A STUDY ON ELASTIC PROPERTIES OF NATURAL FIBER REINFORCED BIO-COMPOSITES

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Abstract

The present work investigates the elastic behavior of bio-composites reinforced with glass, carbon, and sisal fibres in different polymer matrices. Analytical models such as the Rule of Mixing were employed to estimate properties, was performed for Young's modulus, transverse modulus, tensile strength, Poisson's ratio, density, and failure load. The results indicate that fiber concentration and fiber matrix bonding significantly influence stiffness, strength, and ductility. Glass and carbon fibres improved mechanical performance, whereas sisal fibres offered a sustainable alternative with moderate strength. These findings highlight the potential of hybrid and bio-based composites for structural and sustainable applications.

I. INTRODUCTION

Composite materials are widely used in engineering because they combine two or more materials to achieve superior properties. They offer high strength-to-weight ratios, improved stiffness, and customizable performance for specific applications. Fibre-reinforced composites (FRCs) are especially important, where fibres carry the main load while the matrix ensures stress transfer and protects the fibres.

Natural fibre-reinforced composites have gained attention due to their biodegradability, renewability, and low cost, making those environmentally friendly alternatives to synthetic composites. Natural fibres like sisal, jute, and hemp are lightweight and sustainable but generally have lower strength and stiffness compared to synthetic fibres such as glass and carbon. To improve performance, researchers have explored hybrid composites combining natural and synthetic fibres, as well as surface treatments to enhance fibre–matrix bonding.

Studies in this field highlight key factors influencing composite performance. Khalid et al. showed that hybridization and surface treatments improve adhesion and balance performance with sustainability. Jagath Narayana and Burela used micromechanical models like the rule of mixtures to predict composite properties. Sabina et al. demonstrated that fibre arrangement and geometry greatly affect stiffness and Poisson's ratio. These works emphasize the importance of material selection and interface quality.

In this study, theoretical modelling was used to predict the elastic behaviour of composites reinforced with glass, carbon, and sisal fibres using matrices like epoxy, polyester, and phenol formaldehyde. Carbon and glass fibres showed higher stiffness and strength, while epoxy provided the best bonding. Sisal fibres, though lower in strength, offer eco-friendly benefits such as biodegradability and lightweight characteristics, making them suitable for sustainable applications.

Theoretical methods helped determine optimal fibre volume fractions and orientations, providing valuable insights before practical fabrication. Future work should focus on hybrid composites, advanced surface treatments, and recyclable designs, with applications in automotive, aerospace, and other environmentally conscious industries.

II. THEORETICAL APPROACH AND METHODOLOGY

A. Fiber and Matrix Systems

In this study, three different fibers glass, carbon, and sisal were selected as reinforcing agents owing to their distinct mechanical characteristics. Glass and carbon fibers were chosen for their superior strength and stiffness, while sisal was included as a sustainable, biodegradable alternative. The matrix phase comprised epoxy**,** polyester**,** phenol formaldehyde**,** and general purpose polymer resins. The fiber and matrix combinations were designed to evaluate how different reinforcement matrix interactions influence the overall elastic behavior of the composites.

B. Predictive Modeling of Elastic Properties

The mechanical performance of a composite depends on three key elements: the fibers, the matrix, and the fiber matrix interface**.** Predicting elastic properties through micromechanical models helps in understanding material behaviour before theoretical validation, saving time and resources. The Rule of Mixtures (ROM) is commonly used to estimate composite stiffness. For longitudinal modulus**,** where fibers are aligned, the relationship is:

(1). Young's Modulus

For unidirectional composites, longitudinal modulus is given by the Rule of Mixtures:

$$E_{cl} = E_f V_f + E_m V_m \qquad \textbf{(i)}$$

Transverse modulus follows the inverse relation:

$$\frac{1}{E_T} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \qquad \textbf{(ii)}$$

(2). Tensile Strength

Composite strength is dependent on fiber strength and interfacial adhesion:

$$\sigma_t = V_f \sigma_f + (1 - V_f)\sigma_m \qquad \textbf{(iii)}$$

(3). Density

Composite density is calculated as:

$$\rho_c = \rho_f V_f + \rho_m V_m \qquad \textbf{(iv)}$$

(4). Poisson's Ratio

Composite Poisson's ratio is:

$$\nu c = \nu f\, V f + \nu m\, V m \qquad \textbf{(v)}$$

(5). Failure Load

Failure occurs when applied stress exceeds stress transfer capacity across the fiber–matrix interface. Excessive fiber content may introduce voids and reduce failure strength.

