Fabrication and Mechanical Characterization of Advantex Fiber, Glass Fiber, and Hybrid Fiber Reinforced Polymer Composites

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Abstract
Fiber Reinforced Polymer (FRP) composites have become increasingly important in modern engineering applications because of their superior mechanical properties, lightweight nature, corrosion resistance, and design flexibility. The growing demand for high-performance materials in automotive, aerospace, marine, and structural industries has accelerated research into advanced composite systems capable of providing enhanced strength and durability while reducing structural weight. Among various reinforcement materials, glass fibres and advanced glass fibres such as Advantex have gained significant attention due to their excellent mechanical characteristics and environmental resistance. In addition, hybrid composite systems have emerged as promising alternatives by combining the advantages of multiple reinforcement fibres within a single matrix structure.

The present study focuses on the fabrication and mechanical characterization of Advantex fibre, glass fibre, and hybrid fibre reinforced polymer composites using the hand lay-up technique. Polyester and epoxy resin systems were utilized as matrix materials, while glass fibres and Advantex fibres served as reinforcement materials. Composite laminates were fabricated under controlled conditions and prepared according to ASTM standards for mechanical testing. Tensile testing was conducted according to ASTM D3039, hardness testing was performed using ASTM D2240 Shore D standards, and impact testing was carried out according to ASTM D256.

Experimental results revealed significant differences in mechanical behaviour among the fabricated composite systems. Glass fibre reinforced composites exhibited the highest tensile strength of 151.59 MPa and hardness value of 86.9 Shore D, indicating superior load-carrying capacity and resistance to surface deformation. Hybrid composites demonstrated the highest impact strength of 55.59 kJ/m² due to improved energy absorption mechanisms such as fibre pull-out, matrix cracking, and delamination. Advantex fibre composites displayed balanced mechanical properties with enhanced durability and corrosion resistance.

The comparative analysis confirms that reinforcement type, fibre architecture, and hybridization significantly influence the mechanical performance of FRP composites. The study demonstrates that glass fibre composites are suitable for strength-critical applications, while hybrid composites are advantageous for impact-resistant structures. Advantex fibre composites provide an effective balance between strength, toughness, and environmental durability. The findings contribute to the development of lightweight and high-performance composite materials for advanced engineering applications.

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Keywords: Fiber Reinforced Polymer Composites, Advantex Fiber, Glass Fiber Reinforcement, Hybrid Composites, Mechanical Characterization

1. Introduction

Composite materials have revolutionized modern engineering by offering superior mechanical performance while maintaining low structural weight. A composite material is formed by combining two or more distinct materials to achieve properties that are superior to those of the individual constituents. Among the various classes of composite materials, Fiber Reinforced Polymer (FRP) composites have gained widespread acceptance in industries such as aerospace, automotive, marine, construction, sports equipment, and renewable energy systems. FRP composites consist of reinforcement fibres embedded within a polymer matrix. The matrix provides shape, protects the fibres from environmental degradation, and transfers load between fibres, while the reinforcement fibres contribute significantly to strength and stiffness. Due to their high strength-to-weight ratio, excellent corrosion resistance, fatigue durability, and design flexibility, FRP composites have become attractive alternatives to traditional metallic materials.

Glass fibre reinforced composites are among the most commonly used FRP materials because of their excellent balance between cost and performance. Glass fibres exhibit high tensile strength, good stiffness, and resistance to chemical degradation. Recent developments in reinforcement technology have led to the introduction of Advantex fibres, which combine the mechanical benefits of traditional glass fibres with improved durability and corrosion resistance. These characteristics make Advantex fibres suitable for demanding environmental conditions and long-term structural applications.

Hybrid composites have emerged as another important category of advanced composite materials. Hybridization involves combining two or more reinforcement fibres within a single matrix system to achieve improved mechanical performance. Hybrid composites often exhibit enhanced toughness, impact resistance, and energy absorption characteristics compared to conventional single-fibre composites. The synergistic interaction between different fibre systems allows engineers to optimize composite performance for specific applications.

The fabrication method significantly influences the quality and performance of composite materials. The hand lay-up technique remains one of the most widely used manufacturing methods because of its simplicity, low cost, and ability to produce large composite structures. Proper fibre wetting, resin distribution, curing conditions, and laminate configuration are critical factors that determine the final mechanical properties of fabricated composites.

