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Mechanical and Thermal Properties Investigation of Jute Reinforced Epoxy Composites with Rice Husk Ash

Md. Ahtesham Akhter, Dipayan Mondal*, Md. Samir Hossen
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh
E-mail: dipkuet@me.kuet.ac.bd

Abstract

The study explored the use of rice husk ash (RHA) as a filler in jute fiber-reinforced epoxy composites for thermal insulation in buildings. Thermal and mechanical properties were evaluated on four composite samples that had different filler ratios (0%, 1%, 2%, and 3%). The findings showed that thermal conductivity decreased with increasing filler weight percentage; the sample with 3% RHA had the lowest thermal conductivity, measuring 0.037 W/mK. Mechanically, the 3% RHA sample exhibited the best energy absorption, tensile modulus, and ultimate tensile strength (50.07 MPa). It had the highest ultimate flexural strength, a moderate flexural modulus, and respectable energy absorption in flexural tests. The study concluded that the 3% RHA jute fiber composite offers low thermal conductivity, good strength, and adequate stiffness and energy absorption, making it suitable for thermal insulation applications.

Keywords: Jute fiber, Epoxy, RHA, Thermal Conductivity, Tensile, Flexural, Building Thermal Insulation.

1.0 Introduction:

Thermal comfort is essential in tropical regions, where heat waves impact internal temperatures. Effective insulation systems are needed to maintain comfort by acting as heat transfer barriers, keeping homes cool in summer and warm in winter [1]. Insulation materials, often placed between walls, in attics, and on ceilings, must balance properties like strength, low density, and low conductivity. Foamed plastic is common but limited by its mechanical properties [2]. Composite materials, combining different phases, are commonly used [1]. Synthetic fibers like glass fiber improve insulation but have drawbacks like high cost and non-recyclability. Natural fibers such as jute, coconut coir, rice husk, and banana offer low cost, renewability, and low specific gravity [2], [3]. Natural fiber-reinforced composites (NFRCs) are gaining interest for their non-abrasive nature, low energy consumption, and carbon footprint, suitable for automotive and other sectors [4]. These fibers are also lightweight, nontoxic, biodegradable, and have lower heat conductivity than synthetic fibers, making them suitable for insulation [2]. Despite benefits in industries like transportation and construction, natural fibers face challenges like incompatibility and low moisture resistance [5], [6].

Studies highlight the advantages of natural fiber composites. Zakriya and Ramakrishnan [7] found superior qualities in jute and hollow-conjugated polyester-reinforced composites. Praveena et al. [8] emphasized the environmental benefits and applications of housing and automobiles. Sarukasan et al. [9] developed strong jute/coir hybrid composites. Florea and Manea [10] identified recipes with low thermal conductivity. Ghazi and Jaddan [11] aimed to create green shipbuilding materials with epoxy-based composites. Research on hybrid composites, such as by Jani et al. [12] and Bhoopathi et al. [13], highlights improved mechanical and thermal properties with natural and synthetic fiber combinations. Boopalan et al. [14] found banana fiber improves jute-reinforced epoxy composites, reducing moisture absorption. Hameed et al. [15] enhanced flexural strength and hardness with rice husk and ash in coconut fiber composites. Sankar et al. [16] demonstrated significant strength using treated polypropylene and banana fiber composites. Fuzhen Chen's [17] work on natural fiber bio-composites for insulating walls showed increased strength and good thermal insulation with thermal conductivity of 0.078 to 0.089 W/(m K). Investing in well-designed walls optimizes energy use and comfort, with composite walls offering superior insulation and heat control [18].

From the above discussion, several studies have been performed on jute-reinforced epoxy composites. As per the literature, there is little research on different concentrations of rice husk ash (RHA) in jute fiber-reinforced epoxy composites for thermal insulation in buildings. Therefore, the main targets are to investigate the mechanical (tensile and flexure) properties and thermal properties by adopting 3% RHA as a filler weight. Moreover, the study aimed to increase the mechanical qualities while decreasing the thermal properties, and also looking for better alternatives to existing building insulation materials such as wall-inside insulation applications.

