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(Research Article)

Analysis and optimization of tensile strength of glass epoxy laminates subjected to imposed forces

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Abstract

Glass-Reinforced Epoxy Laminate's robust strength, superior insulation qualities, and stability make it a significant material that is frequently utilized in electrical, electronic, and industrial applications. Glass fiber and epoxy resin are combined to create it. The mechanical strength of the finished product is directly impacted by the resin and orientation of laminate. This study investigated the effects of different orientation angle ($0/30/60/90/0^0$, $0/45/90/0^0$ and $0/30/45/60/90^0$) of lamina, different resin (Epoxy and Vinyl ester) and material is Glass epoxy sheet. Experimental studies of Epoxy shows higher hardness values and significantly greater tensile strength across all stacking sequences, indicating superior matrix–fiber bonding and more efficient stress transfer. For both binders, the 0/30/60/90/0° symmetric orientation provides the best performance, demonstrating that balanced multidirectional fiber alignment enhances structural integrity. As the orientation patterns become more irregular, a noticeable decline in both hardness and tensile strength occurs, highlighting the importance of stacking sequence in composite design.

Keywords: Glass-Reinforced; Epoxy; Vinyl ester; Orientation angle; Resin; Binder

1. Introduction

The significance of glass-reinforced epoxy laminate in electrical, electronic, and industrial engineering applications has been emphasized by numerous research. According to research, epoxy glass laminates are ideal for printed circuit boards, transformers, insulation systems, and structural elements because of their exceptional mechanical strength, electrical insulation, thermal stability, and resistance to moisture and chemicals. Fiber-reinforced composites offer improved strength-to-weight ratios and durability for industrial applications, claims Mallick (2007). According to Callister and Rethwisch (2018), epoxy glass laminates are frequently utilized due to their superior insulating qualities, corrosion resistance, and dimensional stability. The significance of FR-4 materials in the electronics sector was highlighted by IPC (2022) standards because of its flame resistance and dependable performance at high temperatures. Additionally, Agarwal, Broutman, and Chandrashekhara (2017) talked about how new production methods and material alterations might increase the performance of composite laminates.

The performance and sustainability of epoxy glass laminates have been the focus of recent research. In order to enhance mechanical and thermal qualities, Drenda et al. (2024) looked at hybrid epoxy-glass laminates that were altered with metal oxides and graphite particles. In order to increase fire resistance and structural performance, Wang et al. (2024) investigated flame-retardant glass fiber reinforced epoxy composites made employing cutting-edge resin infusion techniques. Furthermore, Anuse et al. (2024) investigated how graphene nano-platelets affected the impact and compression strength of glass fiber epoxy laminates, demonstrating a notable improvement in material performance. Additionally, hybrid glass and natural fiber reinforced epoxy composites with enhanced stability and lightweight

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properties were created by Raja et al. (2024). According to these studies, there is a growing need in contemporary engineering and industrial applications for high-performance, lightweight, and ecologically friendly laminate materials.

Table 1 Glass epoxy properties

Property	Description / Typical Value
Density	1.8 – 2 g/cm^3
Tensile Strength	300 – 500 MPa
Flexural Strength	400 – 550 MPa
Compressive Strength	340 – 450 MPa
Dielectric Strength	14 – 26 kV/mm
Water Absorption	Very low
Thermal Resistance	Up to 130 °C – 180 °C

1.1. Experimental work and sample Preparation

To determine the strength and deformation behavior of glass epoxy sheet materials under tensile or pulling loads, tensile testing is a crucial mechanical test. In this test, a glass epoxy laminate specimen is put in a Universal Testing Machine (UTM) after being prepared in accordance with specified dimensions, typically in accordance with ASTM testing standards. After that, a progressively greater tensile stress is applied to the specimen until it fails. The dimensions of the specimen are illustrated in the following graphic.

Table 2 Constant parameters

Sr. No	Constant parameters	
1.	Sheet material	Glass epoxy
2.	Sheet dimension	25mmx150mmx2mm

The mechanical, thermal, and electrical characteristics of the laminate are also significantly influenced by the binder. Tensile strength, impact resistance, dimensional stability, and insulating performance are all improved by a strong link between the epoxy resin and glass fibers. The binder aids in the correct impregnation of glass fiber layers during production and, when curing under pressure and heat, makes a firm laminate. In this research two binders are used.

