

A Comprehensive Review on Mechanical, Thermal, and Dielectric Properties across Various Fiber-Reinforced Systems

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Abstract: An extensive review has been conducted into the complex realm of fiber-reinforced composite materials, capturing a diverse range of studies exploring the mechanical, thermal, and dielectric properties of composite materials. Review primarily focused on Aramid/glass hybrid composites, single carbon fibers, polypropylene composites, hybrid composites with varied glass-to-carbon ratios, and the impact of alkali and SLS treatment on Banana/Kenaf hybrid composites. Investigations into nonlinear mechanical behavior of laminates, tensile properties of glass mat/epoxy composites, and aeronautical grade carbon-epoxy composites provided valuable insights. Studies also touched upon the effects of thermal shock on advanced composites, mechanical properties of Araldite matrix composites with hybrid palms-Kevlar fibers, and Glass & Kevlar woven fabric/epoxy composites. The manufacturing and evaluation of angle-interlock Kevlar composites and the development of thermoplastic matrix composites were addressed, shedding light on advancements in fabrication techniques. Additionally, evaluations of woven factors for different fibers and matrices and the mechanical properties of araldite matrix composites with hybrid carbon-Kevlar fibers were explored. This comprehensive overview provides insights into a wide range of materials, fabrication techniques, and property evaluations in the field of composite materials.

Keywords: Aramid, polypropylene, Kevlar, Araldite matrix, SLS treatment, angle-ply laminates etc.

1. Literature Review

Lan Yao and colleagues [1] conducted experiments on Aramid/glass hybrid composites with three different stacking sequences and their corresponding single fiber type composites. The study focused on investigating the tensile, impact, and dielectric properties of these materials. They observed that the trend of tensile strength and modulus in the composites closely adhered to the rule of mixture (ROM), indicating a small but positive hybrid effect on the tensile strength of the hybrid composites. However, the dielectric constant of the hybrid composites exhibited a non-linear behaviour; it initially decreased and then increased with the volume fraction of aramid fiber. This deviation from the mixing rule for dielectric constants suggested unique characteristics in the hybrid composites. Additionally, the dielectric loss of the composites increased consistently with the volume fraction of aramid fiber, aligning well with the mixing rule. Alireza Ashori [2] conducted a study investigating the mechanical properties, morphology, and thermal properties of composites. The results revealed a significant improvement in both tensile and flexural modulus when biofibers were added in both fiber and flour forms, compared to pure PP. However, the increase in wood flour (WF) content led to a notable reduction in tensile, flexural, and impact modulus, while enhancing thermal stability. This effect is attributed to variations in fiber morphological properties and thermal degradation. The study also found that increasing the fiber aspect ratio contributed to improved mechanical properties. C. Marston et al. [3] conducted tests on single carbon fibers in

both sized and unsized conditions, along with impregnated tows, and tows in a glass-carbon fiber hybrid composite using the same fiber. They observed that the tensile strength of the single fibers remained unaffected by the sizing of the filaments. In the case of impregnated tows, there was a 7% increase in characteristic strength for the unsized fibers. Interestingly, the strength of impregnated tows in hybrid composites was 15% higher than those tested in air, indicating a significant “hybrid effect”. Shao-Yun Fu et al. [4] prepared hybrid composites of polypropylene reinforced with short glass fibers and short carbon fibers using extrusion compounding and injection molding techniques. The study, based on the rule of hybrid mixtures, revealed an increase in both tensile strength and modulus for the hybrid composites. However, the failure strain of the hybrid composites decreased with the rising relative carbon fiber volume fraction in the mixture. The strength exhibited a positive deviation from the prediction of the RoHM (Rule of hybrid mixtures), indicating a positive hybrid effect. On the other hand, the values of the tensile modulus closely matched the predictions of the RoHM, suggesting no existence of a hybrid effect in modulus. Umer Mehmood et al. [5] conducted an evaluation of the tensile strength and impact strength of the hybrid composite across various glass-to-carbon ratios. Their findings revealed an increase in mechanical properties with a decrease in the relative proportion of carbon. Notably, the carbon fibers and glass fiber within the epoxy exhibited multiple failure modes, particularly at lower carbon proportions. It was observed that overall failure did not occur until a significant portion of fiber strands were fractured. In a separate study by K. Murali Mohan Rao et al. [6], elephant grass stalk fibers were extracted through retting and chemical extraction processes. These fibers underwent treatment with a Potassium permanganate (KMnO₄) solution to enhance adhesion with the matrix. The resulting fibers were integrated into a polyester matrix, and the tensile properties of both the fiber and the composite were examined. The fibers extracted through retting displayed a tensile strength of 185 MPa, a modulus of 7.4 GPa, and an effective density of 817.53 kg/m³. Meanwhile, chemically extracted elephant grass fibers demonstrated an increase in tensile strength and modulus by 58% and 41%, respectively. Following treatment, the tensile strength and modulus of the fiber extracted through retting decreased by 19% and 12%, while those of chemically extracted fiber decreased by 19% and 16%, respectively.

