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Effectiveness of Egg Shell Powder on Enhancing the Mechanical Properties of Jute Fiber Mat-Reinforced Epoxy Composite

Sopnil Ahmed, Md Arifuzzaman, Srijib Mukherjee, Nasif Shahriar, Md. Shariful Islam*

Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh

ABSTRACT

Due to environmental concerns, researchers are exploring alternatives to synthetic materials, with a focus on developing sustainable and eco-friendly materials. Besides synthetic material, agricultural waste is also threatening for environment and human health. Egg shells are abundantly available byproducts, obtained from local food restaurants, and may be used as an alternative to synthetic fillers. This research focuses on the impact of filler particles on the mechanical properties of the jute fiber-reinforced epoxy composites. The experimental approach involved the fabrication of composites with varying wt.% of Egg Shell Particle (ESP) (0%, 1%, 2%, 4%, 6%, 8%) via the hand layup technique. The tensile and flexural tests were conducted using relevant standards. The results demonstrated tensile and flexural properties of jute fiber reinforced epoxy composites improved with the addition of filler particles. For instance, the sample containing a 1% ESP showed 14.42% and 28.83% improvement in tensile strength and modulus, respectively. However, the flexural test results indicate that 8% ESP increases the flexural strength and modulus by 4.73% and 9.69%, respectively. It is also noted that the tensile and flexural properties of ESP-filled jute fiber reinforced epoxy composites are higher compared to the base, up to 8% filler addition. These findings suggest the potential use of ESP as a filler in enhancing the mechanical properties of jute fiber-reinforced epoxy composite.

Keywords: Jute Fiber Composite, Egg Shell Filler, Tensile Properties, Flexural Properties, Agricultural Waste Utilization

1. Introduction

Composites which have composed of either synthetic or natural fibers, offering an optimal combination of strength and lightweight characteristics, make them highly suitable for a wide range of applications in automotive, aerospace industries, and marine engineering. These materials are valued for their ability to meet the demanding performance requirements of those sectors while maintaining efficiency and sustainability [1], [2]. Bio-based composite materials are sustainable, low-cost, biodegradable alternatives to traditional composites, offering an eco-friendly solution for diverse applications [3]. The incorporation of natural fillers, including rice husk, eggshell, fish bone and scale, coconut shell, peanut and groundnut shell, wood saw dust, improves the mechanical, thermal, water absorption properties, and reduces the environmental impact [4]. Among these, eggshell powder, which is rich in calcium carbonate, significantly enhances the mechanical, thermal, and environmental properties [5], [6]. Although natural fibers demonstrate high moisture absorption, jute fiber reinforced epoxy composites have gained attention due to their favorable mechanical properties, and facilitate an alternative to the synthetic composite [7]. Maula et. al [8] have examined the effectiveness of biofiber-reinforced composites, focusing on various filler compositions. Despite some drawbacks, such as weak adhesion with the matrix and moisture absorption, natural fiber with proper treatment and hybridization enhances the performance and sustainability of the composite, offering environment friendly alternatives to synthetic fibers. Additionally, Vinod et. al [9] explored the effect of gigantea powder on the mechanical and thermal characteristics of jute-epoxy composites. Investigation revealed that the incorporation of filler particles enhances mechanical and thermal properties. Chandramohan et. al [10] investigated a jute and aloe vera hybrid natural fiber reinforced epoxy composite and conducted the mechanical, thermal, and water absorption test, where the result showed an increase in tensile strength by 13.5%, and in flexural strength by 65%. Moreover, Senthilnathan et. al [11] found that the addition of calcium carbonate fillers (0%, 3%, 6%, 8%) in jute fiber reinforced epoxy composite shows improvement in the mechanical properties.

Although many research has been done on the mechanical and tribological characteristics of eggshell powder reinforced polymer composite, however very few research has been done on the effect of micro-ESP (< 75 µm) as a filler material in four-layer of jute fiber mat reinforced epoxy composite focusing on a wide range of filler content (0%, 1%, 2%, 4%, 6%). In this study, eggshell powder a sustainable byproduct, was incorporated as a micro-filler to reduce the amount of epoxy in jute-fiber reinforced composites, ensuring that mechanical properties remained intact. The composites were made using the hand lay-up technique, and their tensile and flexural properties were assessed in detail.

