Numerical and Experimental Analysis of Mechanical Properties of Glass Fibre with Pet Bottle Yarns Layer

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Abstract - This study investigates the mechanical properties and durability of a composite material comprising glass fibre reinforcement and polyethylene terephthalate (PET) yarns. The objective is to assess the feasibility of utilizing PET yarns as a reinforcing component alongside glass fibres in composite manufacturing. The research employs experimental methods to analyse tensile strength, flexural properties, and Tensile resistance of the composite material. Additionally, environmental testing is conducted to evaluate the composite's performance under various conditions, including moisture exposure and temperature fluctuations. The findings reveal synergistic effects between glass fibres and PET yarns, enhancing the composite's mechanical integrity and resilience to environmental stressors. This study contributes to advancing the understanding of composite materials and underscores the potential for integrating PET yarns in structural applications requiring lightweight, durable materials.

Keywords: PET, GFRP, Resin, Tensile strength, Numerical Analysis.

1.INTRODUCTION

The composite materials are used in many engineering applications due to their excellent properties. The sandwich composite materials replace the metals owing to their excellent strength with low weight. Many of the literature deals with the combination of steel or polyethylene terephthalate (PET) with the Glass Fiber Reinforced Polymers materials (GFRP). The carbon fiber finds application in aerospace and related fields. The cost of fabrication is reduced by using sandwich structures. The polyethylene terephthalate (PET) and glass fiber are used in order to form a excellent qualities such as overall reduced weight, corrosion resistance and environment friendly. The aircraft materials are developed based on polyethylene terephthalate which needs the improved crack growth properties. Competing materials like advanced polyethylene terephthalate (PET) alloys and fiber reinforced composites have potential to increase the cost effectiveness of the structure. Polyethylene terephthalate have hybrid composite structures based on thin sheets of metal alloys and plies of fiber reinforced polymeric materials. The concept is usually applied to polyethylene terephthalate (PET) with aramid and glass fibers, also it is applied to other constituents. Several articles have shown that, PETs possess both the wonderful tensile resistance characteristics of metals and the attractive mechanical properties of fiber reinforced composite materials.

2. Polyethylene Terephthalate (PET)

Polyethylene Terephthalate (PET) composed of several very thin layers of metal (usually polyethylene terephthalate (PET)) interspersed with layers of Glass-fiber Pre-preg, bonded together with a matrix such as epoxy. The Uni-directional pre-preg layers may be aligned in different directions to suit predicted stress conditions.

Fig -1: Polyethylene Terephthalate

2.2 Glass Fiber

Glass fiber (or glass fiber) is a material consisting of numerous extremely fine fibers of glass. Glass fiber is a lightweight, extremely strong, and robust material. Although strength properties are somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using molding processes.

Fig -2: Glass Fibre

2.3 Resin

Among them epoxies are one of the most common and widely used thermosets today in structural and specialty composites applications. Due to their high strength and rigidity (because of high degree of crosslinking), epoxy thermoset resins are adaptable to nearly any application. The term "epoxy", "epoxy resin", or "epoxide" (Europe), α-epoxy, 1,2-epoxy etc. refers to a broad group of reactive compounds that are characterized by the presence of anoxirane or epoxy ring. This is represented by a three-member ring containing an oxygen atom that is bonded with two carbon atoms already united in some other way.

2.4 Epoxy LY556

The Epoxy Resin LY 556 is extensively used as a reinforcing material due to its medium viscosity and chemicals resistivity. Property of this resin can easily be modified within wide limits with the use of fillers and hardeners. The composition of this resin is based on Bisphenol-A which makes it suitable for high-performance FRP composite applications such as pultrusion, pressure molding, filament winding and so on. Epoxy resin is known for exceptional mechanical, good fiber impregnation and thermal & dynamic properties. Also, the Epoxy Resin LY556 is having a low tendency to crystallize, that's why it is preferred for aircraft and aerospace adhesives.

2.5 Hardener HY951

Hardeners are almost always necessary to make an epoxy resin useful for its intended purpose. Without a hardener, epoxies do not achieve anywhere near the impressive mechanical and chemical properties that they would with the hardener. The correct type of hardener must be selected to ensure the epoxy mixture will meet the requirements of the application. Research should always be done on both the resin and the hardener to make sure the final epoxy mixture will perform satisfactorily. Common examples of epoxy hardeners are anhydride-based, amine-based, polyamide, aliphatic and cycloaliphatic. Hardeners are used to cure epoxy resins. However, simply adding a hardener to an epoxy resin may not cause the epoxy mixture to cure quickly enough. If this is the case a different hardener may be required. Also, hardeners with certain additives can be used. These hardener additives serve as catalysts that speed up the curing process.

