

Mechanical Characterization Of Epoxy-Glass Fibre-Aluminium Composites Fabricated By Stir Casting

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Abstract

The present project work concentrated on the construction and experimentation of a metal matrix composite alloy using epoxy resin, glass fiber, and aluminum particles by employing the stir casting technique. In automotive and aerospace industries, aluminum composite materials are popularly employed due to their superior strength, higher malleability, stiffness, excellent corrosion resistance, wear and lightweight. This present work implies the construction of specimens and analysis of specimens with varying proportions of epoxy resin. The mechanical properties such as strength, hardness and toughness were evaluated with the help of constructed specimens. The experimental values show drastic changes on the mechanical properties of the epoxy, glass fibre, and aluminum composite system. In the alloy materials consisting 10% aluminum, 60% Epoxy and 30% Glass fibre, the higher epoxy percentage improved matrix stick but moderately falls resistance of impact because of the lower reinforcement ratio. The adjustment of the composition to 50% epoxy, 35% Glass fibre and 15% aluminum yielded a noticeable augmentation in tensile strength, and rigidity of structure, attributable to the raised reinforcement phase. Compared to development of lower aluminium content, the 50% epoxy, 35% glass fibre, and 15% aluminium mixture shows the best stable stiffness, strength, and resistance of impact. It is observed that significant improvement in tensile and toughness aspects of the composite as the results showed that increasing the aluminium and glass fibre content up to optimal levels.

I. INTRODUCTION

When combined with aluminium, glass fibre-reinforced epoxy composites exhibit enhanced strength, stiffness, and resistance to impact and wear. The inclusion of glass fibres in the polymer matrix restricts crack propagation and distributes applied loads more uniformly, significantly improving the mechanical properties of the composite. Compared to unreinforced epoxy, these composites offer superior tensile strength, rigidity, and dimensional stability. The widespread adoption of fibre-reinforced polymer composites can be attributed to their versatility and ease of integration with other substrates to achieve targeted performance characteristics. These materials are known for their high strength-to-weight ratio, excellent chemical and corrosion resistance, and low thermal expansion. They are fabricated by combining two or more constituents with distinct physical or chemical properties that do not chemically blend but work synergistically to yield advanced properties. In this context, aluminium particulates play a critical role in enhancing stiffness and thermal performance when added to the epoxy-

glass fibre system. Recent mechanical testing of composites fabricated with 50-60% epoxy, 30-40% glass fibre, and 10-15% aluminium showed that increasing the reinforcement content led to improvements in both tensile strength and impact resistance. For instance, the composition with 50% epoxy, 35% glass fibre, and 15% aluminium exhibited a tensile strength of 102.1 MPa, 0.2% proof stress of 84.4 MPa, and impact strength averaging 2.5 J, indicating a balanced combination of strength and toughness. However, higher reinforcement ratios slightly reduced ductility due to increased matrix discontinuity. These composites were fabricated using the stir casting technique, wherein aluminium particles were added to the epoxy matrix and uniformly distributed by

mechanical stirring before integrating the glass fibre. The prepared specimens were cured and machined to standard dimensions, followed by mechanical testing to assess tensile, elongation, and impact properties. The results confirmed that optimal reinforcement combinations could be tailored to meet the specific requirements of structural and semi-structural applications. Currently, much research is focused on optimizing polymer-metal-fibre hybrid composites for applications in aerospace, automotive, marine, and defense sectors. The use of aluminium within the polymer matrix improves thermal conductivity, chemical resistance, and dimensional integrity, making these composites highly suitable for multifunctional engineering components. Furthermore, the size, distribution, and interface bonding of the reinforcement phases are critical in determining overall composite behavior, particularly in dynamic or load-bearing environments. This study highlights the advantages of integrating aluminium and glass fibre within an epoxy matrix to engineer composites with enhanced mechanical performance. The mechanical properties, along with their light weight and corrosion resistance, make these hybrid composites viable alternatives to traditional materials across a range of industrial applications.

MATERIALS AND METHODS

1. Selection of Materials

Epoxy resin was employed as the primary matrix material due to its excellent mechanical properties, chemical resistance, and ease of processing. For reinforcement, aluminium particles and glass fibres were selected owing to their superior strength, stiffness, and thermal stability. The composite formulations were developed with varying weight percentages of aluminium (10%, 12.5%, and 15%), while maintaining a consistent proportion of glass fibre reinforcement (30–40%) across all compositions. The epoxy content was varied between 50% and 60% to evaluate its influence on matrix-reinforcement interaction and mechanical performance. To enhance wetting and interfacial bonding, the epoxy resin was preheated slightly to lower its viscosity and facilitate uniform dispersion of reinforcements. Simultaneously, aluminium particles were preheated to approximately 400–500 °C for 1.5 hours to remove moisture, adsorbed gases, and surface impurities, thereby improving their adhesion to the polymer matrix and preventing interfacial defects. After pre-treatment, the constituents were blended using a mechanical stir casting technique. The mixture was stirred with a mild steel impeller operating at 200 rpm for 20 minutes, ensuring homogeneous dispersion of the aluminium particles and glass fibres throughout the resin matrix. The resulting slurry was immediately transferred into pre-fabricated metallic molds of rectangular profile, sized to 140 mm × 14 mm, suitable for both tensile and impact testing as per ASTM standards.

