

Performance and Durability of Eco-Friendly Natural Fiber-Reinforced Composites with Sea Shell Powder

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ABSTRACT

Synthetic composite materials such as aramid, carbon, and glass fibers are extensively used in engineering applications; however, their non-biodegradability, high cost, and environmental impact have led to increased interest in sustainable alternatives. The present study aims to develop an eco-friendly natural fiber reinforced composite using sisal fiber mat, seashell powder, and bird feather quill in an epoxy matrix. The primary objective is to utilize waste and natural materials to produce lightweight composites with improved mechanical properties. The composites were fabricated using epoxy resin (Araldite AW106) and hardener (HV953 IN) through a compression moulding process. A systematic experimental approach was adopted to study the influence of reinforcement composition on mechanical properties. Tensile, flexural, and hardness tests were conducted to evaluate the performance of the fabricated specimens. The results indicate that the addition of seashell powder enhances stiffness and hardness, while bird feather quill contributes to weight reduction with acceptable strength. An optimal combination of materials exhibited improved tensile and flexural properties compared to other compositions. The study concludes that the developed natural fiber composite can serve as a cost-effective, lightweight, and sustainable alternative to conventional synthetic composites for engineering applications.

Keywords: Epoxy resin (Araldite AW106), Hardener (HV953 IN), Sisal fiber mat, Seashell powder, Bird feather quill.

1. INTRODUCTION

Composite materials have gained significant importance in modern engineering due to their superior mechanical properties, such as high strength-to-weight ratio, stiffness, and durability. These materials are widely used in industries including aerospace, automotive, and construction. Traditionally, synthetic fibers such as glass, carbon, and aramid have been used as reinforcement in polymer composites. However, their limitations, including non-renewability, non-biodegradability, and high production cost, have raised environmental and economic concerns.

In recent years, there has been a growing emphasis on the development of natural fiber reinforced composites as sustainable alternatives. Natural fibers such as sisal, jute, and coir are gaining attention due to their low density, biodegradability, renewability, and cost-effectiveness. Additionally, the utilization of waste materials such as seashell powder and bird feather waste further enhances the environmental benefits by reducing solid waste. Seashell powder, primarily composed of calcium carbonate, improves stiffness and hardness, while bird feather quill, made of keratin, provides lightweight characteristics due to its hollow structure.

Recent research has focused on hybrid composites combining natural fibers with particulate fillers to achieve enhanced mechanical performance. In this context, the present study investigates the development of a hybrid natural fiber composite using sisal fiber mat, seashell powder, and bird feather quill reinforced in an epoxy matrix. The study aims to evaluate the mechanical behavior and suitability of the developed composite for sustainable engineering applications.

2. METHODS AND MATERIAL

The selection of materials used in the development of natural fiber reinforced composites plays a vital role in determining the overall performance and application of the material. In the present study, composite materials are fabricated by combining epoxy resin as the matrix with sisal fiber mat, seashell powder, and bird feather quill as reinforcement and filler materials. The use of these materials is carefully considered to achieve improved mechanical properties along with environmental sustainability. Sisal fiber mat provides good tensile strength and structural support, while seashell powder, rich in calcium carbonate, enhances stiffness and hardness of the composite. Bird feather quill, composed mainly of keratin, contributes to lightweight characteristics due to its hollow structure. The combination of these natural and waste-derived materials results in a composite with balanced strength, reduced weight, and eco-friendly nature. Thus, proper selection and integration of these materials are essential to develop a cost-effective and sustainable composite suitable for engineering applications.

A. Sisal Fiber Mat:

Sisal fiber mat is a natural reinforcement material derived from the leaves of the *Agave sisalana* plant and is widely used in composite applications due to its low cost, biodegradability, and good mechanical properties. It possesses relatively high tensile strength and stiffness among natural fibers, making it suitable for structural and load-bearing applications. In mat form, the fibers are arranged either randomly or in a continuous manner, which helps in uniform load distribution and enhances bonding with the matrix material. Chemically, sisal fiber mainly consists of cellulose, hemicellulose, and lignin, where cellulose contributes to strength and rigidity while lignin provides structural support. In this study, sisal fiber mat acts as the primary reinforcement, significantly improving the tensile and flexural properties of the composite by enabling efficient stress transfer between the matrix and fibers. Additionally, its natural origin, renewability, and eco-friendly characteristics make it an ideal material for developing sustainable composite systems.