2.6 Hand Lay-Up

In the hand lay-up process, the laminate structure, commonly a single continuous strand glass mat, a woven glass mat or an advanced composite mat is manually “hand- laid” in the mold. The catalyzed thermoset resin is introduced, and the materials are formed to fit the mold surface using a “roll-out” process, as well as a number of specialized laminating tools. Additional layers of reinforced mat can be added to key structural points to enhance rigidity and performance.

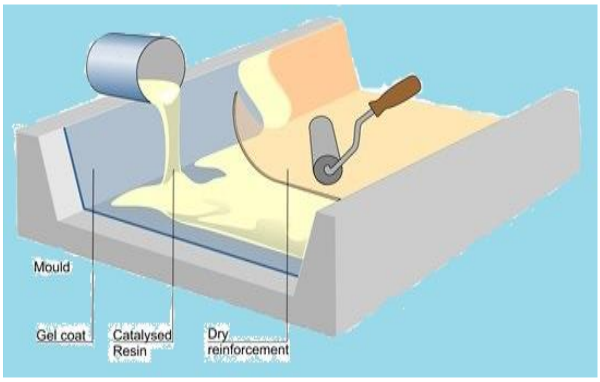

Fig -3 : **Hand Lay-Up**

2.7 Tensile Strength

Tensile strength is a critical property of materials that measures their resistance to being pulled apart under tension. It is a fundamental aspect in materials science and engineering, influencing the design and selection of materials for various applications. This discussion will cover the definition, measurement, significance, factors affecting tensile strength, and applications in different fields. Tensile strength, often referred to as ultimate tensile strength (UTS), is the maximum stress that a material can withstand while being stretched or pulled before breaking. It is typically expressed in units of force per unit area.

2.8 Flexural Strength

The most common test for flexural strength involves placing a rectangular beam of the material on two supports and applying a load at its center until it breaks. The setup typically involves:

For a rectangular beam subjected to three-point bending, the flexural strength (σ) can be calculated using the formula:

$$\sigma = 3PL/2bd^2$$

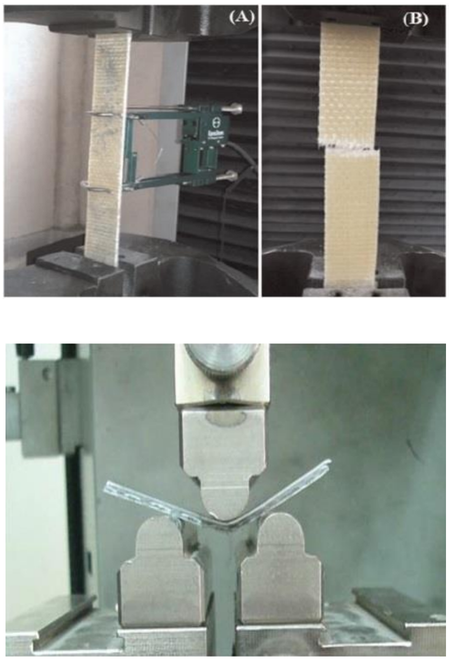

Fig -4 : **Test setup**

2.9 Experimental Result

Experimental results for tensile and flexural tests typically include several key parameters. Below is a summary of what these tests generally measure and how the results are presented.

2.10 Tensile Test

To determine the tensile strength, yield strength, and elongation of a material. The maximum stress that a material can withstand while being stretched or pulled before breaking. The stress at which a material begins to deform plastically. Once the yield point is passed, the material will deform permanently. The amount of strain (expressed as a percentage) a material undergoes before breaking. The ratio of stress to strain in the elastic deformation phase. A graphical representation of the relationship between stress and strain during the test.