2. Materials and Methods

2.1 Materials

The raw jute fiber mat was purchased from local market in Khulna, Bangladesh. The average thickness and the areal density of oven jute fiber mat are 1.002 mm and 0.048 g/cm^{2}, respectively. Chicken egg shell was collected

*Corresponding Author Email Address: arif48@me.kuet.ac.bd

from a local food restaurant and prepared for use as filler material. Epoxy and Hardener (Lapox) were used as the matrix, purchased locally from Muniba Enterprise, Bangladesh. Silicon molds (200×150×13 mm) were purchased from the local market for composite fabrication.

2.2 Egg Shell Powder Preparation

Waste Egg Shells (ES) were collected from a local restaurant, cleaned, and dried under the Sun as shown in Fig. 1(a). The dried egg shells were grinded in a blender to obtain fine powder. The particles were sieved to collect ESP with a size smaller than 75 µm as shown in Fig. 1(b). The sieved powder was kept in a woven at 80°C for 24 hours to remove the moisture before using in composites.

(a) (b)

Fig. 1 (a) Egg shell before grinding and (b) egg shell powder after grinding and sieving

2.3 Fabrication Process of Composite

The composite was fabricated at room temperature using the conventional hand layup technique. The micro filler particles were added to the epoxy and hand stirred for mixing. Later, particles were dispersed by ultrasonic probe sonication with 25 mm diameter horn for 6 minutes to obtain a homogenous mixture. Subsequently, the hardener was added to the filler-epoxy mixture, maintaining epoxy to hardener ratio of 2:1 (manufacturer recommended) and manually stirred with a glass rod to ensure a uniform mixture and eliminate bubbles. Four layers of woven jute fiber were used for each sample. After placing each layer, the matrix was uniformly distributed throughout the mat by a brush and a grooved hand roller. Each layer of the mat was rolled properly to drive out the trapped air bubbles and ensure proper distribution. A transparent plastic sheet was placed over the final layer to create a smooth surface and easy removal. Then a glass plate was placed on the top of the layers, followed by a uniform load of 10 kg on top of the glass plate. The setup was kept for curing for 48 hours. After curing, the composite was released from the mold and cut into different dimensions as required by the ASTM standards. A flow chart of the preparation process is given in Fig. 2.

2.4 Mechanical Testing

The tensile and flexural tests were conducted in a universal testing machine (Shimadzu AGXV-300kN, Japan), which has a load capacity of 300 kN. The tensile test was performed according to ASTM D3039 standard, with specimen dimensions of 180 ×13 mm^2, rectangular shape. A constant gauge length of 100 mm and a testing speed of 2 mm/min were used for the experiment. A specimen size of 90 ×13 mm^2, rectangular shape was used for the flexural test in accordance with ASTM D790. The span length of 70 mm and test speed of 2 mm/min were maintained throughout the experiment. The tension and flexural test setup are illustrated in Fig. 3.

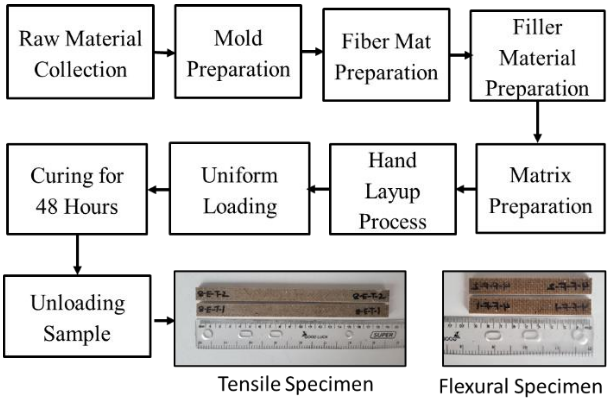

Fig. 2 Flow chart of fabrication process

(a) (b)

Fig. 3 (a) Tensile test and (b) flexural test setup on UTM

3. Result and Discussion

3.1 Density

Fig 4 shows the density variation of different composites due to filler addition. The density of the specimens for ESP filled composites slightly increases with filler particles because of the relatively higher density of ESP. The lowest density found was 1.158 g/cm^3 for the base sample where no filler particles were used. At 8% ESP, the specimen shows the highest density of 1.205 g/cm^3, which is 4.06 % greater than the base sample.