Table 3 Process parameters and their levels

Parameter		Level 1	Level 2	Level 3
1	Binder	Epoxy	Vinyl ester	-
2	Orientation angle	0/30/60/90/0^0	0/45/90/135/0^0	0/30/45/60/90^0

The arrangement and direction of the reinforcing fibers inside the epoxy matrix is referred to as the orientation of glass fibers in a glass epoxy sheet. The mechanical strength, stiffness, impact resistance, and general performance of the laminate material are all significantly influenced by the orientation of the fibers. The alignment of the fibers during the production process determines the characteristics of the glass epoxy sheet. In this research three type of orientation of angle is used.

The mechanical and structural performance of glass epoxy sheet materials is significantly influenced by the parametric combination of resin and fiber orientation angle. The orientation angle of the glass fibers determines the direction of weight carrying capabilities in composite laminates, while epoxy resin serves as the binder or matrix material. Researchers can examine the combined effects of resin composition and fiber orientation angle on the laminate's tensile strength, stiffness, impact resistance, and durability. Following table shows the parametric combination of orientation angle with different binder.

Table 4 Parametric combinations

Sr. no	Binder	Orientation angle
1	Epoxy	0/30/60/90/0^0
2	Epoxy	0/45/90/135/0^0
3	Epoxy	0/30/45/60/90^0
4	Vinyl ester	0/30/60/90/0^0
5	Vinyl ester	0/45/90/135/0^0
6	Vinyl ester	0/30/45/60/90^0

One of the most straightforward and widely used production techniques for glass epoxy composite laminates is the hand lay-up process. Using brushes or rollers, layers of glass fiber sheets or mats are manually positioned on a mold surface and impregnated with epoxy resin. The technique is popular because it is inexpensive, requires little equipment, and can be used to create composite pieces of many sizes and shapes. Experimental set-up of hand layoff technique is as shown in Figurer1. In the present work glass epoxy sheet of 25mmx150mm has been used as specimen. In the process of making composites, resin and hardener are combined to start the curing process, which turns the liquid resin into a robust solid matrix surrounding reinforcement fibers like carbon or glass fiber. The hardener serves as a curing agent by reacting chemically with the resin, which serves as the primary binding element. Because incorrect mixing might result in weak, brittle, or uncured composites, it is crucial to mix them according to the manufacturer's recommended ratio. For a consistent blend and to prevent air bubbles, the mixture should be slowly and properly mixed. The resin system must be applied to the composite material before hardening starts since it has a finite working duration, known as pot life, after mixing. In order to create lightweight and very durable composite structures, this process is frequently employed in manufacturing techniques like hand lay-up, vacuum bagging, and resin infusion.

