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Mechanical Properties of Jute Fiber Polyester Hybrid Composite Filled with Eggshell

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ABSTRACT

Natural fibers are being used in composites as a means of environmental protection through the use of biodegradable components. By combining natural and synthetic fibers, the use of natural fibers might be expanded significantly, potentially lowering the cost of hybrid composites. Fiber reinforced polymer-based composites have been used in a wide range of industrial applications for a very long time because of their high specific strength and modulus. The use of coir, a natural fiber, as reinforcement in reinforced polymers was decided upon due to the availability of different natural fibers. Natural fibers are equally as strong and light as they are affordable. Therefore, the aim of this research is to analyze the mechanical characteristics of a jute fiber/polyester hybrid composite filled with eggshell. In this study, woven jute fibers and polyester filled with eggshell powder were employed to construct composites utilizing the layering technique. In accordance with ASTM standards, tensile, flexural, impact, and water absorption tests are performed to assess the influence of ratio. Five ratios were employed: 80% eggshell powder and 20% polyester (EP80P20), 70% eggshell powder and 30% polyester (EP70P30), 50% eggshell powder and 50% polyester (EP50P50), 40% eggshell powder and 60% polyester (EP40P60), and 20% eggshell powder and 80% polyester (EP20P80). The results show that the composite with EP20P80 has the highest tensile strength, elasticity and flexural strength, followed by EP40P60, EP50P50, EP70P30 and EP80P20. This implies the increment ratio of the eggshell powder leads to the reduction in tensile strength, elasticity and flexural strength. Meanwhile, the statistical data analysis shows that there are a significant difference among the five ratios (p-value < 0.05) for the tensile and flexural tests. However, the impact test shows the opposite result.

1. Introduction

As environmental consciousness has grown, there has been a corresponding evolution in the adaptation of natural materials to fulfil various needs. This evolution has enabled researchers to create materials possessing distinct characteristics such as lightweight nature, accessibility, density,

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reusability, biodegradability, eco-friendliness, and high specific strength. Examples of such natural materials include pineapple leaf [1,2], sawdust [3-5], rice husk [6,7], and jute [8]. These materials, abundant in nature and renewable, are frequently utilized as reinforcement components in the polymer composite industry. Meanwhile, the integration of natural materials with synthetic counterparts has proven to be a favourable option as a reinforcement material, primarily attributed to its heightened strength [9]. Battula and Subbaiah [10] compared the mechanical properties of a new class of epoxy-based hybrid composites reinforced with E-Glass woven roving mat which filled with wood dust ash (WDA), rice husk ash (RHA), and the mix of WDA and RHA. Meanwhile, a comprehensive review of carbon fiber reinforced epoxy composites has been highlighted by Kishore and Subbaiah [11] for automotive applications.

Eggshells, widely utilized in the food industry for their taste and nutritional value, present a waste management challenge when disposed of in landfills, leading to issues like odor and microbial growth [12,13]. In this context, the study aims to repurpose eggshells by integrating them into a sustainable product alongside jute fabric and polyester. In addition, jute fabric which derived from the jute plant, boasts one of the longest natural textile fibers globally, reaching over 10 feet in length [14,15]. Commonly used for various applications such as packaging, fabrics, carpets, and ropes, jute contributes to the eco-friendly aspect of the composite. On the other hand, polyester, chosen for its mechanical resistance and ability to stretch and shrink without losing strength, complements the natural fibers in the composite [16]. The challenge lies in creating a waste-based product that is both durable and structurally sound. Material selection plays a pivotal role, necessitating qualities like durability, compressive strength, tensile strength, and flexibility [17]. The correct ratio of these materials needs identification through rigorous experimentation during the planning phase to ensure optimal structural integrity and performance.

The core objective of the research is to fabricate a jute fiber polyester hybrid composite filled with eggshells. The mechanical properties of this composite are investigated using three different types of tests: tensile, flexural, and impact tests. Through this comprehensive examination, the study seeks to contribute valuable insights into the development of sustainable materials, fostering a better understanding of the mechanical behaviour of the composite under various conditions.