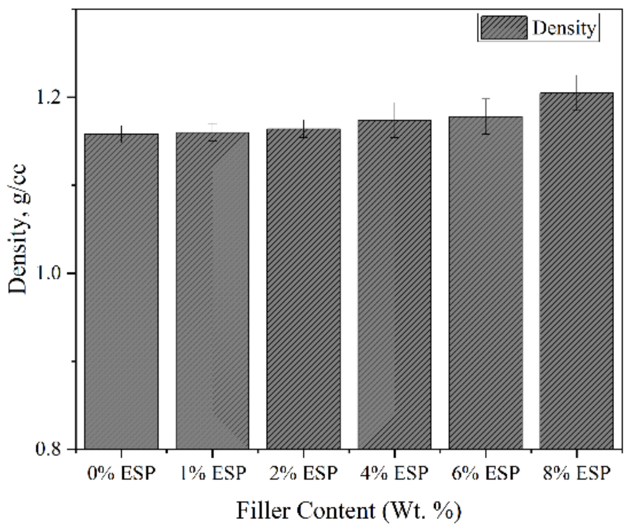

Fig.4 Density of fabricated composite

3.2 Tensile Properties

The incorporation of ESP to jute fiber reinforced epoxy composite improves the tensile strength and specific tensile strength, as shown in Fig 5. The base sample without any filler particles provides the lowest tensile strength of 50.13 MPa. Incorporation of 1% ESP exhibits the highest tensile strength of 57.36 MPa, showing a 14.42 % improvement compared to the base sample. Further addition of the ESP up to 8% reduces the tensile strength, but it remains greater than the base composite without fillers. The maximum specific tensile strength reaches to 49.45 MPa/(g/cm^3) at 1% ESP and beyond this, it decreases gradually following the similar trend as the tensile strength.

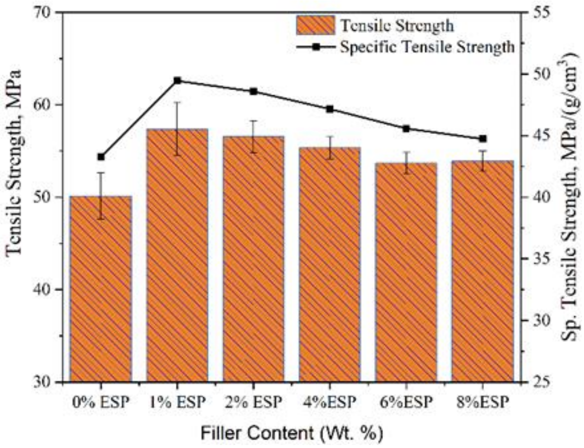

Fig. 5 Tensile strength and sp. tensile strength of ESP-filled composite.

Fig 6 demonstrates the influence of ESP filler particle in tensile modulus and specific tensile modulus on the jute fiber reinforced epoxy composite. It is seen that, the base sample without filler particle showed the lowest tensile modulus of 1064.97 MPa. The incorporation of 2 % ESP showed the maximum modulus of 1371.99 MPa, providing a 28.8 % increment compared to the base sample. Further addition of ESP up to 8 % caused a gradual decline in modulus although the modulus is greater than the base composite. At higher micro filler content, the modulus decreases due to the agglomeration and poor bonding. The specific tensile modulus shows a peak at 2 % ESP with a value of 1178.69 MPa/(g/cm^3), an increase of 28.17 % compared to the base sample.

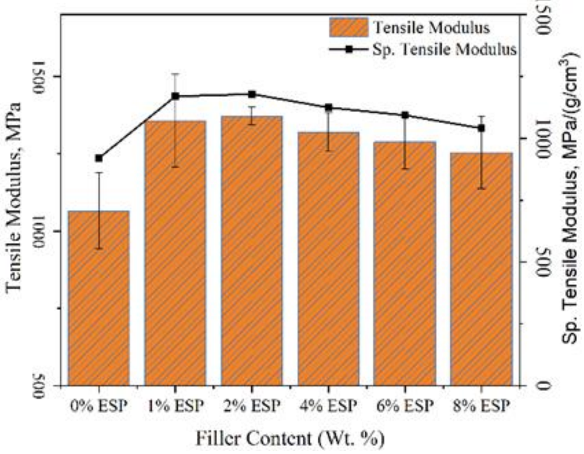

Fig.6 Tensile modulus and sp. tensile modulus of ESP filled composite.