Experimental Results (GFRP + PET)

Ultimate Tensile Strength (UTS): 8.829 MPa

Yield Strength (σy): 6.728 MPa

Elongation at Break: 3.7634%

Experimental Results (GFRP only)

Ultimate Tensile Strength (UTS): 6.867 MPa

Yield Strength (σy): 4.36 MPa

Elongation at Break: 3.169%

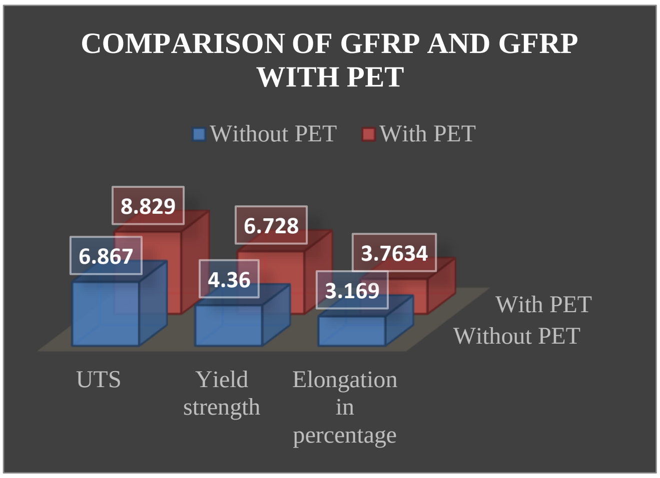

Fig -4 : **Experimental Result**

2.11 Flexural Test

To determine the flexural strength and stiffness of a material. The stress in a material just before it yields in a flexure test. The ratio of stress to strain in flexural deformation. The amount of deflection (bending) at the point of failure. The flexural strength indicates the material's ability to resist deformation under load, and the flexural modulus gives an indication of the stiffness.

Experimental Results (GFRP+PET)

Flexural Strength (σf): 0.6036 MPa

Flexural Modulus (Ef): 18.79 GPa

Deflection at Break: 0.501 mm

Experimental Results (GFRP):

Flexural Strength (σf): 0.4904 MPa

Flexural Modulus (Ef): 13.18 GPa

Deflection at Break: 0.491 mm

Table -1: Experimental Result of Tensile Test

Description	Deflection (mm)	Total Strain Energy (J)
GFRP with PET	0.03763	2.99 x E-5
GFRP without PET	0.03169	2.546 x E-5

Table -2: Experimental Result of Flexural Test

Description	Deflectionn (mm)	Total Strain Energy (J)
GFRP with PET	0.03763	2.99 X E-5
GFRP without PET	0.03169	2.546 X E-5

2.13 Ansys Software

Ansys develops and markets engineering simulation software for use across the product life cycle. Ansys Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analyzing strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. Most Ansys simulations are performed using the Ansys Workbench system, which is one of the company's main products. Typically, Ansys users break down larger structures into small components that are each modeled and tested individually. A user may start by defining the dimensions of an object, and then adding weight, pressure, temperature and other physical properties. Finally, the Ansys software simulates and analyzes movement. Fatigue, fractures, fluid flow, temperature distribution, electromagnetic efficiency and other effects over time.

2.14 Ansys Composite Prepost

ANSYS Composite PrePost (ACP) is a specialized tool within the ANSYS suite designed for the analysis of composite materials. It offers a range of features to model, simulate, and optimize composite structures. Here's a brief overview of its key capabilities Allows detailed definition of composite materials, including fiber, matrix properties, and layup sequences. Supports a wide range of material models for accurate simulation of anisotropic behaviors. Enables the creation and management of complex layup configurations. Supports ply stacking sequences, orientations, and thicknesses.Integrates with ANSYS Mechanical for structural analysis. Facilitates the setup of boundary conditions, loads, and other simulation parameters specific to composites. Provides tools for assessing failure criteria such as Tsai-Wu, Tsai-Hill, and Hashin. Helps predict failure modes and load-bearing capacities. Supports optimization of composite structures for weight, strength, stiffness, and other performance criteria. Utilizes design of experiments (DOE) and other optimization techniques.Offers extensive post-processing tools for visualizing stress, strain, and failure indices in composite components. Generates detailed reports and plots for better interpretation of results. Features an intuitive GUI tailored for composite material analysis. Provides a workflow-based approach for efficient model setup and analysis. ACP is widely used in industries such as aerospace, automotive, marine, and sports equipment, where high strength-to-weight ratios and tailored material properties are critical. It helps engineers design and analyse components like aircraft wings, car bodies, boat hulls, and sports equipment to ensure they meet stringent performance and safety standards.

