Prabha Materials Science Letters
Vol. 3, No. 2, 175-190, 2024
https://doi.org/10.33889/PMSL.2024.3.2.011

Ram Arti Publishers

Effect of the Glass Fiber Orientation on Mechanical Performance of Epoxy based Composites

Neelam Mishra
Department of Mechanical Engineering,
Shambhunath Institute of Engineering and Technology, Prayagraj, 211015, Uttar Pradesh, India.
E-mail: neelumishra2012@gmail.com

Ubaid Ahmad Khan
Department of Mechanical Engineering,
Shambhunath Institute of Engineering and Technology, Prayagraj, 211015, Uttar Pradesh, India.
E-mail: uk.mnit@gmail.com

Anshuman Srivastava
Department of Mechanical Engineering,
Shambhunath Institute of Engineering and Technology, Prayagraj, 211015, Uttar Pradesh, India.
E-mail: anshuman0203@gmail.com

Nidhi Asthana
Department of Physics,
Babasaheb Bhimrao Ambedkar University, Lucknow, Uttar Pradesh, India.
Corresponding author: asthananidhi27@gmail.com

(Received on April 1, 2024; Revised on May 6, 2024; Accepted on May 13, 2024)

Abstract
Composites are one of the most advanced and adaptable engineering materials. The strength of any composite depends upon the volume/weight fraction of reinforcement, orientation angle and other factors. The present work focuses on the determination of the mechanical properties of pure epoxy and unidirectional glass fiber reinforced epoxy. Nowadays, glass fibers are being used in several engineering applications like electronics, aviation, automobile, sport industry etc. Glass fibers are having excellent properties like high strength, flexibility, stiffness, and resistance to chemical attack. With an increase in the content of unidirectional glass fiber volume the properties of unidirectional glass Fiber Reinforcement Polymer (GFRP) composite were improved. It may be used in different forms like chopped, woven mat, short fibers and long fibers etc. Each type of glass fiber has unique properties and is used for different applications. The mechanical and thermal properties of various polymer composites reinforced with glass fibers when subjected to mechanical loading have been studied and reported.

Keyword- Composite, Glass fibers, Epoxy, Tensile strength.

1. Introduction

A composite refers to a blend of two or more elements having various macroscopic or microscopic physical/chemical properties (EI-Assal and Khashaba, 2007; Srivastava, 2012; Torabizadeh, 2013; Sathishkumar et al., 2014; Adekomaya and Adama, 2017). Fibers and matrices are the constituents of composites. The categorization of composite materials involves considering the shapes of reinforcing particles, flakes, and fibers, as well as the matrix polymers and metals, including carbon. The fundamental aim of the composite is to maximize its material qualities, specifically by augmenting the characteristics of the matrix through the incorporation of a reinforcing phase. The primary weight-carrying components are fibers, while the surrounding matrix aids in maintaining their proper position and orientation as well as serving as a load transfer medium (Bhat et al., 1994; Harizi et al., 2014; Sikarwar et al., 2014). The arrangement of fibers within the matrix has a significant impact on the useful qualities of fiber reinforced composites. Properties associated with this design include the volume percentage, fiber aspect ratio, specifications for fiber spacing, and fiber orientation angles. Thermoplastic composites, reinforced with long fibers, short fibers, and mat (fabric) made of natural and synthetic fibers like hemp, jute banana, glass, carbon, and Kevlar, among others, are used in a variety of applications such as aerospace elements, automotive parts, marine structures, structural members, and anti-vibration devices (EI-Habak, 1991; Ferdous et al., 2020). This is due to their combination of resilience, creep resistance, high strength to weight and stiffness to weight ratios and corrosion resistance. Owing to the inherent advantages of composites compared to conventional materials such as metals, their application in designing numerous technical and structural components has seen a significant increase in the last decades. Numerous researchers have examined the tensile, flexural, toughness, fatigue, and other mechanical properties of FRP composites analytically and experimentally. Additionally, some researchers have employed finite element modelling to anticipate the mechanical properties of FRP (Yuanjian and Isaac, 2008; Erden et al., 2010; Karakuzu et al., 2010). When the fiber and matrix function independently, they fail to synergize and offer the composite properties derived from two or more materials. Over many years, fiber-reinforced composites were successfully utilized in various technical applications. The most widely utilized material for producing composites was glass fiber-reinforced polymeric composites (GFRP). Organic, polyester, thermostable, vinyl ester, phenolic, and epoxy resins made up the matrix. When the fiber and matrix function independently, they fail to synergize and offer the composite properties derived from two or more materials (Chandra et al., 1999; Ghassemieh and Naseehi, 2001; Kaw, 2006; EI-Assal and Khashaba, 2007). Over numerous years, fiber-reinforced composites found successful applications in various technical fields. Glass fiber-reinforced polymeric (GFRP) composites emerged as the most extensively used material in composite production. The matrix components comprised organic, polyester, thermosetting, vinyl ester, phenolic, and epoxy resins.

