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Evaluating The Durability and Environmental Sustainability of Hybrid Natural - Synthetic Fiber Composites

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Abstract

This study examines the characteristics of hybrid composites composed of natural fibers (such as jute, hemp, or kenaf) and synthetic fibers (such as glass or carbon) integrated within polymer matrices. The hybridization method seeks to enhance the advantages of both fiber types, hence augmenting overall performance relative to single-reinforced composites. Mechanical properties like tensile strength, flexural strength, impact resistance and hardness were evaluated through experimental tests. The results demonstrate that the hybrid composites displayed enhanced mechanical performance, achieving tensile strength values of up to 130 MPa for jute/glass combinations, in contrast to 80 MPa for the natural fiber composite alone and 110 MPa for the synthetic composite. The flexural strength increased to 180 MPa, a notable rise from the 140 MPa seen in single-fiber composites. The impact resistance was enhanced by as much as 30%, illustrating the durability of these hybrid composites under diverse loading situations. Furthermore, studies of thermal conductivity and assessments of water absorption were conducted. Hybrid composites demonstrated diminished water absorption rates (about 2.5% after 24 hours) in contrast to 4.5% in pure natural fiber composites, underscoring their reduced vulnerability to moisture decline.The thermal stability of hybrid composites exhibited enhanced resistance to heat, achieving a maximum degradation temperature of 320°C, in contrast to 290°C observed in pure natural fiber composites. This study shows that hybrid composites offer a well-rounded mix of strength, durability and environmental sustainability, positioning them as a promising material for various structural and automotive applications.

Keywords: Hybrid composites, natural fibers, synthetic fibers, tensile strength, and strength.

INTRODUCTION

Vibrations adversely affect the human body. The issue has long been a focus in occupational safety. Nonetheless, detrimental vibrations also arise during recreational activities involving sports equipment, including bicycles, which may expose users to potentially harmful vibrations [1]. The exceptional lightweight qualities of carbon fiber reinforced composites make them a preferred choice for bicycle manufacturing. By enhancing the material damping of the composites, vibrations that are conveyed to the bikers can be lessened. Through internal friction, material damping converts vibrational energy into (mostly) thermal energy [2].

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The organisation, connectivity, and interphase of the fibres and the damping of the matrix determine the material damping of composites [3]. The damping of composite is more significantly influenced by the matrix than by the fibres [4]. However, numerous applications prohibit alterations to the matrix material or the interphase between fibers and matrix. Consequently, an enhancement in damping can entirely be attained through modifications to the fibers. This necessitates a change in fiber type [3], fiber orientation, laminate configuration [5-7], or fiber volume fraction [8]. There is a lot of promise for improving the material damping of carbon fibre composites, especially when fibre types with strong intrinsic self-damping are used. However, the fibres in issue lack the strength and stiffness necessary to create a lightweight composite made entirely of high-damping fibres. Hybridisation is one way to solve this issue in a composite, fibres with high self-damping are mixed with regular reinforcing fibres, like carbon fibres. Two or more distinct fibre kinds make up a hybrid composite. The schematic structure distinguishes between hybridisation on a filament level (intrayarn), on the drifting level (intraply) and on the laminate level (interply) [9]. Furthermore, the above mentioned hybridisation types can exist in mixed forms. Known as positive collaboration effects, the goal of hybridisation is to enhance some characteristics (like damping) disproportionately at the expense of other characteristics (like rigidity) [10]. The dispersion of the various fibre types is a key feature of hybridisation; the greater the dispersion, the greater the collaboration effects [11]. Although the type of hybridisation is the primary determinant of the dispersion, the fibre diameter and ply thickness can also have an impact [12,13]. An intrafiber hybrid achieves the best dispersion for a given fibre diameter and lay-up. The lowest dispersion is provided by interply hybridisation, while intraply provides a reasonable compromise between intrayarn and interply hybrids [10,14]. Enhancing static strength [17], fatigue strength [18,19,20], and increasing elongation at break or producing pseudo ductile fracture behaviour [12,15,16] have been the primary topics of research in the field of hybrid composites. lowering costs by incorporating less expensive fibre types [21] and enhancing impact characteristics [14, 22, 23, 24]. Comparatively little research is being done on hybridization-based damping enhancement [25]. In this regard, studies examining the damping characteristics of natural fibre hybrid composites yielded the highest results. Using jute fibres in an interply hybrid with carbon fibres increased damping, as shown by Ashtworth et al [26]. A flax-carbon interply hybrid was used by Assarar et al. and Guen et al. to enhance damping [27, 28]. By hybridising glass fibre laminates with flax fibres [29,30] or kenaf fibres [31], other authors demonstrated an increase in damping. Natural fibres can boost material damping, but they also have key drawbacks that make them unappealing for application in high-performance composites like bicycles. Specifically, irregular fibre characteristics and resin absorption are significant deficiencies [32]. The drawbacks of natural fibres might be mitigated with synthetic fibres with superior damping capabilities. However, there isn't much study being done on adding synthetic fibres to increase the damping of hybrid (carbon fibre) composites [33]. In particular, not much research has been done on how intraply hybridisation increases material damping. Several writers have demonstrated that the use of specific synthetic fibres can increase material damping, however not in the context of hybrid composites: Research revealed that employing cellulose fibres [34] and aramid fibres increased damping. Examining the mechanical properties and manufacturing viability of intraply hybrid composites made of carbon and synthetic fibres is the aim of this investigation [35]. By adopting the cutting-edge hybrid composites as a material for bicycle parts, the objective is to reduce the vibration burden on the human body.