The molded composites were left to cure under controlled ambient conditions to achieve complete crosslinking of the epoxy matrix. This processing route enabled uniform particle distribution and consistent reinforcement-matrix interaction, which are critical for reliable mechanical performance evaluation.

2. Casting

Stir casting is a widely adopted technique for fabricating particle-reinforced polymer matrix composites owing to its operational simplicity, scalability, and economic viability. In this method, the polymer matrix—typically in a semi-liquid or low-viscosity liquid state—is subjected to mechanical agitation while reinforcements such as aluminium particles and glass fibres are gradually introduced. The active stirring action ensures homogeneous distribution of reinforcements throughout the matrix, minimizing agglomeration and promoting uniform mechanical properties. This process is particularly advantageous in enhancing interfacial adhesion between the matrix and reinforcements, which is critical for the load-transfer efficiency and structural integrity of the composite. Following

fabrication, the machining of fibre- and particle-reinforced composites presents several challenges due to the material's anisotropy and the presence of hard, brittle inclusions. Reinforcements such as aluminium particles and glass fibres tend to increase the composite's abrasiveness, leading to accelerated tool wear, inconsistent material removal, and edge chipping. Moreover, the heterogeneous nature of the composite can result in non-uniform cutting forces and localized thermal stresses.

Despite these complexities, conventional machining processes such as turning, drilling, and milling can still be effectively utilized, provided that appropriate tooling (e.g., coated carbide or polycrystalline diamond tools), optimized cutting parameters, and efficient cooling or lubrication systems are employed. These measures are essential to achieve high surface quality, dimensional accuracy, and prolonged tool life while minimizing delamination and other surface defects common in composite machining.

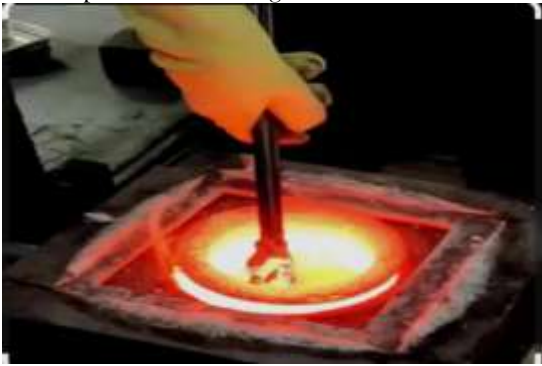


Figure 1: Stir Casting Technique

3. Machining



Figure 2: The alloy contains of a foremost epoxy matrix, reinforced with a average percentage of glass fibres and a little amount of aluminium grains to strengthen strength and stiffness

After the curing process was completed under ambient conditions, the solidified composite samples were removed from the moulds and subjected to secondary processing to obtain standard test specimens. The cured cylindrical or rectangular castings were first trimmed to approximate size and then machined to precise dimensions in accordance with relevant ASTM standards for tensile and impact testing.

A vertical milling machine was employed to achieve accurate specimen geometry, ensuring dimensional consistency and repeatability across all samples. Following machining, the specimens underwent surface finishing and edge polishing using fine abrasive tools to eliminate burrs and surface irregularities. This step was crucial in preventing stress concentrations, which can lead to localized failure during mechanical testing.

The final specimens were rectangular in shape with dimensions of 140 mm × 14 mm, suitable for both tensile and Charpy impact testing. Care was taken throughout the preparation process to maintain the structural integrity of the composite, especially near the edges and notches, ensuring reliable and reproducible test results.

4. Vickers Hardness Test



Figure 4: Vickers Hardness Test

The Vickers hardness test is widely preferred among hardness evaluation techniques due to its indenter geometry-independent calculations and broad applicability across materials with varying hardness levels. One of its key advantages is that a single diamond indenter can be used for both soft and hard materials, ensuring consistency and comparability in results without the need for indenter-specific corrections.

5. Impact Test



Figure 5 : Impact Test

The impact test is a critical method used to evaluate a material's ability to absorb energy under sudden or dynamic loading, offering a direct measure of its toughness. This test is particularly important for fibre-reinforced composites, where materials are expected to resist crack propagation and dissipate impact forces effectively. In the present study, standardized Charpy impact specimens were fabricated and tested to assess the energy absorbed at fracture.