2.0 Methodology

2.1 Materials

The materials utilized were jute fiber, epoxy resin mixed with a hardener in a 3:1 ratio, rice husk ash, and a releasing agent, specifically wax shown in Fig. 1. These components were chosen for their potential to enhance the composite's performance in terms of thermal insulation and mechanical strength.



(a) **(b)** **(c)**

Fig. 1. (a) Jute fiber mat, (b) Epoxy resin, and (c) Wax

The filler material was rice husk ash as shown in Fig. 2. First, the rice husk was cleaned to get rid of contaminants before being screened for filth. To make the ash used in this study, it was air-dried for 48 hours and burned for about 6 hours at 550˚C in a furnace [19].



(a) **(b)**

Fig. 2. (a) Rice husk, and (b) Rice husk ash

2.2 Composite fabrication

The composite fabrication process involved using silicon mold with a 300x300x20mm mold size for uniform layer formation. Fiber mats were cut into the same shape based on the mold size, using masking tape and permanent markers to prevent edge damage. Epoxy resin and hardener were mixed in a 3:1 ratio, with rice husk ash filler mixed through sonication for uniform distribution. The process was completed using a digital weight balance for accurate weight measurements. The specimen was prepared using the 'Hand-Layup Process' [20]**.** A total of three layers of fiber mats were used to fabricate each composite specimen.

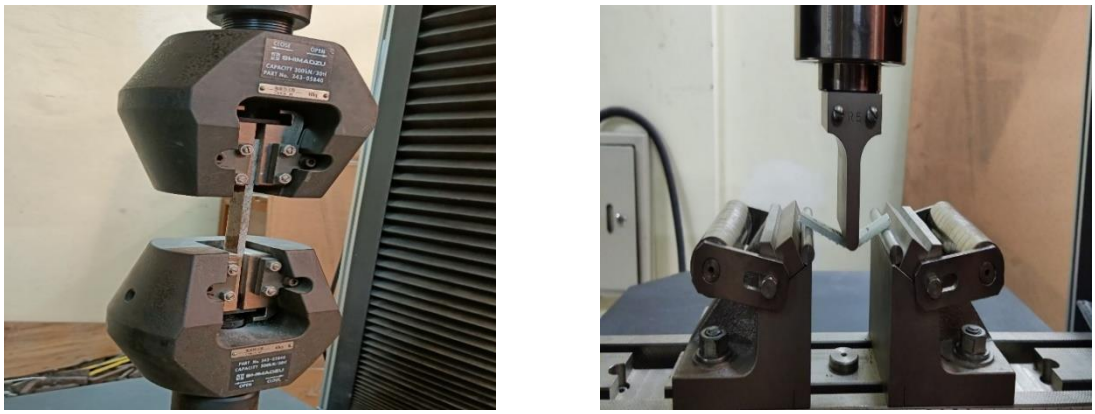


(a) **(b)** **(c)**

Fig. 3. (a) Silicon mold, (b) Mixture of resin & filler, and (c) Fabricated composite plate

2.3 Mechanical properties measurement apparatus

The tensile test was done in the UTM machine as shown in Fig. 4 (a). The crosshead speed was 2 mm/min and the gauge length was 91 mm. The specimens for the tensile test were prepared according to ASTM D3039 [21]. The tensile test was done on three samples of each composite specimen. While, the flexural test was also done in the UTM machine as shown in Fig. 4 (b). The crosshead speed was 5 mm/min. The specimens for the flexural test were prepared according to ASTM D790 [22]. The flexural test was also done on three samples of each composite specimen.



(a) **(b)**

Fig. 4. Setup of (a) Tensile test in UTM, and (b) Flexural test in UTM

2.4 Thermal properties measurement apparatus

The thermal conductivity was tested using the TRSYS101 measurement system [23], which has been developed at the department of Energy Science Engineering, KUET. A 5.8×8 inch rectangular composite sample was prepared and carefully cleaned on all sides to evaluate thermal conductivity. The samples outside surface had a heat flux sensor and temperature sensor connected, while its inside had a data logger and temperature sensor. The sample was placed in a measurement chamber with a controlled heat source (heater). Temperature readings from the data logger and sensor were recorded periodically as the heat source reached a steady temperature. Heat flux was derived from the power input, and temperature difference was calculated from sensor readings. Thermal conductivity (k) was computed using Fourier's law of heat conduction [24], where q is the heat flux, dT is the temperature difference, and dx is the thickness of the sample, then $k = \frac{q\,dx}{dT}$. Multiple measurements were taken over 5-7 hours to obtain average values for accuracy. Fig. 5 shows the CAD model of the whole thermal conductivity test setup.