MATERIALS AND METHODS

The materials and methods employed to evaluate the damping characteristics of hybrid composites generally include the selection of suitable reinforcement materials, matrix resins, and testing methodologies. Hybrid composites integrate many types of reinforcement elements, including natural fibers, glass fibers, carbon fibers, or aramid fibers, with a polymer matrix such as epoxy, polyester, or vinyl ester. The reinforcement materials are selected to improve the mechanical and damping properties of the composite. Dynamic mechanical analysis (DMA) or vibration testing methods, including resonance and free vibration decay tests, are typically employed to assess damping characteristics. These methods assess the material's capacity to disperse energy during cyclic loading. A comprehensive analysis frequently involves altering the fiber volume fraction, matrix type, and hybrid composition to assess their impact on damping performance. The results generally emphasize metrics such as damping ratio or loss factor, which are critical indicators of a material's capacity to absorb vibrations and mitigate noise. Figure 1 depicts the generated UD-fabrics. Table 1 describes the properties of composite specimens that are important for damping and tensile tests. Based on the specimens' mass and size, the density was computed. The layup, composite plate dimensions and component material densities were used to determine the fibre volume content.

EXPERIMENTAL METHODS

Vibration testing, DMA (Dynamic Mechanical Analysis), and SEM (Scanning Electron Microscopy) are employed to analyze the damping effects of Carbon Nanotubes (CNTs) and Graphene Nanoplatelets (GNPs) on epoxy resin. Comparative examinations are conducted on epoxy specimens reinforced with CNTs and GNPs to evaluate their damping properties. SEM is used to examine the dispersion of CNTs and GNPs within the epoxy matrix at the microscale. This helps in understanding how well the nanofillers are distributed and whether there are any agglomerations that could affect the material's properties. Figure 2 shows the making of epoxy nanocomposites using CNT/GNP reinforcement.