The inclusion of glass fibers plays a significant role in enhancing the composite's toughness by bridging micro-cracks and distributing stress throughout the matrix, thereby preventing abrupt or catastrophic failure. The synergistic interaction between the epoxy matrix and the embedded fibrous reinforcement contributes to improved energy absorption characteristics. The data obtained from the impact test provides valuable insight into the composite's suitability for applications involving shock loads, vibrations, or accidental impacts.

6. Tensile Test



Figure 6: Tensile Test

The tensile test is a fundamental mechanical evaluation technique used to determine a material's capacity to withstand uniaxial tensile loads without failure. This method provides critical insights into mechanical parameters such as ultimate tensile strength (UTS), yield strength (0.2% proof stress), and elongation at break, which are essential for characterizing the structural performance of composite materials. In this study, tensile testing was performed on epoxy-based composites reinforced with glass fibres and aluminium particles. The specimens were subjected to a controlled loading rate until fracture, and the corresponding stress-strain curves were recorded. The presence of glass fibres improved load distribution and resistance to matrix cracking, while the metallic aluminium phase contributed to enhanced stiffness and load-bearing capacity.

The combined reinforcement system effectively restricted matrix deformation and contributed to an increase in tensile strength and rigidity, demonstrating the beneficial interaction between the polymer matrix and the reinforcements. These results are indicative of the composite's potential in structural applications requiring both strength and lightweight characteristics.

II. LITERATURE SURVEY

The integration of nano-reinforcements such as $\gamma\text{-Al}_2\text{O}_3$ particles into epoxy resin matrices has emerged as a promising strategy for enhancing both mechanical and thermal performance of polymer composites, as evidenced by multiple research studies. Cheng-Ho Chen et al. (2014) laid a strong foundation by demonstrating that the incorporation of $\gamma\text{-Al}_2\text{O}_3$ nanoparticles significantly improved the tensile strength and thermal stability of epoxy composites. Their study, utilizing Transmission Electron Microscopy (TEM) and Dynamic Mechanical Analysis (DMA), confirmed that fine dispersion of nanoparticles resulted in enhanced interfacial bonding and structural uniformity. Importantly, they observed that optimal performance was achieved at around 5 phr loading, beyond which agglomeration effects hindered further property enhancement. This finding emphasizes the critical need to control nanoparticle dispersion and loading levels in nanocomposite design. They proposed further exploration using hybrid fillers or chemical coupling agents to enhance the interfacial adhesion between the filler and polymer matrix.

Building upon this, Zheng Zhang and his team introduced multiphase reinforcement by combining Al_2O_3 particles with glass fibers, resulting in a synergistic improvement in tensile, flexural, and thermal conductivity properties. This multiphase approach allowed the benefits of particulate reinforcement (stiffness and thermal conductivity) to be complemented by the load-bearing capacity

of fibers, offering a balanced improvement in both mechanical and thermal domains. Their morphological analysis underlined that uniform dispersion of both reinforcements is vital for consistent performance. They also recommended exploring nano-sized Al_2O_3 and functionalized glass fibers to promote better matrix-filler interactions and mitigate the risk of fiber pull-out or debonding under load conditions.

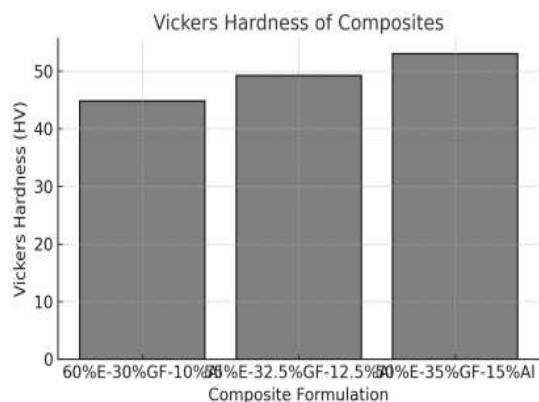
In another important contribution, N. Ozdemir and F. Yakuphanoglu focused on the effect of Al_2O_3 particle size on composite performance. Their findings revealed that smaller nano- Al_2O_3 particles led to significantly higher thermal conductivity and moderately improved mechanical properties compared to larger micro-sized particles. This size dependency was attributed to the higher surface area-to-volume ratio of nano-fillers, which provides more active surface area for stress transfer and thermal conduction. Their study highlights the importance of particle engineering and supports the idea that nano-sized reinforcements are more effective in tailoring functional properties of polymer composites. The researchers proposed further research into hybrid-size reinforcement systems, where nano- and micro-sized fillers are combined to optimize performance and cost-efficiency. Complementing these findings, Osman A.S. focused on glass fiber- Al_2O_3 reinforced epoxy systems and demonstrated that composites containing both fibers and particles exhibited superior tensile and impact resistance compared to those reinforced with only one type of filler. The inclusion of fibers contributed to crack bridging and energy absorption, while the particles enhanced stiffness and thermal properties. This study supports the concept that synergistic effects between different reinforcement types can be harnessed to create composites with tailored multifunctional properties. Osman emphasized the potential for improving fiber orientation techniques, interfacial adhesion, and dispersion methods to further optimize performance in advanced structural applications.