Taketa et al. [7] conducted research on hybrid composites featuring interlaid layers of carbon fiber reinforced polypropylene (CFRPP) between self-reinforced polypropylene (SRPP) layers. Their tensile testing revealed an improvement in the failure strain of the hybrid composites compared to CFRPP. However, the modulus and strength were noted to be lower than expected according to the rule of mixture.

In a separate study, Seung-Hwan Lee et al. [8] made a comparison with conventional carbon fiber reinforced plastic (CFRP) hybrid composites using NWCT. The results indicated high reliability and a significant strengthening effect on mechanical properties under tensile static and fatigue loadings. Although Type 1 and Type 2 hybrid specimens were lower than those of the CFRP specimen, the strength scatter of hybrid specimens was smaller. The transverse tensile Young's modulus and strength of the Type 2 hybrid specimen were higher than those of the CFRP specimen, and the strength scattering of hybrid specimens was smaller. This highlighted the importance of the "Toughening and Strengthening Technique" at critical positions for the required strength in laminated composite materials. M. Thiruchitrambalam et al. [9] conducted an investigation into the impact of alkali and SLS (Sodium Lauryl Sulphate) treatment on Banana/Kenaf Hybrid composites and woven hybrid composites. Their findings indicated that modification by SLS had a more pronounced positive effect on mechanical properties compared to alkali treatment. Specifically, the SLS treatment enhanced the mechanical properties, including tensile, flexural, and impact strength, in both random mix and woven hybrid composites. Shunsuke Yoshida et al. [10] experimentally evaluated the nonlinear mechanical behavior of unidirectional laminates and angle-ply laminates in tension and compression. Using a modified one-parameter plasticity model and classical lamination theory, they predicted and compared the stress-strain relation of angle-ply laminates with experimental results. The study revealed that the present model effectively described the distinct nonlinear behaviors observed in tension and compression for both unidirectional and angle-ply laminates.

A. Valenza and V. Fiore et al. [11] conducted tension and flexural tests on glass mat/epoxy composite material with aluminum alloy 6016-T4. Their findings revealed that by replacing an external layer of glass mat with uniaxial carbon fabric parallel to the x-direction, structures with specific modulus and strength values equal to or better than the reference aluminum alloy were achieved. Consequently, these hybrid laminates are proposed for use in the topside structures of a ship, replacing the reference alloy. R.S. Sharma et al. [12] performed experiments on Glass/Epoxy laminate composite specimens with varying fiber orientation to assess tensile properties. They discovered that glass/epoxy with a 0° orientation exhibited higher strength, stiffness, and load-carrying capacity than any other orientation. Therefore, it is recommended to prefer a fiber orientation of 0° for designing structures.

José Ricardo Tarpani et al. [13] determined and compared the quasi-static tensile properties of four aeronautical

grade carbon-epoxy composite laminates, both in the as-received and pre-fatigued states. Their results indicated that unidirectional carbon tape reinforcements impregnated with either standard or rubber-toughened epoxy resin demonstrated optimal performance under tensile stresses.

Muhsin J et al. [14] conducted experimental and theoretical investigations into the modulus of elasticity for various types of composite materials, including long, short, woven, powder, and particle reinforcements with different volume fractions of Glass, Aramid, or Kevlar (very light), Carbon (high modulus or high strength), Boron (high modulus or high strength), and Silicon carbide (high temperature resistant) fibers. Their findings revealed that unidirectional composite materials exhibit the minimum modulus of elasticity in the transverse direction compared to other types of composite materials.