The present study investigates the fabrication and mechanical characterization of Advantex fibre, glass fibre, and hybrid fibre reinforced polymer composites. Mechanical properties including tensile strength, hardness, and impact resistance are evaluated through experimental testing. The research aims to provide a comprehensive comparison of different composite systems and identify suitable materials for lightweight engineering applications.

1.1 Research Objectives

The primary objectives of the present research are:

- ✓ To fabricate Advantex fibre reinforced polymer composites using the hand lay-up technique.
- ✓ To fabricate glass fibre reinforced polymer composites under controlled processing conditions.
- ✓ To develop hybrid fibre reinforced polymer composites by combining Advantex and glass fibres.
- ✓ To prepare ASTM standard specimens for mechanical characterization.
- ✓ To evaluate tensile strength using ASTM D3039 standards.
- ✓ To determine hardness characteristics using ASTM D2240 Shore D testing.
- ✓ To evaluate impact resistance using ASTM D256 testing procedures.
- ✓ To compare the mechanical performance of Advantex, glass fibre, and hybrid composites.
- ✓ To investigate the influence of reinforcement type on composite behaviour.
- ✓ To identify suitable composite systems for lightweight structural applications.

1.2 Problem Statement

Modern engineering industries continuously seek materials that provide high strength, reduced weight, corrosion resistance, and improved durability. Conventional metallic materials such as steel and aluminium possess excellent structural strength; however, they suffer from limitations including high density, susceptibility to corrosion, and increased maintenance requirements. These limitations create the need for advanced materials capable of delivering improved performance while reducing structural weight.

Fiber Reinforced Polymer composites offer a promising alternative because of their excellent mechanical properties and lightweight characteristics. Nevertheless, the performance of FRP composites depends heavily on reinforcement type, matrix selection, fabrication quality, and interfacial bonding. Although glass fibre composites provide high tensile strength and stiffness, they often exhibit brittle behaviour under impact loading. Similarly, Advantex fibres offer improved durability and corrosion resistance, but their comparative mechanical performance requires further investigation.

Hybrid composites have been proposed as a solution to improve toughness and energy absorption by combining multiple reinforcement fibres. However, hybridization can also introduce challenges such as non-uniform stress distribution and interfacial compatibility issues. Furthermore, fabrication defects including voids, poor resin wetting, and delamination may significantly influence mechanical behaviour.

Therefore, a detailed comparative experimental study is required to evaluate the tensile strength, hardness, and impact resistance of Advantex fibre, glass fibre, and hybrid fibre reinforced polymer composites fabricated under identical processing conditions. Understanding these characteristics is essential for optimizing material selection and improving composite performance in practical engineering applications.

2. Materials and Methodology

The present study focuses on the fabrication and mechanical characterization of fibre-reinforced composite laminates. Composite specimens were manufactured using high-strength reinforcing fibres embedded within an epoxy resin matrix to obtain lightweight structures with enhanced mechanical properties. The selected reinforcement material was arranged in predetermined orientations to achieve uniform load distribution and improved structural performance. Epoxy resin and a suitable hardener were used as the matrix system due to their excellent bonding characteristics, corrosion resistance, and dimensional stability.

The composite laminates were fabricated using the hand lay-up technique followed by compression and curing under controlled environmental conditions. Initially, the mold surface was cleaned and coated with a release agent to facilitate easy removal of the laminate after curing. Layers of reinforcing fibres were placed sequentially in the mold, and the resin-hardener mixture was uniformly applied to ensure complete fibre wetting. Air bubbles and excess resin were removed using rollers to minimize void formation and improve laminate quality. The fabricated laminates were then allowed to cure at room temperature, followed by post-curing to achieve optimum mechanical properties.

After curing, the laminates were cut into standard test specimens according to ASTM specifications using precision cutting tools. Mechanical characterization was carried out to evaluate the performance of the fabricated composites. Tensile tests were conducted in accordance with ASTM D3039 to determine tensile strength and modulus, while flexural properties were measured following ASTM D790. Impact resistance was evaluated using ASTM D256 standards, and hardness measurements were performed according to applicable ASTM procedures. All tests were conducted using calibrated testing equipment under controlled laboratory conditions. The experimental results were recorded, analysed, and compared to assess the effectiveness of the composite fabrication process and the influence of reinforcement on the overall mechanical behaviour of the composite material.