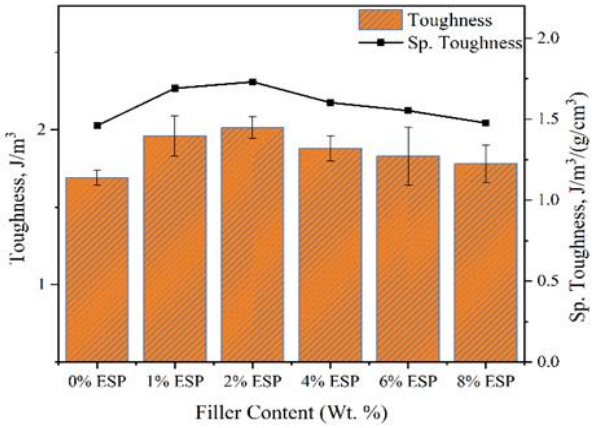

Fig. 7 Toughness of ESP filled composite

Fig. 7 illustrates how the toughness and specific toughness of jute-epoxy composites is influenced by the ESP addition. Incorporating lower percentage of filler particles improves the toughness by absorbing additional energy through fiber-matrix debonding and crack deflection. The base sample exhibited the lowest toughness 1.69 J/m^3 among all the specimen. At 1 % ESP the toughness showed a slight increase to 1.96 J/m^3. The highest toughness was found 2.01 J/m^3 at 2 % filler particles, an equivalent of 18.94 % enhancement compared to the base sample. The toughness decreases beyond 2 % ESP addition indicating its optimal concentration. The specific toughness of composite increases to 1.73 J/m^3/(g/cm^3), indicating 18.49 % increment compared to the base sample. Further addition of filler beyond 2 % ESP reduces the toughness gradually showing just above the base composite at 8 % ESP filler content.

The tension test results demonstrate that the incorporation of filler particles enhances the tensile properties at lower filler concentration up to 2 %. Beyond 2 % ESP addition in the composite decreases the tensile properties gradually. At lower content, the fillers uniformly distribute throughout the matrix which ensures better bonding between matrix and fiber, leading to an increased tensile property. The higher filler concentration causes agglomeration and voids which weaken the fiber-matrix bonding, resulting degradation of the tensile properties. The higher tensile properties compared to the base composite without filler even at 8 % filler addition indicates that the epoxy volume fraction can significantly be reduced with the addition of ESP fillers without affecting the mechanical properties negatively. These results align with previous findings by Senthilnathan et. al [11], where $CaCO_3$ was used as a filler material in jute fiber reinforced epoxy composite providing 7.91 % increment in tensile strength.

3.3 Flexural Properties

The flexural strength and the specific flexural strength of jute fiber reinforced epoxy composite with varying ESP filler are shown in Fig. 8. It is found that the base sample without any filler particles shows the lowest flexural strength of 88.78 MPa and the lowest specific flexural strength of 76.66 MPa/(g/cm^3) among all the composites. The observation showed a slight increment in flexural strength to 91.37 MPa with the addition of 1% ESP. The maximum flexural strength of 92.98 MPa was obtained at 8% ESP, an equivalent to 4.73 % increment compared to the base composite. The highest specific flexural strength is found for a 2 % ESP addition which is 3.80 % greater than the base composite. The filler particles enhance the load transmission capacity of the fabricated composite which helps to provide greater resistance to failure. It is noted that the flexural strength is consistently greater than the base composite up to 8 % ESP filler addition.

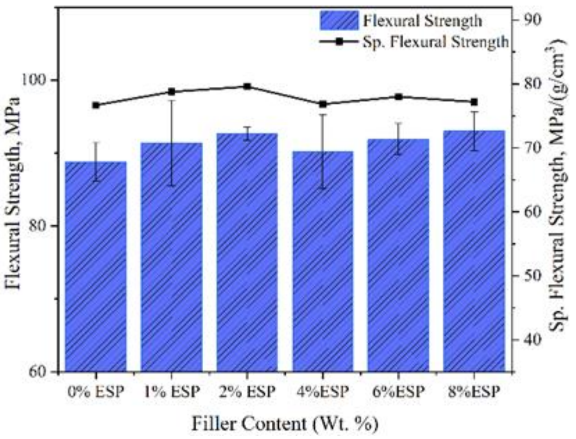

Fig. 8 Flexural strength and sp. flexural strength of ESP filled composite

Fig. 9 illustrates the flexural modulus and specific flexural modulus of jute fiber reinforced composites incorporated with ESP fillers. The base sample exhibited the flexural modulus of 4187.66 MPa and the specific flexural modulus of 3558.22 MPa/(g/cm^3). Incorporating the filler particles into the composite enhances both flexural modulus and specific flexural modulus. At 1 % ESP, the highest value of flexural strength (4593.45 MPa) and specific flexural strength (3959.87 MPa/(g/cm^3) were obtained among all the ESP filled composites. They are respectively 9.69 % and 11.29 % greater than the base composite. The flexural strength and specific flexural strength gradually declined with further addition of ESP particles up to 8 % ESP addition, but they are still greater than the base composite.