Mohammed Abdul Hamza Mohammed et al. [15] investigated the effect of thermal shock at 80°C on some engineering properties of advanced composites with an unsaturated polyester matrix reinforced by artificial fibers, specifically (E glass) and (Kevlar), in both woven and continuous forms, with a weight percentage of 7%. Their results indicated that the Kevlar-reinforced specimens demonstrated superior quality compared to those reinforced with glass fiber when subjected to thermal shock. Ali I. Al-Mosawi et al. [16] conducted an evaluation of the mechanical properties of Araldite matrix composites reinforced with hybrid palms and Kevlar fibers. Their findings indicated a notable improvement in these mechanical properties after the incorporation of fibers, with the value of mechanical properties increasing with a higher percentage of reinforcement. Youjiang Wang et al. [17] conducted an experimental study on Glass & Kevlar woven fabric/epoxy composites, focusing on their mechanical properties under various loading conditions such as uniaxial tensile, flexural, compressive, short beam shear, and Mode I interlaminar fracture. The composites consisted of fiber glass and Kevlar 49 woven fabrics, featuring different fabric constructions and microfiber additives. The study analyzed the effects of the reinforcing fabric structure and microfiber additives on the mechanical behavior and failure mechanisms of the composites.

Bilal Zahid et al. [18] undertook the manufacturing, fabrication, and evaluation of a 5-layer through-the-thickness angle-interlock composite structure using Kevlar. The study revealed that composites developed from angle-interlock fabric exhibited significantly different and superior tensile properties in the weft direction compared to the warp direction. Breaking the fibers in the weft direction proved to be much more challenging than in the warp direction for this specific construction of Kevlar-based composite. This behavior suggests the potential for creating improved products when developing advanced textile-based composite structures. Herbert Yeung K [19] highlighted the development of thermoplastic matrix composites aimed at enhancing the toughness and damage tolerance of composite laminates. The ductility of thermoplastic resins implies a more pronounced plasticity in service. Kevlar fiber, with a tensile strength comparable to that of carbon fiber, a modulus between those of glass and carbon fibers, and a lower density than both, plays a crucial role in this development. The study included a systematic costing analysis of respective thermoplastic composites, providing valuable guidelines for designers in selecting appropriate composites.

Kadhim H. Ghilaim [20] conducted an evaluation of woven factors for composites featuring various weave patterns, fiber materials, and matrix materials. Mechanical properties were measured through tensile tests on woven composites and cross-unidirectional composites made from the same materials. The study utilized three types of fibers: E-Glass, Kevlar, and Carbon with epoxy and polyester serving as matrices. The findings revealed that Kevlar had higher woven factors compared to E-Glass and Carbon, and composites reinforced with epoxy exhibited superior woven factors compared to those reinforced with polyester. Abbas A. Al-Jeebory et al. [21] explored the mechanical properties of araldite matrix composites incorporating hybrid carbon-Kevlar fibers. A comprehensive review on Mechanical, Thermal, and Dielectric properties across Various fiber-reinforced systems emphasize the significance of careful selection and combination of materials in composite fabrication to achieve optimal mechanical Thermal, and Dielectric performance. The exploration of different weave patterns and fiber-matrix combinations opens avenues for further advancements in the design and application of high-performance composite materials in various industries.

2. Conclusion

The following conclusions can be drawn from the review of fiber-reinforced systems:

1. The diverse studies presented in the review highlight the extensive exploration and advancements in composite materials reinforced with various fibers. Researchers investigated hybrid composites, considering factors like stacking sequences, single fiber types, and their impact on mechanical, thermal, and dielectric properties.

2The incorporation of biofibers and the careful selection of fiber orientation were examined for enhancing tensile and flexural modulus while maintaining thermal stability. Studies on single carbon fibers and hybrid composites reinforced with short glass and carbon fibers showcased the positive hybrid effects on tensile strength and modulus.

3Research on woven fabric composites, such as Glass & Kevlar, demonstrated their mechanical properties under different loading conditions, providing insights into their applications. Further investigations into the effects of thermal shock on advanced composites revealed the superiority of Kevlar-reinforced specimens over glass fiber-reinforced ones. Hybrid palms-Kevlar fiber-reinforced araldite matrix composites exhibited improved mechanical properties with increasing reinforcement percentages.

4Studies on specialized structures, like through-the-thickness angle-interlock composites and thermoplastic matrix composites, highlighted advancements in toughness, damage tolerance, and the systematic costing analysis for composite selection guidelines.

5Evaluations of woven factors emphasized the significance of fiber type and matrix choice, with Kevlar-reinforced composites demonstrating superior woven factors.

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