2.1 Materials

The materials used in the present investigation include:

Matrix Materials

- Polyester Resin
- Epoxy Resin
- MEKP Catalyst
- Hardener (H5951)

Reinforcement Materials

- Glass Fiber Mat (300 GSM and 450 GSM)
- Advantex Fiber
- Hybrid Combination of Glass and Advantex Fibers

2.2 Composite Fabrication

Composite fabrication is the process of manufacturing composite materials by combining two or more distinct constituents, typically a reinforcement material and a matrix material, to achieve enhanced mechanical and structural properties. In engineering applications, fiber-reinforced composites are commonly fabricated using techniques such as hand lay-up, vacuum bag molding, resin transfer molding, compression molding, and filament winding. During fabrication, reinforcing fibres such as glass, carbon, or aramid fibres are carefully arranged in specific orientations and impregnated with a polymer matrix, usually epoxy, polyester, or vinyl ester resin. The composite laminate is then subjected to curing under controlled temperature and pressure conditions to ensure proper bonding between the fibres and matrix. The quality of fabrication significantly influences the strength, stiffness, durability, and overall performance of the composite structure. Proper control of fibre volume fraction, resin distribution, curing parameters, and defect minimization is essential to produce high-performance composite components for aerospace, automotive, marine, civil engineering, and advanced structural applications.

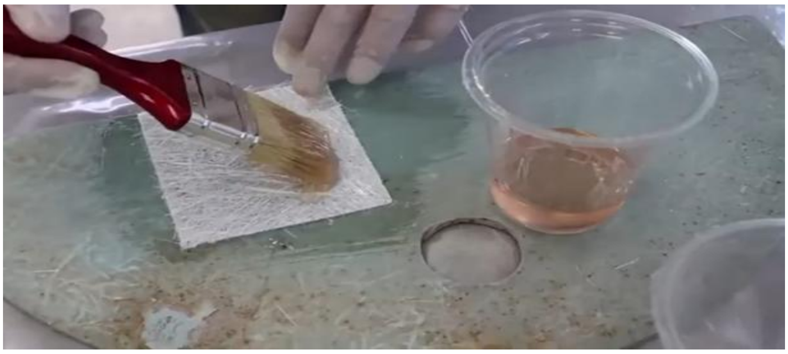

Fig 1: Preparation of Composite Layer

2.3 Mechanical Testing

Mechanical characterization was performed according to relevant ASTM standards to evaluate the structural and mechanical performance of the fabricated composite specimens. Tensile testing was conducted to determine ultimate tensile strength, Young's modulus, and elongation at break, while flexural testing was carried out to assess bending strength and stiffness. Impact resistance was evaluated using standardized impact tests to measure the material's energy absorption capability under sudden loading conditions. Additionally, hardness measurements were performed to examine surface resistance to indentation and wear. All tests were conducted under controlled laboratory conditions using calibrated testing equipment, and multiple specimens were tested to ensure repeatability and accuracy of the results. The obtained mechanical properties were analysed to assess the effectiveness of the composite fabrication process and the contribution of the reinforcement materials to the overall structural performance.

Test	Standard
Tensile Test	ASTM D3039
Hardness Test	ASTM D2240
Impact Test	ASTM D256

3. Applications

The fabricated composite systems can be utilized in various engineering sectors:

- Automotive body panels
- Aerospace interior structures
- Marine components
- Wind turbine blades
- Railway coach interiors
- Sports equipment
- Structural strengthening systems
- Industrial storage tanks

The lightweight nature of FRP composites contributes to improved fuel efficiency, reduced maintenance costs, and enhanced service life.

4. Results And Analysis

The mechanical performance of Advantex fibre, glass fibre, and hybrid fibre reinforced polymer (FRP) composites was evaluated through tensile, hardness, and impact testing according to ASTM standards. The primary objective of the analysis was to investigate the influence of reinforcement type and hybridization on the mechanical behaviour of composite materials.

The experimental results demonstrated noticeable variations among the fabricated composite systems. Glass fibre reinforced composites exhibited the highest tensile strength of 151.59 MPa, indicating superior load-bearing capability. The high tensile performance can be attributed to the strong fibre–matrix interfacial bonding, efficient stress transfer, and high stiffness characteristics of glass fibres. During tensile loading, glass fibres effectively resisted deformation and delayed crack initiation, resulting in improved structural integrity.

Advantex fibre reinforced composites showed a tensile strength of 109.2 MPa, which was lower than that of glass fibre composites but still demonstrated satisfactory structural performance. Advantex fibres provided enhanced durability and environmental resistance, making them suitable for applications exposed to corrosive environments. The balanced tensile behaviour observed in Advantex composites indicates good compatibility between the fibre and polymer matrix.