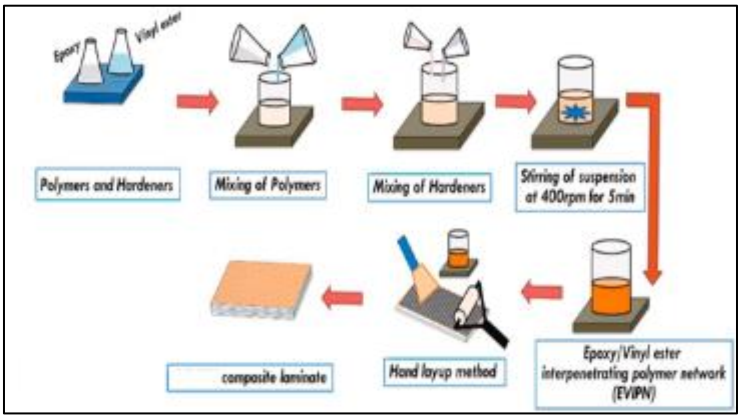

Figure 1 Steps for Making Composite Material

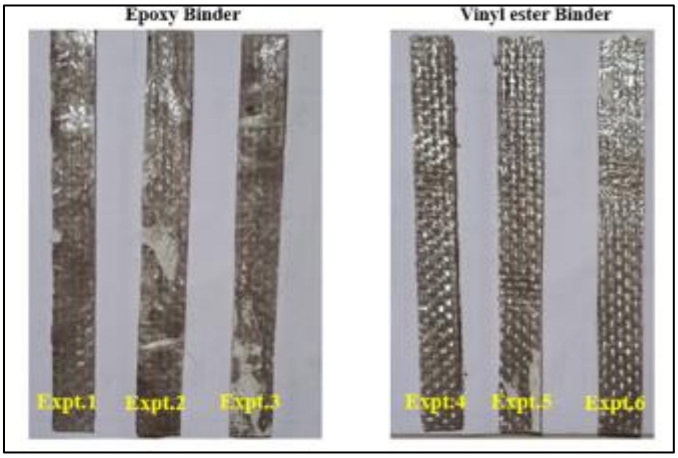

Figure 2 Glass epoxy sample with different binder

Tensile testing of glass epoxy material is done using a Universal Testing Machine (UTM) to ascertain its mechanical characteristics, including elongation, Young's modulus, and tensile strength. This test involves fixing a glass epoxy specimen between the UTM's grips and applying a progressively higher tensile load until it fractures which is as shown in figure 3. In order to calculate stress and strain, the machine records the load and deformation. Glass epoxy composites typically have brittle failure, high strength, and lightweight properties.

Figure 3 Tensile test setup

2. Result and Discussion

In table 5, the tensile characteristics at different orientation of epoxy and vinyl ester composites are summarized. For the test, a total of twelve specimens are tested.

Table 5 Result of tensile strength

Sr. no	Binder	Orientation angle	Avg. reading tensile strength MPa
1	Epoxy	$0/30/60/90/0^0$	370
2	Epoxy	$0/45/90/135/0^0$	359
3	Epoxy	$0/30/45/60/90^0$	278
4	Vinyl ester	$0/30/60/90/0^0$	295
5	Vinyl ester	$0/45/90/135/0^0$	253
6	Vinyl ester	$0/30/45/60/90^0$	215

According to the results of the tensile test, glass epoxy composites outperform vinyl ester composites in terms of tensile strength across all fiber orientation angles. The epoxy binder with a 0/30/60/90/0° orientation had the highest tensile strength of 370 MPa, while the vinyl ester binder with a 0/30/45/60/90° orientation had the lowest value of 215 MPa. The findings show that the binder type and fiber orientation have a major impact on the composite material's tensile behavior.

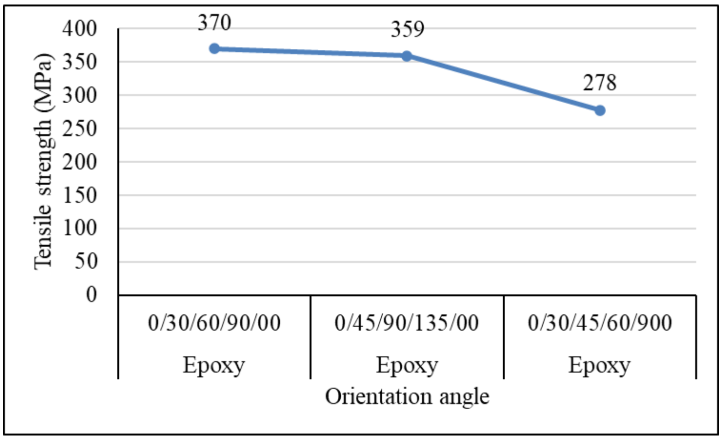

Figure 4 Tensile strength for Different Orientation Angles with epoxy binder

The graph shows how glass fiber reinforced epoxy composites' tensile strength varies for various fiber orientation angles. Due to improved fiber alignment in the direction of applied load, the composite with the 0/30/60/90/0° orientation had the maximum tensile strength of 370 MPa among the evaluated samples, showing outstanding load-bearing capabilities. The slightly decreased tensile strength of 359 MPa in the 0/45/90/135/0° orientation may be the result of a shift in fiber direction that reduces stress transmission efficiency. Due to the fibers' uneven load distribution and reduced resistance to tensile stresses, the 0/30/45/60/90° orientation had the lowest tensile strength of 278 MPa.