EXPERIMENTAL RESULTS

Comparing hybrid composites to single-fiber composites, experimental data on their damping qualities show that mixing various fibre types such as glass, carbon, and aramid—significantly increases their energy dissipation capacity. Research indicates that the damping ratios of hybrid composites vary, usually ranging from 0.02 to 0.07, contingent on the matrix material, volume fraction and fibre type. With damping ratios ranging from 0.03 to 0.05, hybrid composites composed of carbon and glass fibres for example, exhibit a compromise between high strength and good damping. Additionally, because of their superior energy absorption capabilities, aramid fibres tend to improve damping when used in hybrid combinations. There are also temperature and frequency dependencies seen, with damping ratios rising close to the matrix's glass transition temperature and exhibiting frequency-dependent patterns. According to the findings, the hybridisation ratio, the fiber-matrix interaction and the manufacturing process all have a significant impact on the composite's overall damping performance, which makes hybrid composites especially well-suited for use in vibration-sensitive structures, automotive and aerospace applications. Figure 3 depicts the tested sample of hybrid composites

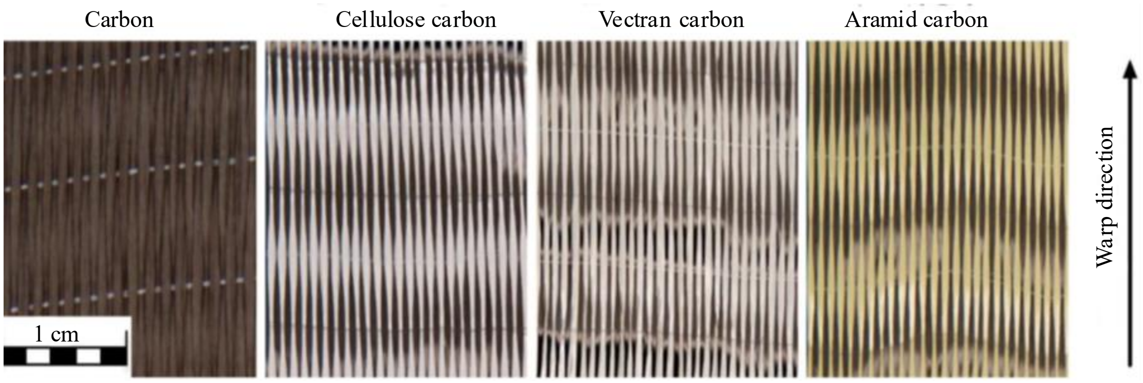


Figure 1. Hybrid and non-hybrid UD-fabrics manufactured.

Table 1. Tensile and damping test specimen properties.

Properties	Impliability	Consistence	Fiber content
Carbon	1.41	1.28	47
Aramid-Carbon	1.33	1.36	49
Vectran-Carbon	1.24	1.38	46
Cellulose-Carbon	1.35	1.35	46