Figure:1 Sisal Fiber Mat

B. Sea Shell Powder :

Seashell powder is a naturally derived filler material obtained from crushed and processed marine shells, primarily composed of calcium carbonate (CaCO_3). It is widely used in composite materials due to its ability to enhance stiffness, hardness, and dimensional stability. The fine particle size of seashell powder allows for uniform dispersion within the matrix, improving the overall mechanical performance of the composite. Its rigid nature contributes to increased resistance to deformation and surface wear. In this study, seashell powder acts as a filler material that significantly improves the hardness and stiffness of the composite while maintaining cost-effectiveness. Additionally, the use of seashell waste supports environmental sustainability by promoting recycling and reducing marine waste.



Figure 2: Sea Shell Powder

C. Bird Feather Quill :

Bird feather quill is a lightweight natural material derived from poultry waste, primarily composed of keratin, a fibrous protein known for its strength and flexibility. The quill, or rachis, has a hollow structure that contributes to low density and excellent weight reduction properties when used in composites. Despite being lightweight, it provides adequate mechanical strength and improves energy absorption capacity. In this study, bird feather quill is used as a secondary reinforcement material, where it helps in reducing the overall weight of the composite without significantly compromising strength. Its natural availability, biodegradability, and waste utilization make it an eco-friendly and sustainable reinforcement option for composite material development.



Figure 3 : Bird Feather Quill

D. Epoxy Resin and Hardener :

Bird feather quill is a lightweight natural material derived from poultry waste, primarily composed of keratin, a fibrous protein known for its strength and flexibility. The quill, or rachis, has a hollow structure that contributes to low density and excellent weight reduction properties when used in composites. Despite being lightweight, it provides adequate mechanical strength and improves energy absorption capacity. In this study, bird feather quill is used as a secondary reinforcement material, where it helps in reducing the overall weight of the composite without significantly compromising strength. Its natural availability, biodegradability, and waste utilization make it an eco-friendly and sustainable reinforcement option for composite material development.



Figure 4 : Epoxy Resin and Hardner

E. Compression Moulding Method :

The compression moulding technique is a widely used and efficient method for manufacturing natural fiber reinforced composites with improved mechanical properties and uniform structure. In this process, the reinforcement materials such as sisal fiber mat are placed in a mould cavity along with a prepared mixture of epoxy resin, hardener, seashell powder, and bird feather quill. The mould surface is first coated with a releasing agent to prevent sticking. The mould is then closed and subjected to controlled pressure and temperature, which allows the resin to flow and uniformly impregnate the fibers while removing air voids. Additional layers can be arranged to achieve the desired thickness and strength of the composite. The applied heat initiates the curing process of the resin, resulting in a rigid and well-bonded composite structure.

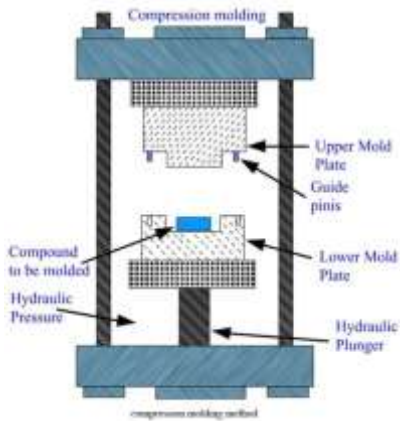


Figure 5: Compression Moulding Method

The key advantages of this method include good surface finish, high dimensional accuracy, reduced void content, and improved mechanical strength compared to manual methods. It is also suitable for producing components with consistent quality and is more efficient for medium-scale production. However, limitations include the requirement of moulding equipment, higher initial setup cost, and less flexibility for highly complex shapes. Despite these limitations, compression moulding is widely preferred in both research and industrial applications for producing high-quality composite materials.