The findings show that epoxy-based composites have better tensile qualities than vinyl ester composites. Stronger connection between the glass fibers and matrix is made possible by epoxy resin, which enhances stress transfer and increases mechanical strength. Additionally, it is clear that fiber orientation has a big impact on the composite material's tensile performance. Strength and stiffness are increased when fibers are oriented correctly; tensile performance is decreased when fibers are oriented randomly or in a wide variety. Thus, boosting the structural efficiency of composite materials used in engineering, automotive, marine, and aerospace applications requires choosing the right fiber arrangement.

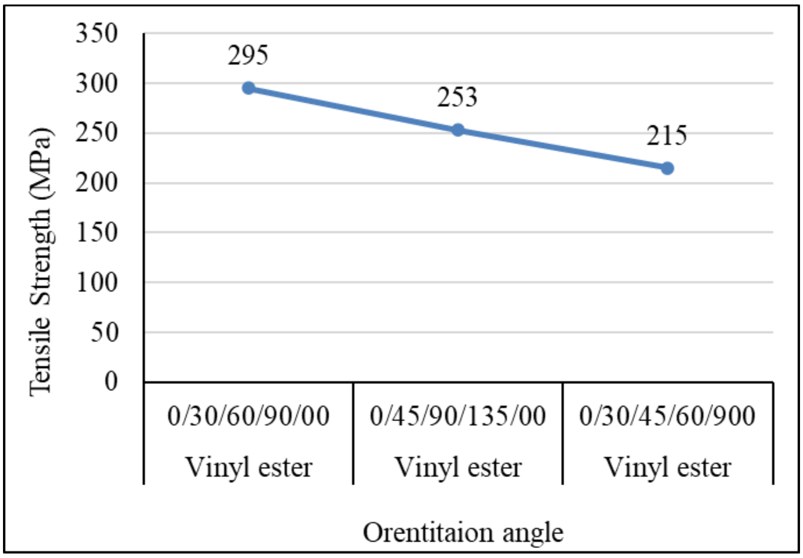

Figure 5 Tensile strength for Different Orientation Angles with vinyl ester binder

The graph shows how fiber orientation affects vinyl ester glass fiber reinforced composites' tensile strength. It is evident that as the fiber orientation sequence changes, the tensile strength gradually declines. With a tensile strength of 295 MPa, the composite with the 0/30/60/90/0° orientation demonstrated superior load distribution and stronger fiber alignment along the loading direction. Due to variations in fiber angles, which decreased the fibers' direct load-carrying efficiency, the specimen with the 0/45/90/135/0° orientation displayed a moderate tensile strength of 253 MPa. Due to greater angular variation and uneven stress transfer between fibers and matrix, the 0/30/45/60/90° orientation had the lowest tensile strength (215 MPa), indicating a lower resistance to tensile loading.

The findings unequivocally show that the mechanical performance of vinyl ester composites is significantly influenced by fiber orientation. While uneven orientation lowers the material's overall strength, good fiber alignment increases tensile characteristics and stress distribution. These results are crucial for the design of composite materials used in structural, automotive, aerospace, and marine applications that call for high tensile strength and lightweight qualities.

3. Conclusion

It can be concluded from the tensile strength graphs of epoxy and vinyl ester glass fiber composites that the binder type and fiber orientation have a substantial impact on the material's tensile characteristics. Because of the stronger link between the glass fibers and the epoxy matrix, epoxy-based composites outperformed vinyl ester composites in terms of tensile strength across all orientation angles. With epoxy exhibiting 370 MPa and vinyl ester exhibiting 295 MPa, the 0/30/60/90/0° orientation yielded the best tensile strength in both binders. Due to uneven stress distribution and lower load transfer efficiency, the tensile strength steadily dropped as the fiber orientation shifted to increasingly variable angles. As a result, the mechanical performance of glass fiber reinforced composites is enhanced by appropriate fiber alignment and the use of epoxy resin, making them more appropriate for structural and engineering applications.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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