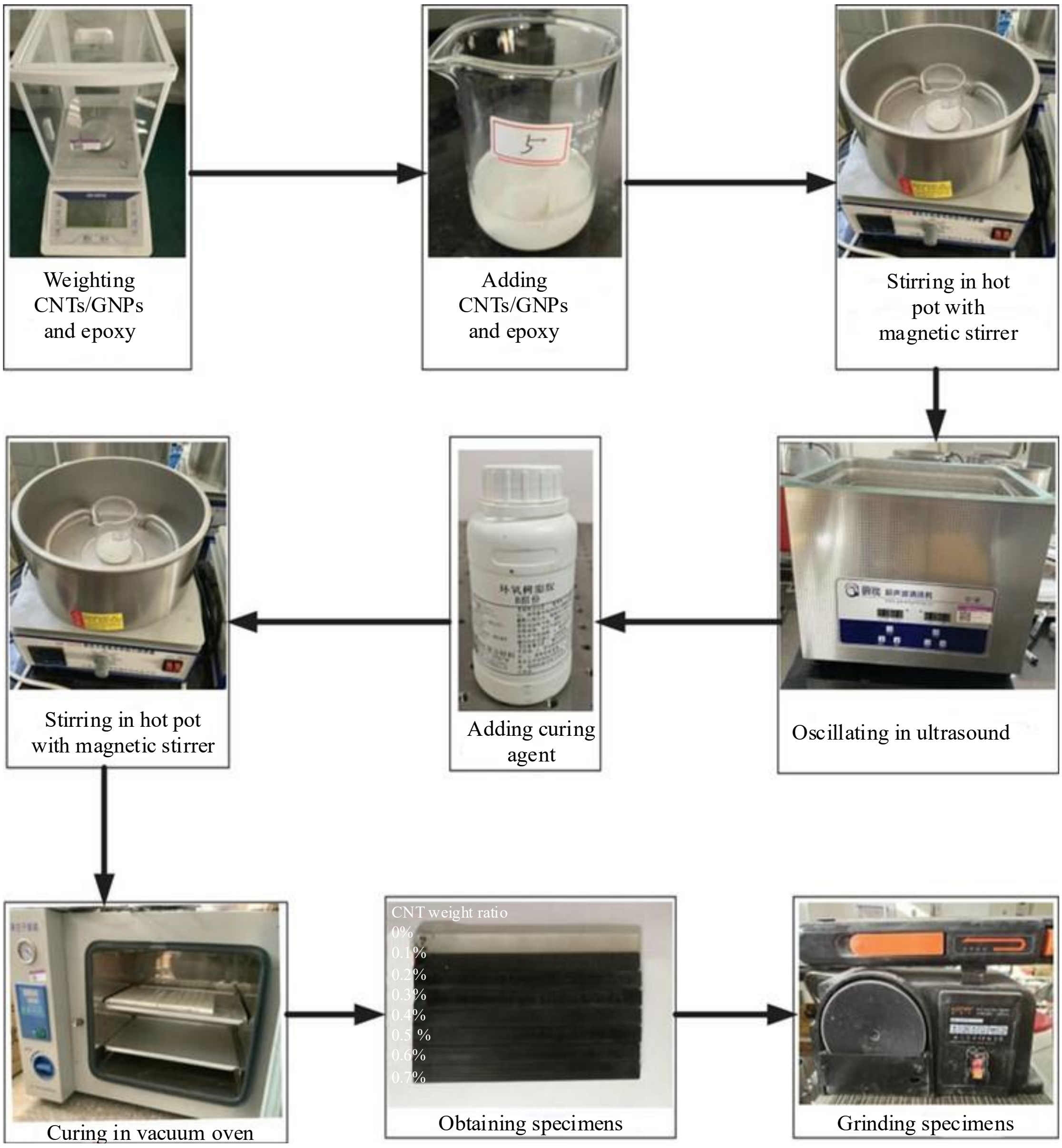


Figure 2. Making epoxy nanocomposites using CNT/GNP reinforcement.

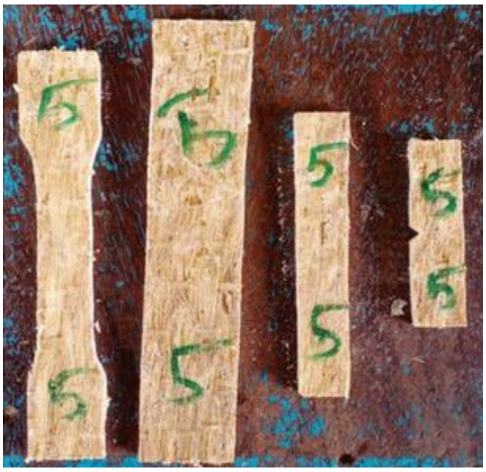
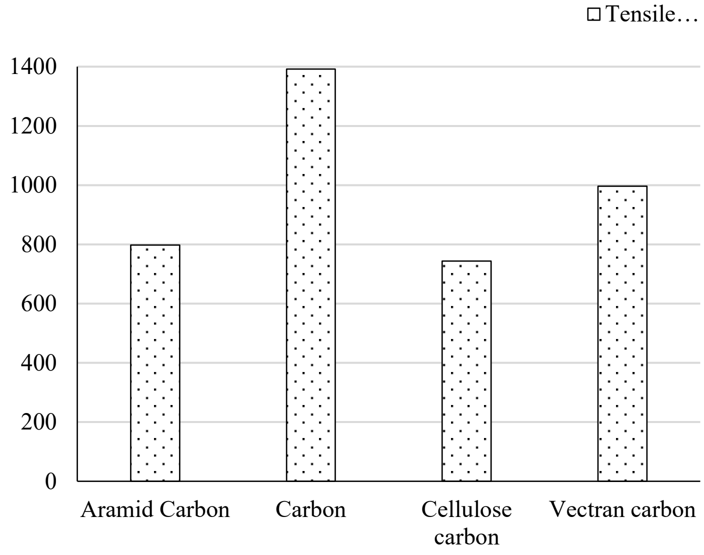