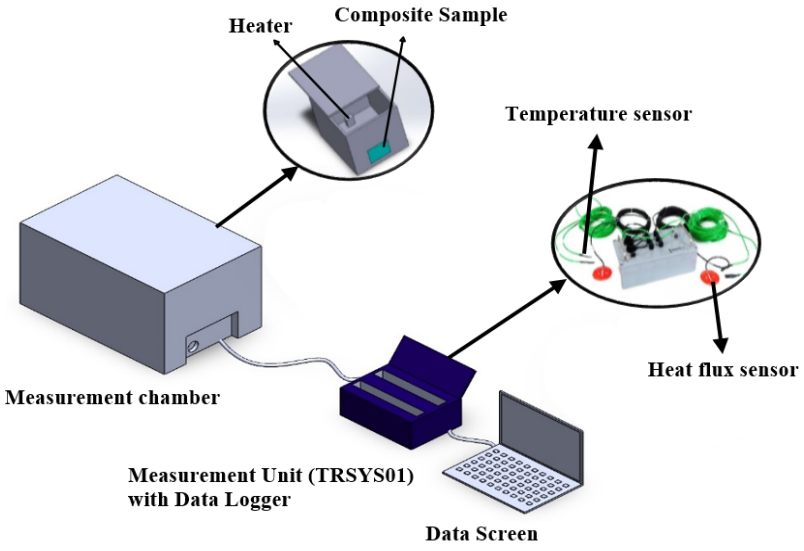
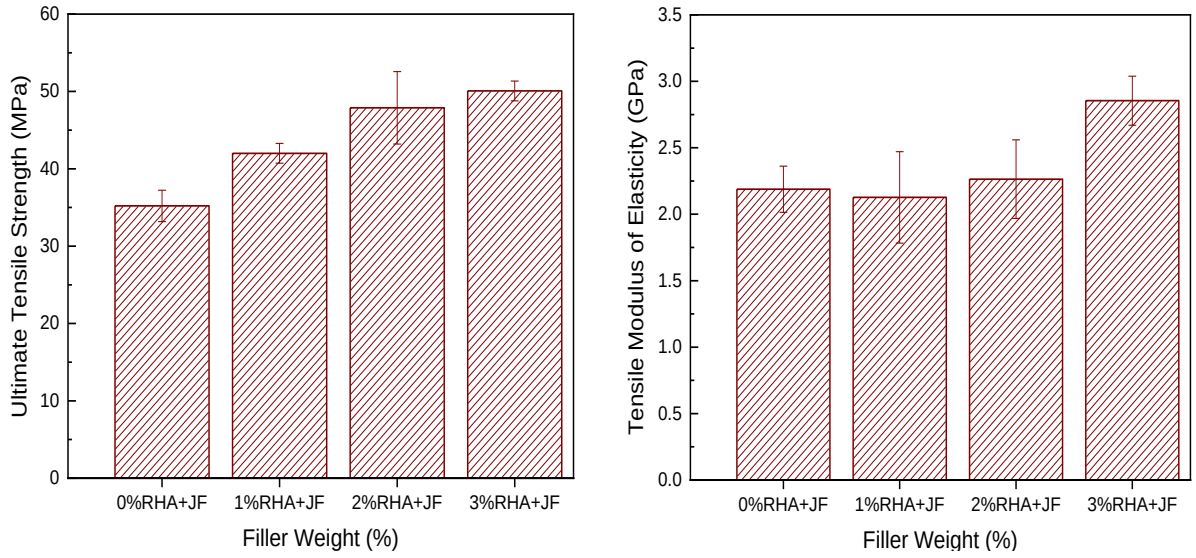