2. Methodology

Three materials were involved in this study: eggshell powder, polyester and jute fiber. The eggshell powder (0.4236 g/cm3), polyester (1.15 g/cm3) and jute fiber were obtained from a local market. The samples used in this study were prepared by using layering method.

2.1 Sample Preparation

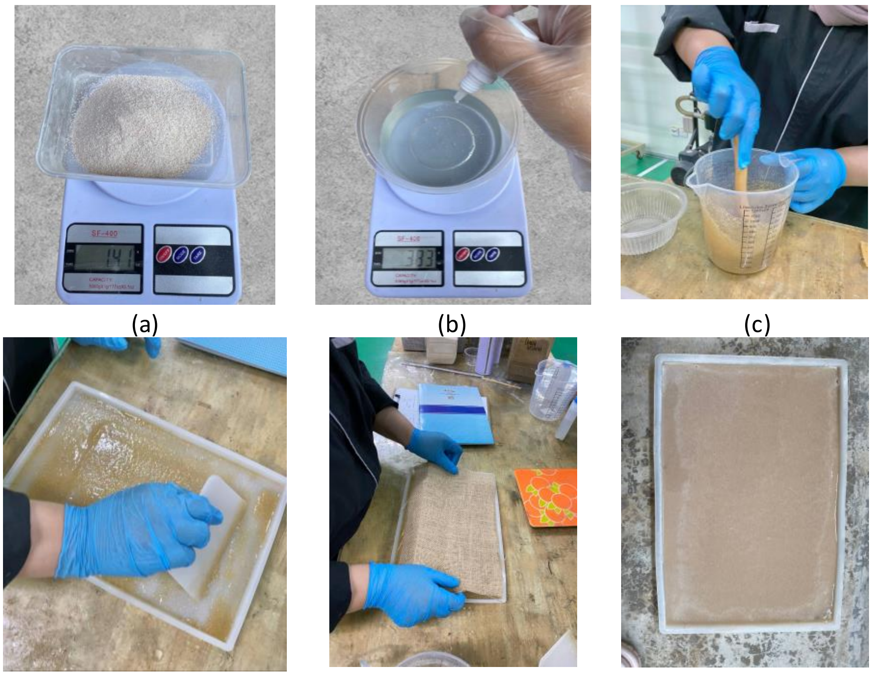
The waste chicken eggshell recycling process involves several steps: washed, soaked in water and sun-dry for two days as shown in Figure 1 [16]. Once dried, the eggshells are ground with a mechanical grinder, repeating the process until achieving a uniform micron size. Figure 2 shows the final step involves sieving the ground eggshells using a Test Sieve to obtain an average grain size of 500 µm. In the fabrication process, a silicon mold is utilized to create the sample, integrating polyester, eggshell powder, and hardener. As depicted in Figure 3, the mixing procedure involves measuring polyester and hardener according to a specific ratio, while the hardener is measured at a 0.3:100 (g) ratio with polyester. The layering process started with pouring a quarter of the mixture, followed by placing jute, and finally pouring the entire mixture into the silicon mold.

(a) (b) (c)

Fig. 1. Eggshell powder preparation processes; (a) Waste eggshells are washed; (b) Cleaned eggshells are soaked in water for 24 hours; (c) Eggshells were then dried under the sun for 48 hours

(a) (b)

Fig. 2. Sizing process; (a) Test sieve; (b) Final size of eggshell powder: 500μm



(a) (b) (c)

(d) (e) (f)

Fig. 3. Mixing and layering process; (a) Weighing the eggshell powder; (b) Weighing the polyester and hardener; (c) Mixed the eggshell powder, polyester and hardener; (d) Spread out quarter of mixture; (e) Placed the jute; (f) Poured all mixture on top of jute

2.2 Mechanical Properties

Specimens for both tensile and flexural tests underwent examination using the Shimadzu Universal Testing Machine, prepared in accordance with ASTM D3039 and ASTM D790 standards, featuring dimensions of 250mm in length and 25mm in width. For assessing the resilience of plastics to flexural shock, the ASTM D6110 standard with dimensions of 60mm length and 15mm width was employed. Tests were conducted on the INSTRON CEAST 9050 Impact Tester Machine to determine the force required to break the specimens. Charpy Impact tests were conducted on specimens with a V-notch (2mm diameter, 45-degree angle) for result analysis.