2.15 GFRP With Pet Yarn

After the post processing the result of fiber metal laminates was obtained. In this single layer the minimum strain energy obtained is **6.1364 e^{-8}J** and the maximum strain energy obtained in the numerical analysis is **2.990 e^{-5}J** and total deformation was obtained **0.0376 mm**

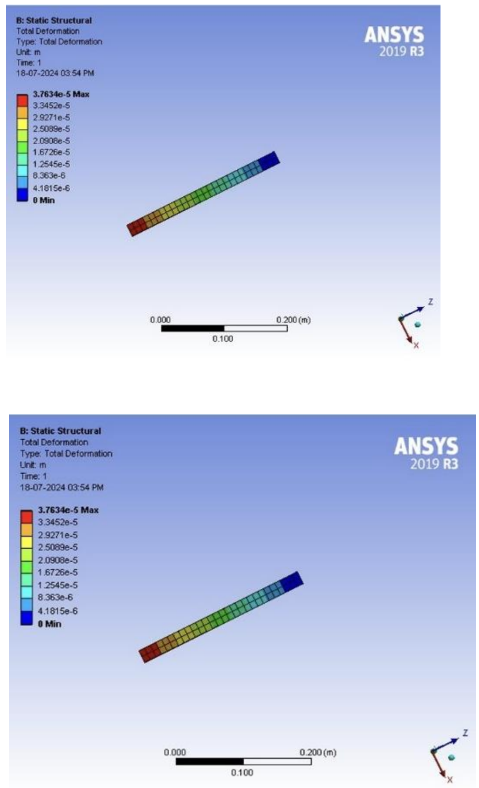

Fig -5: **Analysis work**

2.16 GFRP without PET

After the post processing the result of fiber metal laminates with single layer was obtained. In this single layer the minimum strain energy obtained is **3.914 e-9 J** and the maximum strain energy obtained in the numerical analysis is **1.727 e-5 J** and total deformation was obtained **0.0191 mm**.

2.17 Numerical Result

Finally, all the three combinations of fiber metal laminates with numerical result were tabulated and

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compare the all the three results. To validate the effect of increasing of GFRP Layers in the fiber metal laminates with the help of graphical representation drawned by number of layers and strain energy in J.

Description	Total Deformation in mm	Total Strain Energy in J
GFRP with PET	0.03763	2.99 X E-5
GFRP without PET	0.03169	2.546 X E-5

2.18 Result and Discussion

In summary, the incorporation of PET into GFRP composites enhances their mechanical performance, environmental resistance, and sustainability, making GFRP with PET a promising alternative for advanced engineering applications.

2.19 Results From Tesile Test

Table 7.1. Comparison of Total Deformation (mm)

Description	Theoretical Deformation	Numerical Result (ANSYS)
GFRP WITH PET	0.0929	0.0425
GFRP WITHOUT PET	0.0345	0.0191

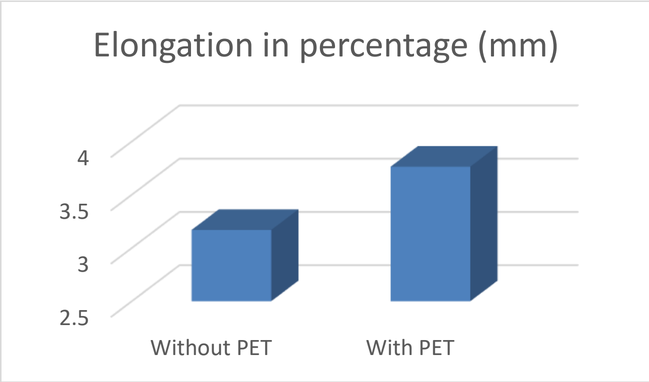

Fig-6 Comparison of Total Deformation

Table 7.2. Comparison of Strain Energy

Description	Experimental Result	Numerical Result (ANSYS)
	Total Strain Energy in J	
GFRP with PET	2.27 X E-5	2.99 X E-5
GFRP without PET	1.93 X E-5	2.546 X E-5

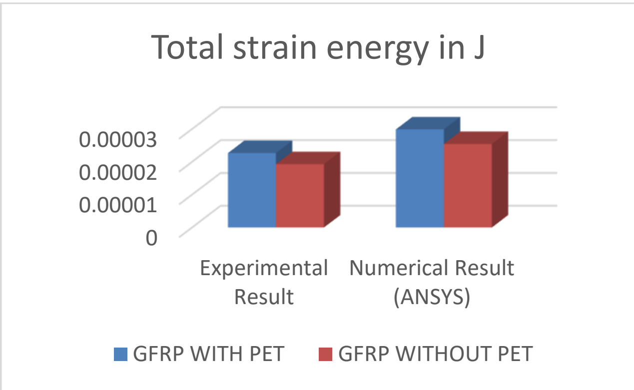

Fig-7 Comparison of Strain Energy

2.20 Results From Flexural Test

Table 7.3. Comparison of Total Deformation (mm)