Hybrid composites exhibited a tensile strength of 76.2 MPa, which was comparatively lower due to differences in fibre stiffness and non-uniform stress distribution. However, the hybrid composites displayed superior impact resistance, achieving an impact strength of 55.59 kJ/m². The enhanced impact performance was attributed to energy absorption mechanisms such as matrix cracking, fibre pull-out, interfacial debonding, and delamination. These mechanisms dissipated fracture energy and delayed catastrophic failure.

Hardness testing revealed that glass fibre composites possessed the highest hardness value of 86.9 Shore D. The rigid structure of glass fibres improved resistance to localized deformation and surface indentation. Hybrid composites exhibited a hardness value of 78.4 Shore D, while Advantex composites recorded 74.2 Shore D.

The overall analysis indicates that reinforcement type significantly influences composite performance. Glass fibre composites are suitable for applications requiring high strength and stiffness, whereas hybrid composites provide superior toughness and impact resistance. Advantex composites offer a balanced combination of strength, durability, and environmental resistance. These findings demonstrate the importance of selecting appropriate reinforcement materials based on specific engineering requirements.

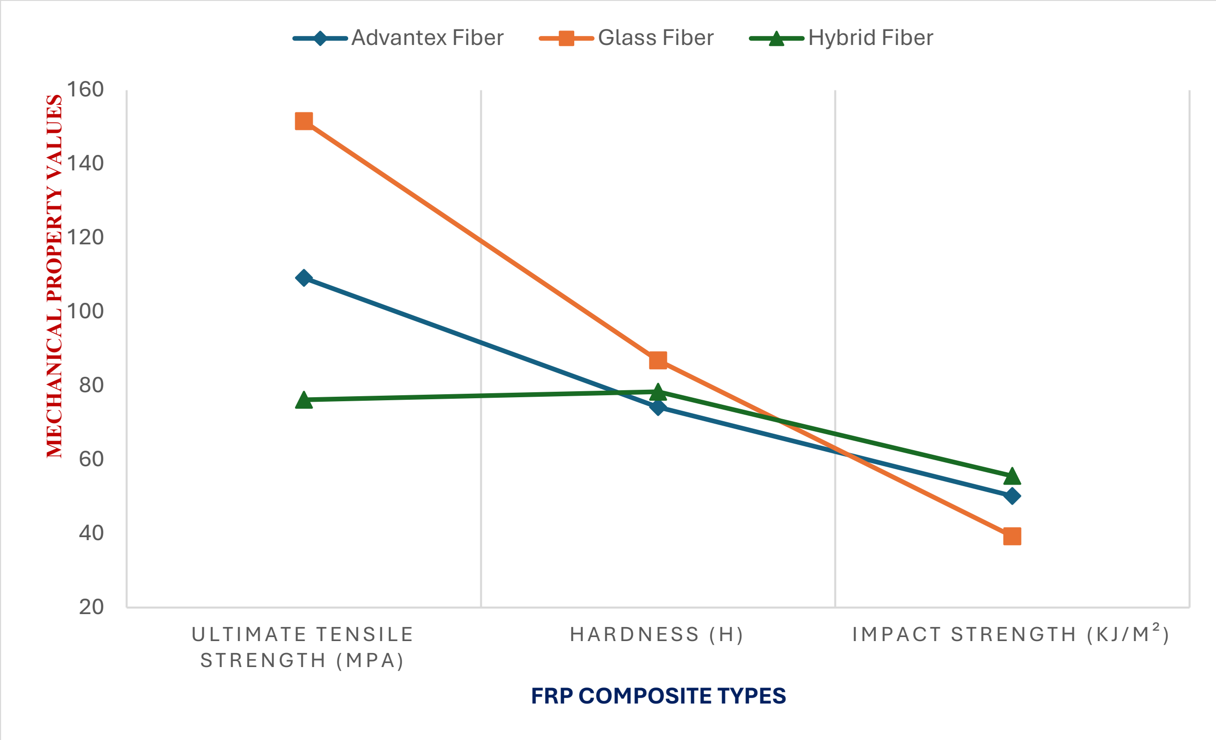

Fig 2: Comparison of Mechanical Properties across FRP Composite Types

5. Discussion

The experimental investigation provides valuable insights into the mechanical behaviour of different fibre reinforced polymer composite systems. The results clearly demonstrate that the selection of reinforcement material plays a critical role in determining the tensile strength, hardness, and impact resistance of composite structures.