Fig. 5. CAD model of the whole thermal conductivity test setup

3.0 Results and Discussion

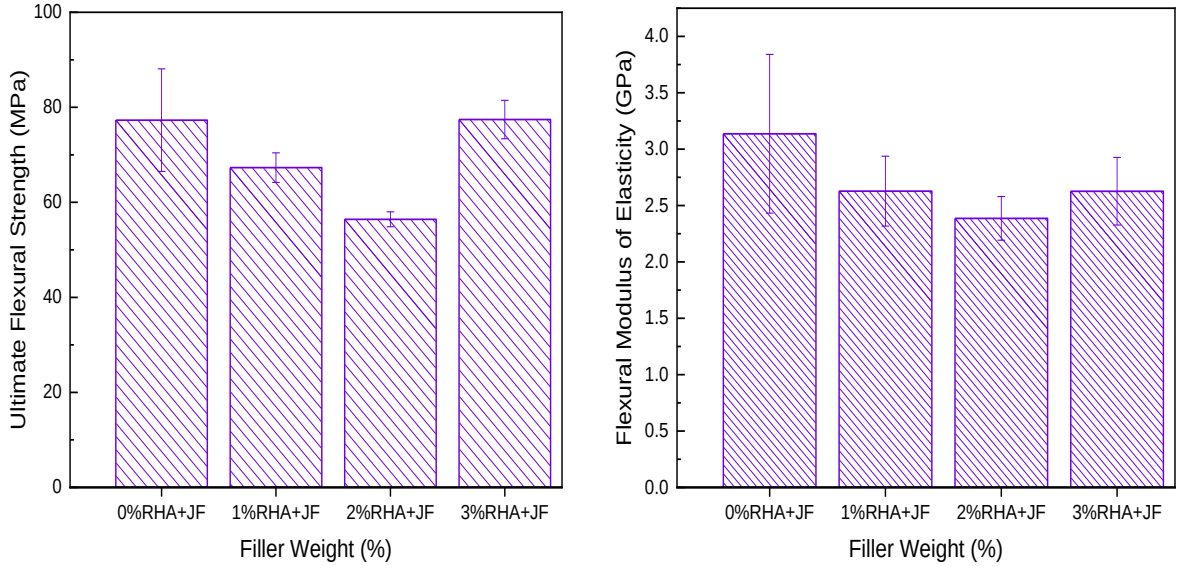
3.1 Mechanical properties measurement

Fig. 6 illustrates the tensile test results for considered specimen. While in Fig. 6 (a), it is shown that ultimate tensile strength increased gradually with the increase in filler content. Adding filler particles further increases the composite's strength. The 3% RHA + Jute Fiber composite has the highest strength of 50.07 MPa, which indicates that it is the strongest of all. In terms of stiffness, the 3% RHA + Jute Fiber composite also has the highest tensile modulus of elasticity of 2.85 GPa. This indicates that the 3% RHA + Jute Fiber composite is the stiffest material of the four, as shown in Fig. 6 (b).



(a) **(b)**

Fig. 6. Variation of (a) Ultimate Tensile Strength, and (b) Tensile Modulus of Elasticity at different ratios of filler contents



(a) **(b)**

Fig. 7. Variation of (a) Ultimate Flexural Strength, and (b) Flexural Modulus of Elasticity at different ratios of filler contents

Fig. 7 demonstrates the flexural test results for considered specimen. While Fig. 7 (a) shows that the flexural strength of the jute fiber-reinforced epoxy composite exhibits a non-linear trend with filler content. The addition of filler up to 2% initially decreases the flexural strength, possibly due to filler-induced defects or reduced matrix-fiber interactions. However, at 3% filler content, the flexural strength increases, suggesting a potential reinforcement effect from optimized filler dispersion or interfacial bonding. With the increase in filler contents, the modulus of elasticity of the composites has decreased considerably, as shown in Fig. 7 (b).

Fig. 8 shows the variation of energy absorption with different ratios (0 to 3%) of filler contents of JF. The energy absorption was obtained at 19.97J during the tensile test for 2% RHA+JF composite, while for flexure test of 3% RHA+JF composite found a maximum at 2.06 J. Moreover, 3% RHA+JF composite also exhibits a moderate value of 16.15 J in the time being of the tensile test, which is the second highest value of energy absorption. However, the higher energy absorption capability indicates that the composite material can absorb more energy before failing or causing substantial damage.