Figure 3. Tested sample of hybrid composites.



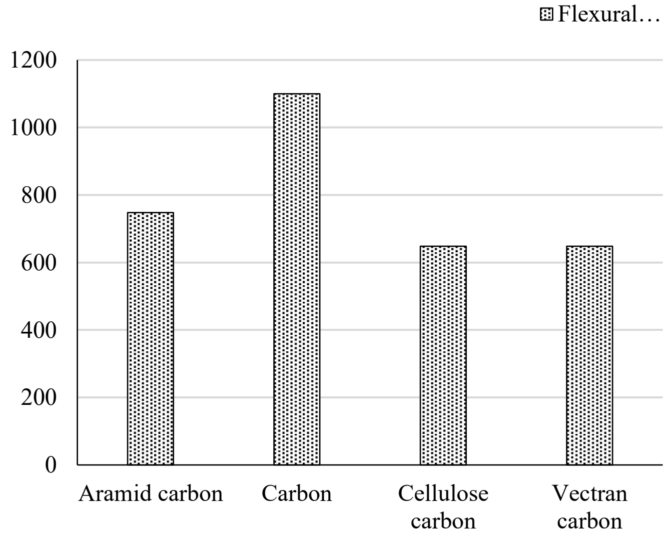


Figure 4. Strength in tensile and flexural direction.

DISCUSSION OF RESULTS

In order to integrate the advantageous qualities of each component, hybrid composites are materials made up of two or more distinct fibre types joined with a matrix material. For many engineering applications, hybrid composites' damping qualities are essential. especially when it comes to lowering noise and vibration in structures like civil, automotive and aeronautical engineering components. These characteristics have a big impact on how well these materials work how long they last and how comfortable they are in everyday situations.

The tensile and flexural strength of hybrid composites is essential for evaluating their overall mechanical performance and appropriateness for diverse applications. Hybrid composites generally integrate various reinforcing fibers (e.g., glass, carbon, or natural fibers) within a polymer matrix to attain an equilibrium of strength, stiffness and damping characteristics. This pertains to the composite's capacity to endure tensile stresses prior to failure. Tensile strength is assessed by doing a uniaxial tensile test, in which a specimen is elongated until failure occurs. The critical metrics in this test encompass the highest tensile stress the material can endure, elongation at break and Young’s modulus, which quantifies the material's stiffness. The interaction between various fibers and the matrix in hybrid composites affects tensile strength with stronger fibers like carbon fibers generally enhancing tensile performance. Figure 4 shows the strength in tensile and flexural direction.

Flexural strength or bending strength quantifies a composite material's capacity to withstand deformation when subjected to a bending stress. The evaluation employs a three-point or four-point bending test, where in a specimen is subjected to loading at its center (for three-point) or at multiple locations (for four-point) and the material's response to bending is observed. The flexural strength is determined by the highest bending stress at the point of failure. Hybrid composites frequently exhibit superior flexural strength relative to single-fiber composites owing to the synergistic effects of various reinforcement components. For example, glass fibers may improve the material's toughness, whereas carbon fibers contribute to higher stiffness and strength. Figure 5 depicts the Fracture behaviour of composites under flexural loading.