The water absorption of hybrid composites was evaluated under ASTM D570 standards, measuring the maximum percentage. Specimens were submerged for varying exposure times, removed, dried, and weighed after surface water removal with a dry cloth. This process was repeated over several days. To calculate the percentage of water absorption, the equation below was applied. Where m_1 is the weight in grammes before being submerged in water, and m_2 is the weight in grammes after being submerged in water.

$$\text{Water absorption } (\%) = \frac{m_2 - m_1}{m_1} \times 100 \quad (1)$$

3. Results and discussion

3.1 Tensile Test

First test that was conducted was tensile strength (see Figure 4) and elasticity in five eco-friendly EPPR (Eggshell powder-Polyester) composite ratios. As shown in Figure 5, EP20P80 exhibited higher tensile strength and elasticity, while EP80P20 showed the lowest values. This suggests that increased eggshell powder in EPPR composites leads to reduced tensile strength. The results highlight the effect of bonding between matrix and filler in particulate-filled polymer composites by attributing such losses to filler particle clumping and poor matrix adherence [18]. Tensile modulus reduction can indicate increased resistance to deformation, enabling heavier loads with higher filler loading [19].

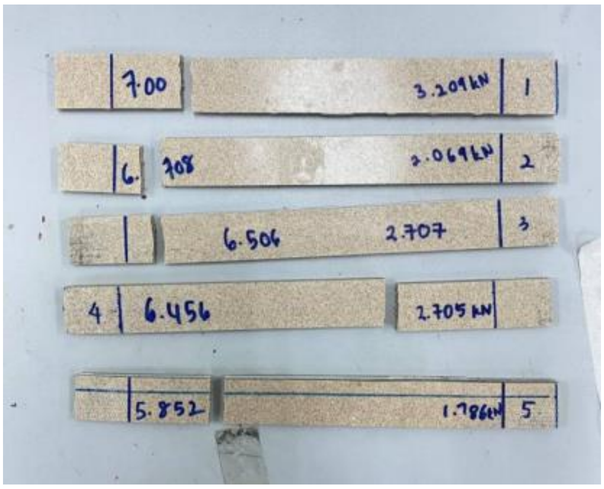
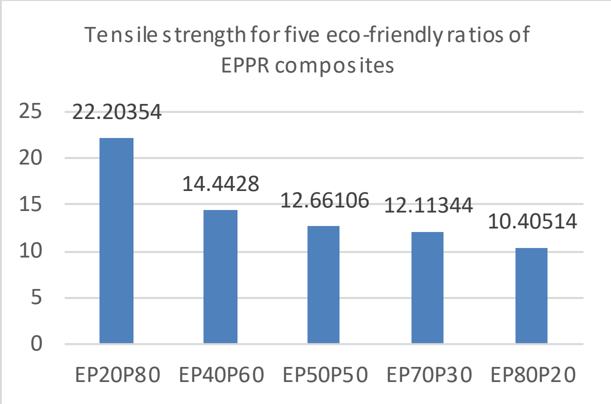
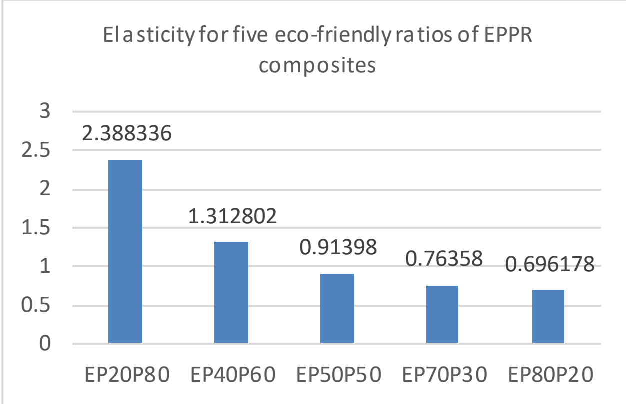