3.2 Thermal properties measurement

Fig. 9 shows the comparison of the thermal conductivity of composites with varying ratios of filler material. Comparing all of the composites generated, we can see that the thermal conductivity of jute fiber-reinforced epoxy composites decreases as the filler weight percentage increases, which was desirable for this study. Rice husk ash includes silica, which helps reduce the thermal conductivity of composite materials. The 3% RHA + JF sample has the lowest thermal conductivity value, 0.036967425 W/m.K.

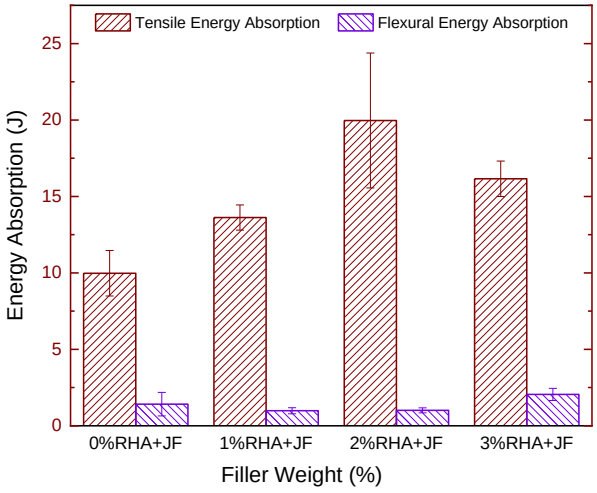


Fig. 8. Variation of energy absorption with different ratios of filler contents

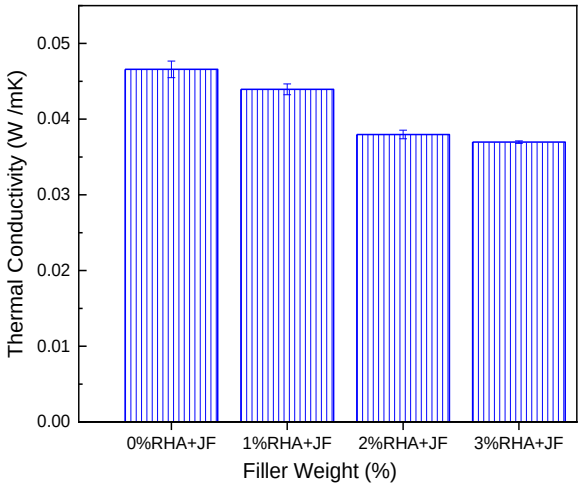


Fig. 9. Variation of thermal conductivity with different ratios of filler contents

Lastly, it is said that, the content of rice husk ash filler was kept up to a maximum of 3% to focus on the initial trends of its impact on the thermal and mechanical properties of jute fiber-reinforced epoxy composite. This range allowed meaningful observation, which showed an increase in the content of filler strengthens the mechanical properties while decreasing thermal conductivity. Therefore, the limit of filler weight to 3% is a process-performance-cost compromise that yields an optimal level for the attainment of desired performance. Possibly, longer-term studies might exhibit similar trends at these higher filler percentages, but time constraints justified reducing the time to make sure the accuracy and reliability of the results are ensured.

4.0 Conclusion

The specific findings of this research are as follows:

- The thermal conductivity of the composites decreased with increasing filler weight percentage. The minimum thermal conductivity was found to be 0.03696 W/mK in 3% RHA+JF composite.
- Tensile values improved with increasing filler percentage while in 3% RHA+JF composite found the ultimate tensile strength of 50.07 MPa and the highest tensile modulus of elasticity.
- In terms of flexural strength, the composites exhibited a non-linear trend with filler content. Filler addition initially decreased flexural strength up to 2%, possibly due to defects or reduced interactions.

At 3%, strength increased, possibly due to optimized filler dispersion or interfacial bonding, but the modulus of elasticity decreased.

- The tensile test shows 19.97 J energy absorption for the 2% RHA+JF composite, while the 3% composite peaks at 2.06 J during the flexure test. Additionally, the 3% RHA+JF composite has a moderate tensile value of 16.15 J. These findings indicate strong energy absorption, enhancing resistance to failure.

The study concluded that the 3% RHA+JF composite sample has low thermal conductivity, good strength, and reasonable stiffness and energy absorption capacity, making it suitable for improving the thermal insulation in buildings inside wall insulation applications.

5.0 Acknowledgement

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