F. Compositions:

No of Composites Bar – 3nos

- 140g(Resin+Hardner+10g Sisal Fiber Mat+30g Sea Shell Powder)
- 135g(Resin+Hardner+10g Sisal Fiber Mat+5g Bird Feather Quill+20g Sea Shell Powder)
- 155g(Resin+Hardner+10g Sisal Fiber Mat+5g Bird Feather Quill+40g Sea Shell)

G. Mechanical Testing Methods

1. Tensile Test

Tensile testing was performed using a universal testing machine to determine the ultimate tensile strength and load-bearing capacity of the composite specimens.

2. Flexural Test

Flexural testing was carried out under three-point bending conditions to evaluate bending strength and stiffness of the composites.

3. Hardness Test

Hardness testing was conducted to measure the resistance of the composite surface to indentation, indicating surface strength and durability.



Fig.1. Composite material

3. RESULTS and DISCUSSION

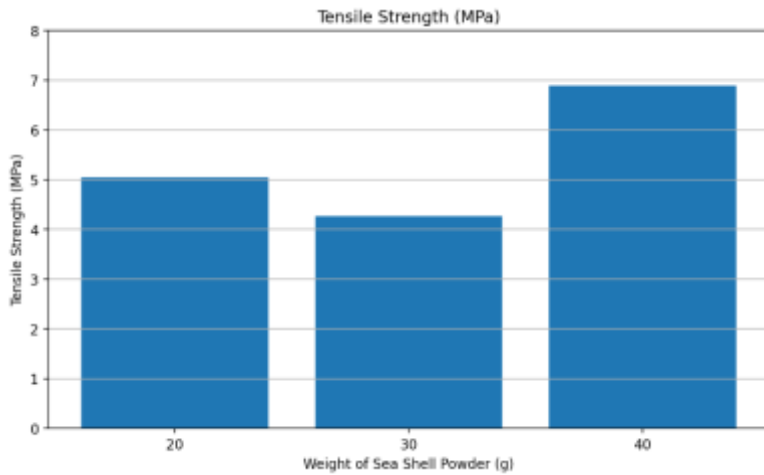
The mechanical performance of the developed natural fiber reinforced composites was evaluated through tensile, flexural, and hardness tests. The results obtained for different compositions of epoxy resin, sisal fiber mat, seashell powder, and bird feather quill were analyzed to understand the effect of reinforcement and filler materials on the overall behavior of the composite.

Table 1. Details of the Sample

SN.	Composite material	Size of sample(mm)	Tensile strength (MPa)	Elongation (%)	Hardness (Shore D)	Flexural strength (Mpa)
1	30grms of seashell powder+100grms of resin hardener	100*150mm	4.268	7.50	24.61	60,61,63
2	20grms of seashell powder + 100grms of resin hardener + 5grms of bird feather quill	100*150mm	5.046	6.37	25.25	60,62,64
3	40grms of seashell powder + 100grms of resin hardener + 5grms of bird feather quill	100*150mm	6.886	7.17	27.38	65,67,64