Fig. 4. Specimen of tensile test



(a)



(b)

Fig. 5. Tensile for five ratios of EPPR composites; (a) Tensile strength for five eco-friendly ratios of EPPR composites; (b) Elasticity for five eco-friendly ratios of EPPR composites

Table 1
ANOVA of tensile strength for five eco-friendly ratios of EPPR composites

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
RATIO	4	425.511	98.18%	425.511	106.378	269.87	0.000
Error	20	7.884	1.82%	7.884	0.394		
Total	24	433.395	100.00%				

As depicted in Table 1, ANOVA analysis on tensile strength revealed significant differences among the five eco-friendly ratios, with P-values below the α = 0.05 threshold. This underscores variations in average tensile strength and elasticity. The study concludes that the optimal tensile characteristics are achieved by mixing eggshell powder and polyester resin in ratios of 20% and 80%, respectively.

3.2 Flexural Test

The flexural strength information for the five eco-friendly EPPR composite ratios is shown in Figure 6. Of all the ratios, EP80P20 had the lowest flexural strength and EP20P80 had the maximum. The increased elasticity caused by the addition of eggshell powder, which lowers the material's strength, is the reason for the drop in tensile strength in EPPR composites with an increase in eggshell powder content [20]. The capacity of the filler to promote stress transmission from polymer filler to matrix is indicated by the greater elongation break with higher filler loading [18].

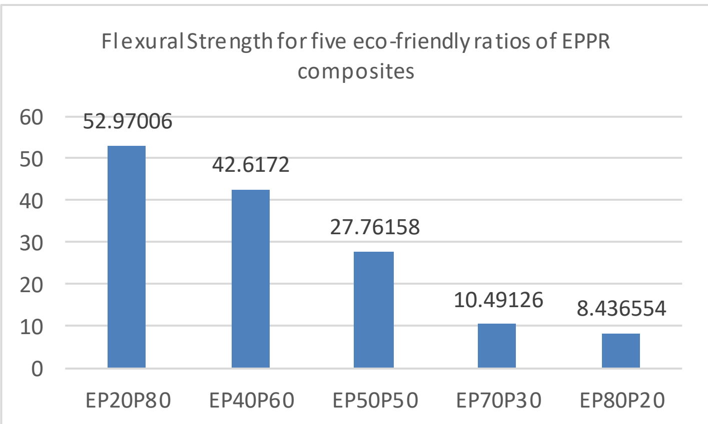


Fig. 6. Flexural strength for five eco-friendly ratios of EPPR composites

Table 2
ANOVA of flexural strength for five eco-friendly ratios of EPPR composites

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
RATIO	4	7627.36	99.90%	7627.36	1906.84	4977.22	0.000
Error	20	7.66	0.10%	7.66	0.38		
Total	24	7635.02	100.00%				

The flexural strength of EPPR composites was further analyzed using one-way ANOVA as shown in Table 2. The obtained P-value, below the α = 0.05 threshold, indicates that the flexural strength of EPPR composites was significant for each of the five eco-friendly ratios. This implies differences in mean flexural values across the environmentally approved EPPR composite ratios. Consequently, the optimal flexural properties are achieved when eggshell powder and polyester resin matrix are combined in ratios of 20% and 80%, respectively.

3.3 Impact Test

In Figure 7, the relationship between impact energy and filler content is depicted, shows that increasing filler content enhances the stiffness of polyester due to the addition of eggshell powder [21]. Eggshell powder serves as a solid "plasticizer," enhancing the flexibility of polymers and their ability to absorb and dissipate energy. This may explain the observed rise in impact strength, as higher impact energy is required to fracture the polymers [21]. Optimal impact properties are achieved by combining 80% eggshell powder with a 20% polyester resin matrix.