III.RESULTS AND DISCUSSION

A. Young's Modulus of Glass, Carbon and Sisal Fiber Composites

As the fiber concentration increases, the overall stiffness of the composite rises because the load is primarily carried by the fibers, following the Rule of Mixtures. Carbon fibers offer the highest stiffness due to their superior elastic modulus, glass fibers provide balanced performance at a moderate cost, and sisal fibers, though less stiff, contribute to sustainability and perform better when combined with epoxy matrices.

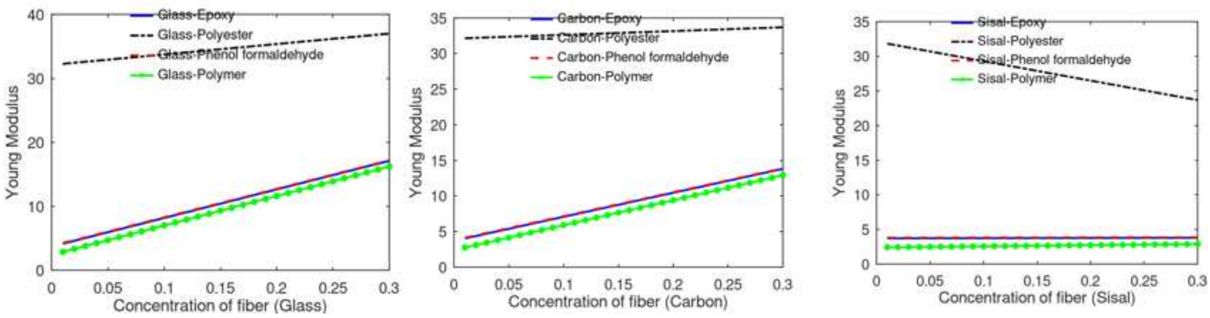


Figure 1: Variation of Young's Modulus with Glass Fiber Concentration

B. Transverse Young's Modulus of Glass, Carbon, and Sisal Fiber Composites

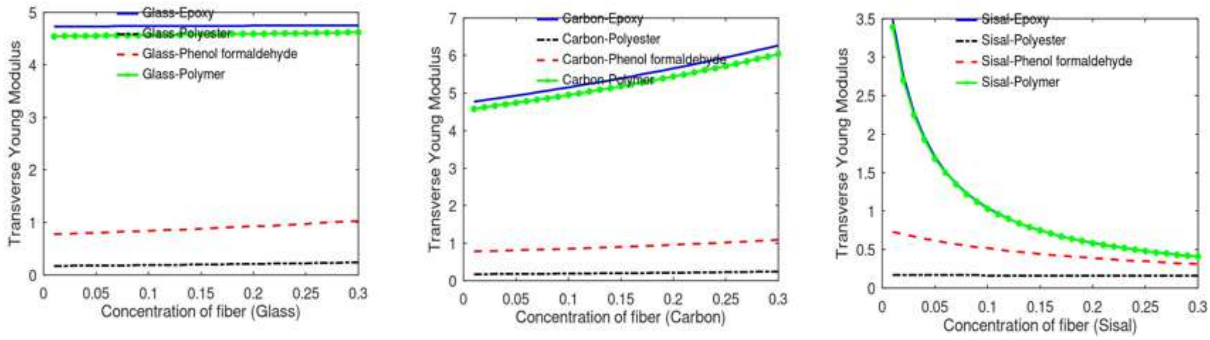


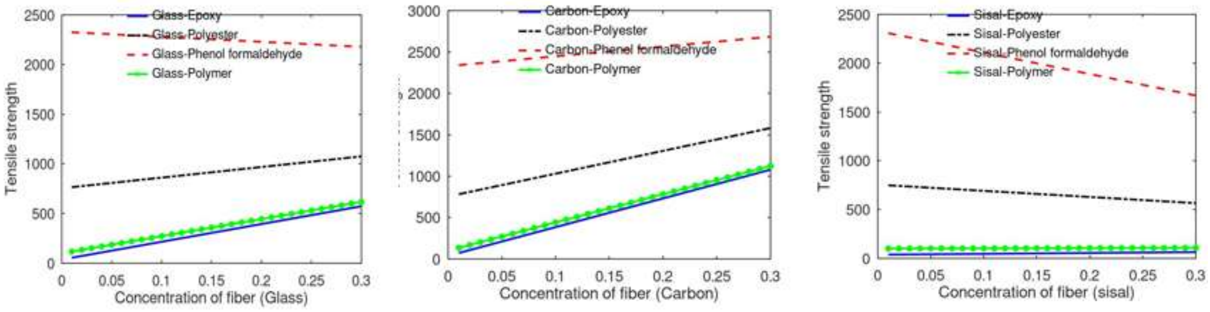
Figure 2: Variation of Transverse Young's Modulus with Fiber Concentration

The he transverse modulus reflects the composite's stiffness perpendicular to the fiber direction and is strongly influenced by the matrix and fiber matrix bonding. Carbon fibers achieve the highest transverse stiffness, especially with epoxy due to superior bonding. Glass fibers offer moderate stiffness, with epoxy providing better performance. Sisal fibers, having weaker interfacial bonding, show lower and sometimes decreasing values as their concentration increases.