Description	Theoretical Deformation	Numerical Result (ANSYS)
GFRP with PET	0.5732	0.5011
GFRP without PET	0.4867	0.4908

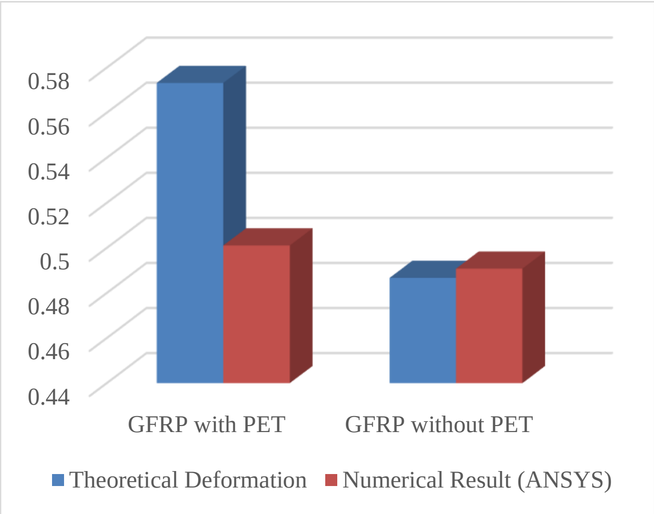

Fig-8 Comparison of Total Deformation (mm)

Table 7.4. Comparison of Strain Energy

Description	Experimental Result	Numerical Result (ANSYS)
	Total Strain Energy in J	
GFRP WITH PET	2.564X E-5	2.6188 X E-5
GFRP WITHOUT PET	2.733X E-5	2.6616 X E-5

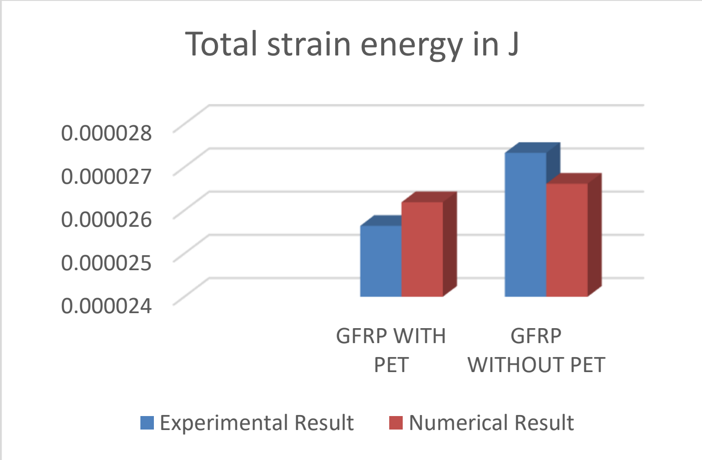

Fig-9 Comparison of Strain Energy

3. CONCLUSIONS

In recent studies comparing Glass Fiber Reinforced Polymer (GFRP) with GFRP enhanced with Polyethylene Terephthalate (PET), several key findings have emerged. GFRP, known for its high strength-to-weight ratio and excellent corrosion resistance, is a widely used material in various structural applications. However, integrating PET, a type of thermoplastic polymer, into GFRP composites has demonstrated potential improvements in mechanical properties and durability. The addition of PET fibers to GFRP has been shown to enhance tensile strength and impact resistance. This hybrid composite material benefits from the inherent flexibility and toughness of PET, which contributes to better energy absorption and damage tolerance. Moreover, the presence of PET can improve the composite's resistance to environmental degradation, including moisture and UV exposure, thus extending the material's lifespan in outdoor applications.

Furthermore, studies indicate that GFRP with PET exhibits better thermal stability compared to traditional GFRP. This makes it suitable for applications where temperature fluctuations are a concern. The synergy between GFRP and PET also results in a more sustainable material, as PET can be sourced from recycled plastics, aligning with environmental goals.

In summary, the incorporation of PET into GFRP composites enhances their mechanical performance, environmental resistance, and sustainability, making GFRP with PET a promising alternative for advanced engineering applications.

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