Fig 10 shows the energy absorption behaviors of the eggshell powder filled fabricated composites. The base sample without any filler particles provides the energy absorption of 1.29 J and specific energy absorption of 1.12 J/(g/cm^3).

The maximum energy absorption of 1.32 J was found for 8 % ESP which indicates a slight (2.3 %) increment over the base sample. All ESP-filled composites show greater energy absorption compared to the base composite except the composite with 1 % ESP.

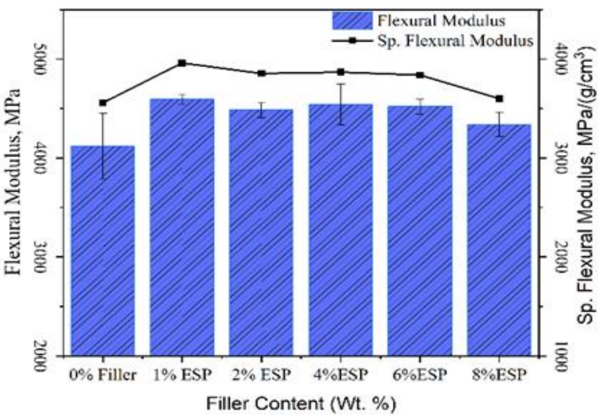

Fig. 9 Tensile modulus of ESP filled composite

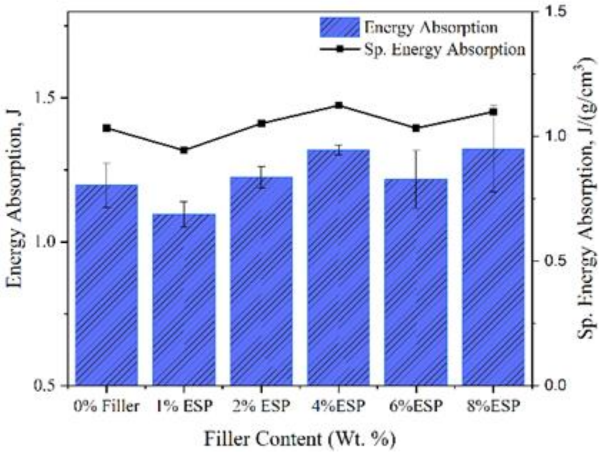

Fig. 10 Energy Absorption of ESP Filled Composite

The flexural test results showed that the addition of ESP filler in jute fiber reinforced epoxy composite up to 8 % results in positive improvement in flexural properties. The greater flexural properties up to 8 % ESP addition show the potential to reduce epoxy volume fraction in the composites without sacrificing the mechanical properties of the jute fiber reinforced epoxy composites. Incorporating fillers reduces the internal voids of the fabricated composite, which helps to absorb energy and slow down crack propagation, which makes the material stronger and more durable [12], [13]. The incorporation of $CaCO_3$ fillers also increased the flexural strength, which aligns with the findings in this work [11].

4. Conclusion

In this work, the influence of waste egg shell particles on tensile and flexural properties of jute fiber reinforced epoxy composite was explored and the following conclusions can be drawn:

- The incorporation of 2 wt.% ESP provides significant improvement in toughness (18.94%), and tensile modulus (28.8%) and the maximum tensile strength (14.42%) was found at 1% ESP compared to the base sample. Further addition of the filler particles decreases the tensile properties of the composite due to the poor distribution of filler particles into the matrix.
- ESP incorporation in jute fiber reinforced epoxy composite enhances the flexural properties, with maximum flexural strength (92.98 MPa) and energy absorption (1.32 J) at 8% ESP, while the highest flexural modulus (4593.45 MPa) was obtained at 1% ESP.

The study concludes that incorporating eggshell powder (ESP) as filler in jute fiber reinforced epoxy composites improves both tensile and flexural characteristics at lower concentrations, particularly up to 2% for tensile strength. While higher ESP content leads to agglomeration and voids that reduce tensile properties, the composites still outperform the base composite even at 8% addition. This indicates that epoxy volume fraction can be reduced without compromising overall performance. Moreover, ESP fillers promote environmental sustainability by reducing epoxy use, providing a pathway for waste eggshell utilization, and contributing to biodegradable and ecofriendly composite development.

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