C. Tensile Strength of Glass, Carbon, and Sisal Fiber Composites

The tensile strength indicates the composite's ability to resist failure under tension and depends on the fiber strength and the quality of the fiber matrix interface. Carbon fibers exhibit the highest tensile strength due to their superior properties and strong bonding, especially with epoxy and phenol formaldehyde matrices. Glass fibers provide moderate tensile strength with balanced performance, while sisal fibers, being natural and less uniform, display lower strength values, though epoxy improves their bonding and performance.

Figure 3: Variation of Tensile Strength of Glass, Carbon, and Sisal Fiber Composites



D. Poisson's Ratio of Glass, Carbon, and Sisal Fiber Composites

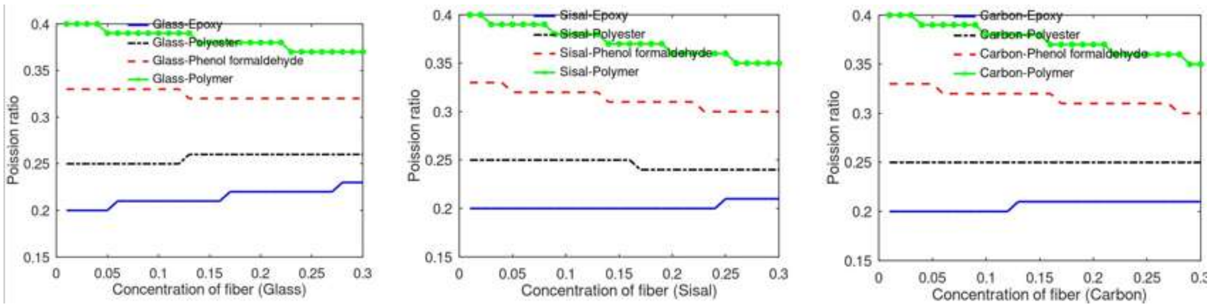


Figure 4: Variation of Tensile Strength of Glass, Carbon, and Sisal Fiber Composites

Poisson's ratio represents the lateral deformation behaviour of composites under axial loading. Carbon fiber composites maintain nearly constant values due to strong bonding between fibers and matrices, especially in epoxy systems. Glass fiber composites show moderate values, reflecting a balance between fiber rigidity and matrix flexibility. Sisal fiber composites exhibit a slight decrease in Poisson's ratio with increasing fiber concentration, indicating weaker interfacial adhesion and the natural variability of plant fibers. This trend underscores the role of fiber matrix compatibility in controlling lateral strain response.

E. Density of Glass, Carbon, and Sisal Fiber Composites: The density of a composite material rises as the fiber concentration increases since fibers typically possess higher densities than the matrix. Carbon fiber composites exhibit the greatest density due to the intrinsic properties of carbon fibers, while glass fiber composites show moderate density, balancing fiber and matrix contributions. Sisal fiber composites have the lowest density, making them ideal for applications where lightweight structures are essential. This demonstrates how fiber type and volume fraction directly influence the overall weight of the composite.

F. Failure Load of Glass, Carbon, and Sisal Fiber Composites: Failure load gradually decreases with increasing fiber concentration because of stress concentrations and imperfections at the fiber matrix interface. Carbon fiber composites retain higher failure loads owing to their superior mechanical strength and strong interfacial bonding, especially with epoxy. Glass fiber composites show moderate resistance to failure, while sisal fiber composites display lower values due to weaker bonding and natural inconsistencies. These findings emphasize the critical role of fiber matrix compatibility and uniform fiber distribution in enhancing structural performance.

IV. CONCLUSION

This study highlights the significant influence of fiber type, matrix type, and fiber volume fraction on the elastic properties of fiber-reinforced bio-composites. Among the tested fibers, carbon and glass fibers demonstrated superior stiffness, tensile strength, and overall performance due to their higher modulus and strong interfacial bonding. Sisal fiber, while offering lower mechanical properties, provides notable environmental advantages such as biodegradability and cost effectiveness, making it a sustainable alternative for lightweight structural applications. Across all tests, epoxy matrices consistently delivered the best fiber–matrix adhesion, resulting in enhanced load transfer and improved composite performance compared to polyester and phenol formaldehyde matrices. Future research should focus on hybrid composites that combine natural and synthetic fibers to achieve a balance between mechanical performance and sustainability, paving the way for eco-friendly engineering solutions.

V. REFERENCES

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