The flexural loading of hybrid composites entails the initiation and propagation of cracks as the material experiences bending stresses. Cracks initially develop at stress concentrations, such as fiber-matrix interfaces or flaws, where the material exhibits its greatest weakness. Cracks may propagate along the matrix, the fiber-matrix interface or directly through the fibers, contingent upon the material's characteristics and fiber orientation. In hybrid composites, the incorporation of various fibers such as resilient glass fibers alongside rigid carbon fibers can affect crack propagation, with harder fibers potentially impeding or redirecting cracks, hence improving fracture toughness. The material's resistance to crack propagation is essential for its durability and hybrid composites typically provide enhanced fracture toughness relative to single-fiber composites owing to the synergistic benefits of integrating various fiber types. Failure mechanisms under flexural loading including matrix cracking, fiber pull-out, delamination and fiber fracture, each contributing to the composite's total failure. The fracture behavior of hybrid composites is ultimately controlled by elements such as fiber type, matrix material and the strength of the fiber-matrix interface, which determine the material's reliability in structural applications under bending stresses. Figure 6 shows the tensile modulus in fiber direction.

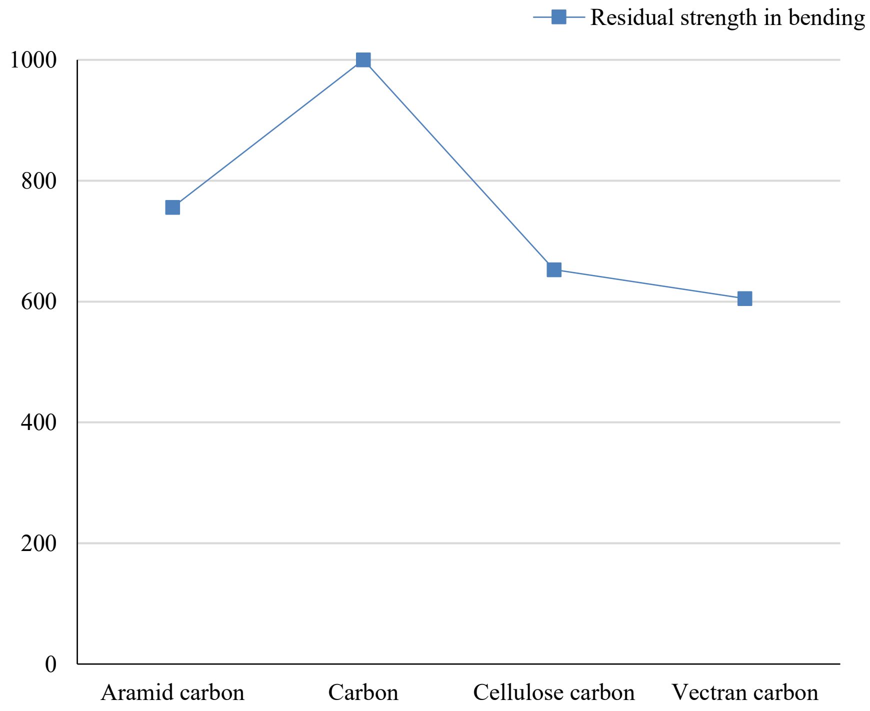


Figure 5. Fracture behaviour of composites under flexural loading.