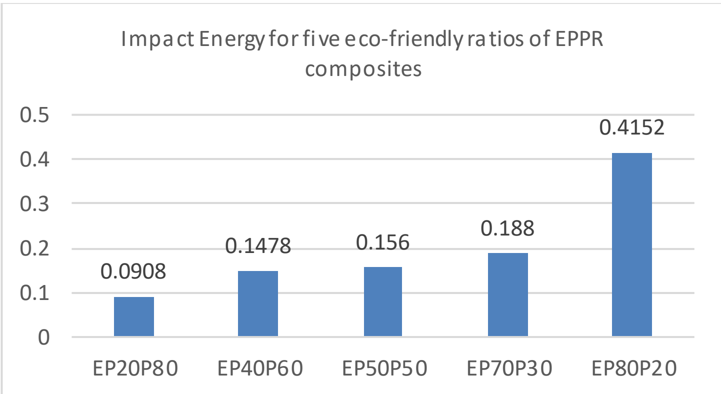


Fig. 7. Impact Energy for five eco-friendly ratios of EPPR composites

Table 3
ANOVA of impact energy for five eco-friendly ratios of EPPR composites

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
RATIO	4	0.3152	28.34%	0.3152	0.07880	1.98	0.137
Error	20	0.7968	71.66%	0.7968	0.03984		
Total	24	1.1120	100.00%				

Impact energy of EPPR composites, were analyzed further using one-way ANOVA. The results shown in Table 3, with a P-value exceeding the α = 0.05 threshold, indicate that the impact energy composites were significantly different for each of the five eco-friendly ratios.

3.4 Water Absorption Test

Figure 8 illustrates the variation in water absorption ratio over exposure time (5 days, 10 days, 15 days, 20 days, and 25 days) for EPPR composite, showing that higher filler content leads to increased water absorption. This attributed to the higher capacity of composites with greater filler content to absorb water, facilitated by the challenge of achieving homogeneous filler dispersion with high concentrations [21].

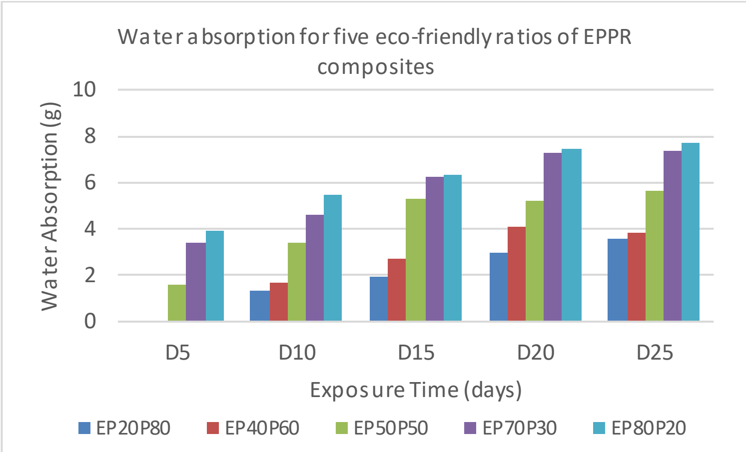


Fig. 8. Water absorption for five eco-friendly ratios of EPPR composites

Table 4
ANOVA of water absorption after fifteen-day exposure

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Ratio	4	83.77	18.26%	83.77	20.94	1.12	0.376
Error	20	374.90	81.74%	374.90	18.75		
Total	24	458.67	100.00%				

One-way ANOVA has been conducted to analyze water absorption in EPPR composites for all five environmentally friendly ratios for various exposure of time (days). Table 4 shows the result for water absorption after fifteen-day exposure. The obtained P-values, exceed the $\alpha = 0.05$ significance threshold, indicate significant differences in mean water absorption values across the certified EPPR composite ratios.

4. Conclusion

Some improvement in the mechanical characteristics of EPPR has been observed with the inclusion of eggshell filler. The filler had a modest negative impact on the EPPR composite's tensile strength, modulus of elasticity, and flexural strength. With an increase in filler material, the impact strength progressively increases. Research has also been done on the water absorption of the composites' behaviors as a function of days, showing that increasing filler contents result in optimum water absorption. The results showed that the ratio of EP20P80 yields the best in tensile strength, elasticity and flexural strength, while EP80P20 yields best in impact strength and water absorption.

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