardness using shore D. Average was computed after the test was completed on ten separate locations of the same sample. Figure 7 depicts the hardness results of the suggested composites.

According to the data, C1 exhibits the least hardness, and it rises until C3 composite. Furthermore, the addition of graphene to C2 enhances hardness, with the highest value attained for C3 samples, followed by a little drop for C4, C5, and C6 composites.

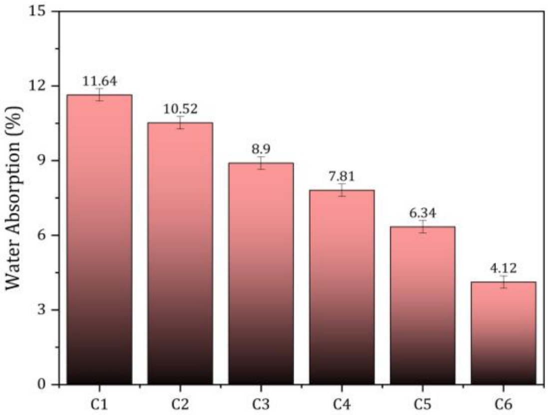

Figure 8. Variation in the suggested composites' water absorption rate

According to ASTM D 570 requirements, the water intake test is conducted. Figure 8 displays the variation in water intake of the recommended composites. C1 samples with 40 percent jute fiber content have the highest intake of water due to the hydrophilic nature of jute. Fibers include free hydroxyl groups that may hydrogen bind with water molecules, and the hollow tubular shape of the fibers allows water molecules to diffuse into composites. Apart from these reasons, the flaws, voids, and interface at the fiber and matrix can also affect the water intake behavior of the composite [38]. The proportion of water intake, on the other hand, was dramatically reduced when graphene was added. This is owing to the graphene nanoplatelets' hydrophobic nature. The void content is also reduced by the inclusion of graphene powder. As a result, graphene nanoplatelets may physically prevent water molecules from penetrating, lowering water absorption.

3.2. Cost Comparison

Table 2 displays the information about the comparison of costs for various PMCs. Carbon fiber composite is the most costly among others considered as it is 5.55 times more expensive than glass fiber composite and 58.38 times more expensive than the recommended composite. In comparison to glass fiber composites, the suggested composites are 10.5 times less expensive. As a result, the suggested composite is both sustainable and less expensive.

Table 2. Comparison of cost for various PMCs

PMCs	Cost in INR	Reference
Fiberglass composite	5960.07	[39]
Carbon fiber composite	33128.70	[39]
Jute graphene polymer composite	567.41	Present study

4. Conclusions

The current research aims to explore the influence of powdered graphene on the physical as well as mechanical behavior of PMC developed using jute and epoxy. Results obtained revealed that the tensile strength of unfilled jute epoxy composites is 25 MPa which is the lowest among the developed composites. Maximum strength during tensile loading which is 47.52 MPa, is shown by the suggested hybrid composite containing 4% graphene powder, which is 90.08% greater than unfilled composites. The composite containing 4% graphene powder has the maximum strength during impact and flexural loading, in contrast to its counterparts. In comparison to composites without powdered graphene, the strength during flexural and impact loading of composite with 4% graphene powder is 19.6% and 112.42% higher. This demonstrates that 4% graphene powder is the ideal concentration for improving mechanical characteristics. It is also discovered that adding graphene powder raises the hardness values of the suggested composites by up to 4% and that adding more graphene powder causes only a small drop in hardness. According to the water absorption study, graphene's hydrophobic properties make it more resistant to water absorption when added to other ingredients. In summary, the proper proportions of jute fibers and filler in the form of powdered graphene in an epoxy-based matrix results in composites with special characteristics that are suitable for engineering applications including dashboards, seat liners, and automotive bumpers.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the authors have entirely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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