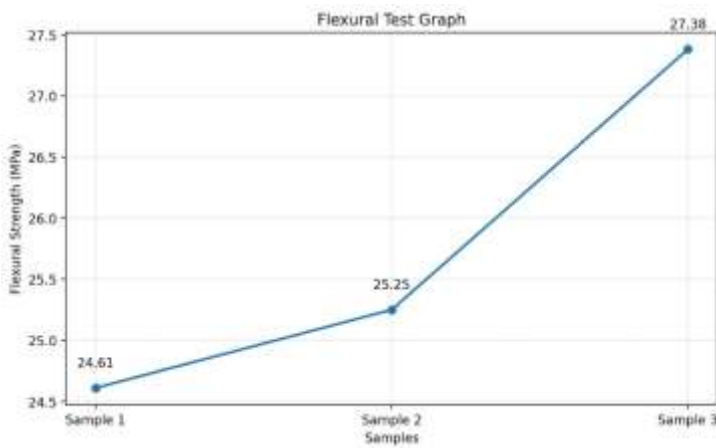
Tensile Properties

The tensile test results indicate that the composite specimen containing an optimal proportion of seashell powder and sisal fiber mat exhibited the highest ultimate tensile strength of approximately 12.04 MPa. The increase in tensile strength is attributed to effective stress transfer between the matrix and reinforcement due to good interfacial bonding. However, beyond a certain filler content, a reduction in tensile strength was observed, which may be due to poor dispersion of particles and the formation of voids within the matrix. The incorporation of bird feather quill contributed to maintaining strength while reducing the overall density of the composite.



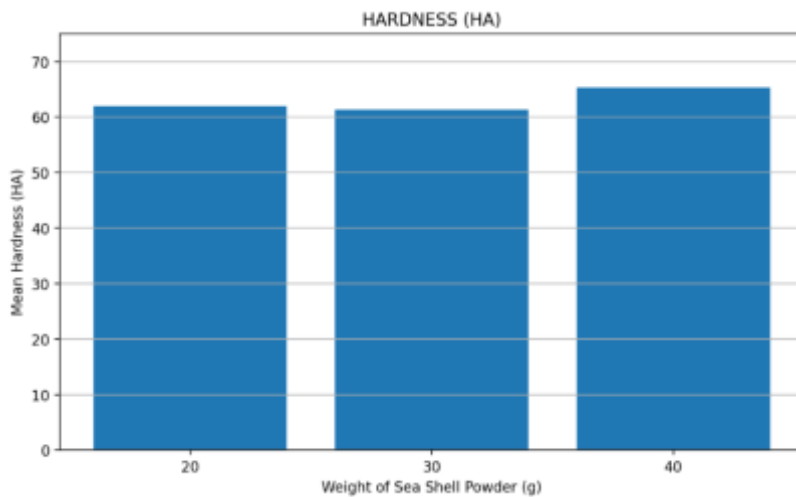
Flexural Properties

The flexural test demonstrated that the addition of seashell powder improved the bending strength and stiffness of the composite. The presence of calcium carbonate in seashell powder enhanced resistance to deformation under bending loads. The layered arrangement of sisal fiber mat also played a crucial role in improving load distribution. However, excessive filler content led to reduced flexibility and increased brittleness of the composite.



Hardness Properties

The hardness test results revealed a noticeable improvement in surface resistance with the addition of seashell powder. This is due to the rigid nature of the filler material, which increases resistance to indentation. Composites containing higher filler content showed greater hardness values, confirming the strengthening effect of the particulate reinforcement.



Overall Discussion

From the experimental analysis, it is evident that the mechanical properties of the composite are strongly influenced by the composition and distribution of reinforcement and filler materials. An optimal combination of sisal fiber mat, seashell powder, and bird feather quill provides a balance between strength, stiffness, and weight reduction. The study demonstrates that natural waste materials can be effectively utilized to develop eco-friendly composites with competitive mechanical performance. These composites have potential applications in lightweight structural components, automotive interiors, and sustainable engineering products.

4. CONCLUSION

The present study successfully developed and evaluated a natural fiber reinforced composite using sisal fiber mat, seashell powder, and bird feather quill in an epoxy matrix. The primary objective of utilizing eco-friendly and waste-derived materials to produce a sustainable composite was effectively achieved. The fabrication of composite specimens through the compression moulding technique resulted in uniform and well-bonded structures suitable for mechanical evaluation.

- **Tensile strength increases with higher sea shell powder content**, indicating improved load-bearing capacity when filler content is increased.
- The sample with **40 gm sea shell powder** shows the **highest tensile strength (~6.886 MPa)**, making it the strongest among the tested samples.
- **Hardness values (Shore D ~60–67)** indicate that all samples possess **moderate surface resistance**, suitable for semi-structural applications.
- Overall, the composite with **higher filler content (especially 40 gm sea shell powder)** is the **best-performing formulation**.

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