Glass fibre reinforced composites exhibited superior tensile and hardness properties due to their high modulus and strong fibre–matrix interaction. The woven architecture of glass fibres contributed to uniform stress distribution and improved load transfer efficiency. These characteristics make glass fibre composites suitable for structural applications where high stiffness and load-bearing capability are essential.

Advantex fibre composites demonstrated balanced mechanical properties and improved environmental durability. Although their tensile strength was lower than that of conventional glass fibre composites, they provided better resistance to corrosive environments and long-term degradation. This characteristic makes Advantex composites particularly attractive for marine structures, chemical processing equipment, and outdoor applications.

The hybrid composite system showed unique mechanical behaviour. While the tensile strength decreased compared to single-fibre composites, the impact resistance increased significantly. Hybridization introduced multiple energy absorption mechanisms, including crack deflection, fibre bridging, fibre pull-out, and delamination. These mechanisms delayed crack propagation and enhanced fracture toughness. As a result, hybrid composites are particularly suitable for applications subjected to impact loading and dynamic stresses.

The influence of fabrication quality was also evident in the results. Proper resin distribution, fibre wetting, and curing conditions contributed to improved mechanical performance. Any defects such as voids, poor bonding, or delamination can reduce composite strength and initiate premature failure. Therefore, fabrication parameters must be carefully controlled during composite manufacturing.

The findings of this study align with previous research on FRP composites, which reported that glass fibre composites provide superior tensile properties while hybrid systems improve toughness and impact resistance. The results confirm that no single composite system is ideal for all applications. Instead, material selection should be based on specific performance requirements such as strength, stiffness, toughness, durability, and environmental resistance.

Overall, the study demonstrates the effectiveness of hybridization and advanced reinforcement systems in tailoring composite properties. Future research involving nano-reinforcements, optimized stacking sequences, and advanced fabrication techniques could further enhance composite performance and expand their engineering applications.

Parameter	Advantex Fiber Composite	Glass Fiber Composite	Hybrid Composite
Tensile Strength (MPa)	109.2	151.59	76.2
Hardness (Shore D)	74.2	86.9	78.4
Impact Strength (kJ/m^2)	50.2	39.3	55.59
Durability	High	Moderate	High
Corrosion Resistance	Excellent	Good	Very Good
Toughness	Moderate	Moderate	Excellent

Energy Absorption	Good	Moderate	Excellent
Structural Applications	Marine Structures	Load-Bearing Structures	Impact-Resistant Structures
Overall Performance	Balanced	Strength-Oriented	Toughness-Oriented

6. Conclusion

The present study successfully investigated the fabrication and mechanical characterization of Advantex fibre, glass fibre, and hybrid fibre reinforced polymer composites using the hand lay-up technique. The experimental evaluation was carried out through tensile, hardness, and impact testing according to ASTM standards to understand the influence of reinforcement type on composite performance.

The results revealed that glass fibre reinforced composites exhibited the highest tensile strength of 151.59 MPa and hardness value of 86.9 Shore D. These superior properties were attributed to effective fibre–matrix bonding, high stiffness of glass fibres, and efficient load transfer mechanisms. Consequently, glass fibre composites are highly suitable for structural applications requiring high strength and rigidity.

Advantex fibre composites demonstrated balanced mechanical performance with moderate tensile strength, hardness, and impact resistance. The improved corrosion resistance and durability of Advantex fibres make them attractive for applications operating in harsh environmental conditions. The results indicate that Advantex composites provide an effective compromise between strength, toughness, and environmental stability.

Hybrid composites achieved the highest impact strength of 55.59 kJ/m² due to enhanced energy absorption mechanisms such as fibre pull-out, matrix cracking, interfacial debonding, and delamination. Although their tensile strength was lower than that of glass fibre composites, their exceptional toughness and impact resistance make them suitable for dynamic and impact-loaded structures.

The study confirms that reinforcement selection significantly influences the overall mechanical behaviour of FRP composites. Glass fibre composites are preferred for strength-critical applications, Advantex composites for durability-oriented applications, and hybrid composites for impact-resistant structures. The findings contribute to the understanding of advanced composite materials and provide valuable guidance for material selection in automotive, aerospace, marine, and structural engineering sectors.

Future research may focus on fatigue behaviour, thermal characterization, finite element modelling, and nano-reinforced hybrid composites to further enhance composite performance and broaden their industrial applications.

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