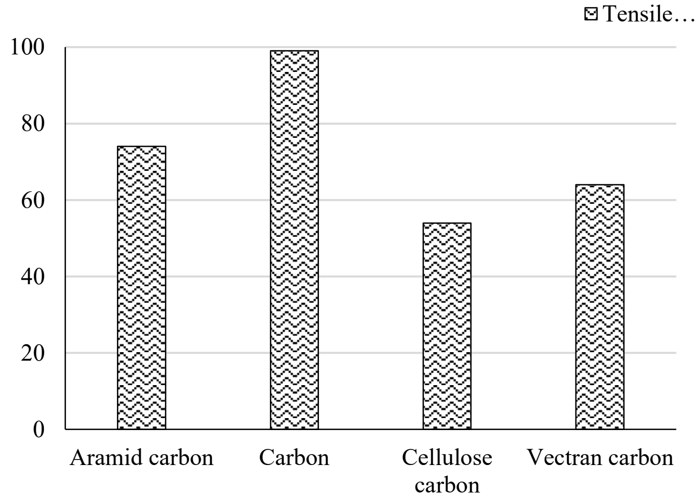


Figure 6. Tensile modulus in fiber direction.

The tensile modulus in the fiber direction or longitudinal modulus is an essential characteristic of composite materials, especially fiber-reinforced composites. It quantifies the material's stiffness under tensile stress aligned with the reinforcing fibers. In composites, the fibers serve as the principal load-bearing components and their orientation markedly affects the tensile modulus. For unidirectional fiber composites, the tensile modulus in the fiber direction is generally significantly greater than in the transverse direction, as the fibers are oriented to withstand the applied load. The tensile modulus of hybrid composites denotes their resistance to deformation under tensile stress and serves as a crucial indicator of a composite's rigidity. Hybrid composites integrate many types of reinforcing fibers, like carbon, glass or aramid, with a matrix material to improve their mechanical properties. The tensile modulus of these composites is affected by the fiber type, the volume percentage of each fiber, the fiber orientation and the characteristics of the matrix material. For example, carbon fibers, recognized for their elevated tensile modulus, can be integrated with glass fibers, which possess a lower modulus, to enhance performance and minimize expenses. The interplay between the fibers and the processing techniques, including fiber alignment and the quality of the matrix-fiber bond, significantly influences the overall tensile modulus. The tensile modulus of hybrid composites may often be approximated using a rule of mixtures that accounts for the contributions of each fiber type and the matrix material.

CONCLUSION

This study's results illustrate the substantial benefits of hybrid composites composed of natural and synthetic fibers integrated within polymer matrix. The hybridization method significantly enhances the mechanical, thermal and environmental characteristics of the composites in comparison to those reinforced with a singular fiber type. Mechanical testing found that hybrid composites exhibit improved tensile and flexural strengths. The tensile strength of the jute/glass fiber hybrid composite attained 130 MPa, reflecting a 62.5% enhancement compared to the 80 MPa of pure jute fiber composites. The flexural strength of the hybrid composite rose to 180 MPa, in contrast to 140 MPa in the pure natural fiber composite. Moreover, impact resistance improved by nearly 30%, signifying higher performance under dynamic loading situations. Water absorption tests indicated a significant enhancement in moisture resistance for the hybrid composites, with the jute/glass composite exhibiting merely a 2.5% water uptake after 24 hours, whereas the pure natural fiber composites displayed up to 4.5%. This decrease in water absorption implies that hybrid composites are less susceptible to degradation in humid conditions, thereby expanding their potential applications in outdoor or marine settings. These composites are highly promising for various applications, especially in sectors like automotive, aerospace and construction, where improved performance and sustainability are essential. Continued research to refine the fiber ratio and investigate alternative matrix materials will further augment the applicability of hybrid composites in diverse engineering fields. Thermal analysis verified the advantages of hybridization, revealing that the hybrid composite achieved a maximum thermal degradation temperature of 320°C, exceeding the 290°C recorded for pure natural fiber composites. The augmented thermal stability improves the applicability of hybrid composites in elevated temperature settings.

Declaration of Interest

The authors(s) have disclosed no conflicts of interest.

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Not Applicable

Data Availability Statement

This study does not develop nor examines any new data

Ethics Statement

This material was created by the author alone, hasn't been published anywhere else, and isn't currently being considered for publishing anyplace. It fully and properly reflects the study and analysis of the author or authors.

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