III. RESULTS AND DISCUSSION

The mechanical properties of epoxy-glass fibre-aluminium hybrid composites were studied to evaluate the influence of varying reinforcement content. The addition of glass fibres and aluminium particles significantly enhanced hardness, tensile strength, and yield strength, with a slight reduction in ductility.

3.1 Hardness

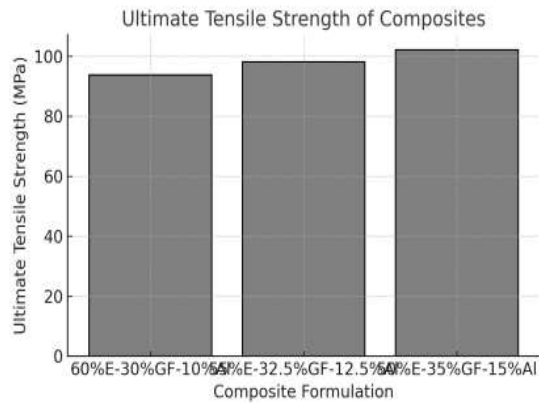
The Vickers hardness values showed a steady increase with higher reinforcement. Composite 1(60%E-30%GF-10%Al) recorded 44.8 HV, while Composite 3 (50%E-35%GF-15%Al) reached 53.0 HV (~18% increase). Aluminium particles provided resistance to indentation and glass fibres improved stress transfer. Excess filler content reduced ductility, which is a common trade-off.



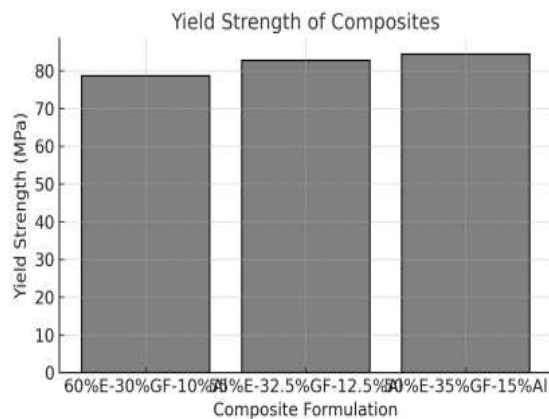
3.1 Vickers Hardness of Composites

3.2 Tensile Properties

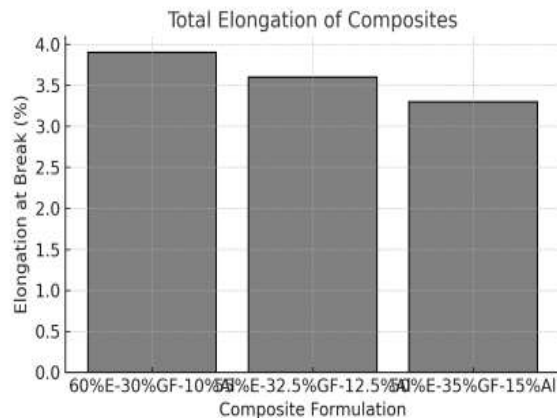
Ultimate Tensile Strength (UTS) increased from 93.8 MPa in Composite 1 to 102.1 MPa in Composite 3. Yield Strength also improved from 78.7 MPa to 84.4 MPa. These improvements were due to better load transfer and matrix stiffening by the reinforcements. However, elongation decreased from 3.9% to 3.3%, indicating increased brittleness. The following figures illustrate the trends observed in hardness, tensile strength, yield strength, and elongation for the composites



3.2 Ultimate Tensile Strength of Composites



3.3 Yield Strength of Composites



3.4 Total Elongation of Composites

IV. CONCLUSION

The study confirmed that epoxy-glass fibre-aluminium hybrid composites exhibit enhanced mechanical properties with increased reinforcement content. Composite 3 (50%E-35%GF-15%Al) showed superior hardness (53.0 HV), tensile strength (102.1 MPa), and yield strength (84.4 MPa). Although ductility decreased slightly (3.3%), the composites are suitable for structural applications requiring high strength and wear resistance.

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