The two main categories of polyester resins are isophthalic and biphenolic. The mechanical performance of a fiber-reinforced composite depends largely on factors such as the strength and modulus of the fibers, chemical stability, strength of the matrix, and the bonding at the interface between the fiber and matrix, which aids in stress transmission. The intended physical and functional characteristics of GFRP composites matched those of steel, exhibited higher stiffness than aluminums, and should have a specific gravity one-fourth to that of steel, all attributed to the precise compositions and fiber orientations employed (Chou and Ko, 1989; Jones, 2018). To enhance the mechanical and tribological characteristics of composites, different GF reinforcements have been developed such as long, longitudinal, woven mat, chopped fiber (distinct), and chopped mat.

The properties of the composites are dictated by the fibers deposited or laminated in the matrix during the preparation process. The high cost of Polymers is a great barrier for their adoption in commercial applications. The incorporation of fillers will enhance the attributes of composites. Laminated GF reinforced composite materials find application in the maritime sector and piping industries due to its high specific strength and stiffness, exceptional damage tolerance for impact loading, and broad range of industrial applications (Ghassemieh and Naseehi, 2001; Erden et al., 2010; Aramide et al., 2012; Lopez et al., 2012). Owing to their lightweight nature, heightened resistance to fastener fatigue, and versatility in component quantity, polymeric composites have been predominantly utilized in the aircraft industry for elements such as rudders, elevators, fuselages, and landing gear doors. Polyester matrix-based composites have found widespread use in marine applications. In the marine industry, the degradation of polymer composites was significantly influenced by water absorption (Alam et al., 2010; ASTM-D3039). Various mechanisms, such as initiation, propagation, branching, and termination, were employed to identify the material degradation. For the mentioned applications, epoxy resins are frequently employed because of their great chemical and corrosion resistance and low shrinkage during the curing process. The high degree of cross-linking in epoxy resin networks and their ability to be cured under various conditions contribute to the formation of a brittle material. When composites were exposed to a vibratory environment, the crucial factor for composites was the dissipation of energy (Sanjay et al., 2014). The energy dissipation of FRP composites was influenced by a number of variables, including fiber volume, orientation, matrix material, temperature, moisture etc. The temperature sensitivity is evident in the mechanical characteristics of polymeric composites. To assess these traits in diverse temperature scenarios, a thorough comprehension of the dynamic stability of polymer matrix composites is imperative, with a focus on parameters such as storage modulus and damping effects. Damping was assessed through four distinct methods, encompassing both time domain and frequency domain techniques. Time domain methodologies comprised Hilbert transform analysis and logarithmic decrement analysis, whereas frequency domain approaches encompassed moving block analysis and the half-power bandwidth method (Hsiao and Daniel, 1998; Avci et al., 2004; Husic et al., 2005; Putic et al., 2009). The composites were subjected to a range of tribological actions, involving sliding, rubbing, and rolling interactions with both other materials and their own components. Evaluating the tribological performance involved considering factors like load, sliding distance, duration of sliding, sliding speed, and specific sliding conditions (El- Sobanty et al., 2004; Husic et al., 2005; Putic et al., 2009). The incorporation of fillers proved effective in achieving an optimal wear rate and coefficient of friction within the GFRP matrix. Composite materials have been successfully applied in diverse tribological components, including bearings, gears, wheels, and bushes. The adoption and application of Fiber Reinforced Polymer (FRP) composites are on the rise, thanks to their outstanding durability, impressive strength-to-weight ratio, excellent resistance to environmental factors, and versatile design possibilities (Avci et al., 2004).

Recently, the use of FRP, particularly Glass Fiber Reinforced Polymer (GFRP), has extended to include various applications in civil construction. This includes, but is not limited to, bridge girders, bridge decks, space frames, retaining walls, and railway sleepers. Frequently subjected to repetitive loading, these constructions encounter challenges like matrix cracking, fiber/fiber de-bonding, and fiber/matrix fracture, which can result in a gradual deterioration of their performance. Emphasizing the endurance of composite structures under sustained loads, Manalo et al. highlighted the importance of these structures being capable of withstanding such demands throughout their service life. In the realm of civil infrastructure, the design considerations for FRP often prioritize serviceability over sheer strength. Thus, to guarantee the safety and integrity of composites over their intended design lifespan, it is crucial to have a thorough understanding of how repetitive loading influences structural performance. Due to their heightened specific strength and stiffness, Fiber Reinforced Polymer (FRP) composites are frequently utilized in structural roles, including ship hulls, airframes, and components for wind turbines. The components of these structures are regularly subjected to diverse forms of tensile loads, featuring both constant and fluctuating amplitudes. As a result, besides having robust static mechanical properties, these composite materials must also demonstrate relatively high tensile strength, impact resistance, and fracture toughness. This ensures the secure and efficient operation of the structure over its intended technical lifespan. The predominant engineered composite materials in use today primarily involve continuous carbon or glass fibers strengthened by an epoxy polymeric matrix. Through polymerization, epoxy transforms into a densely cross-linked, amorphous material. The microstructure of the epoxy polymer imparts numerous advantageous traits, including a high modulus, failure strength, and low creep. Nevertheless, it introduces an undesirable characteristic in the form of relative brittleness.

It is evident that these less favorable fracture traits have the potential to impact the overall tensile and fracture performance of Fiber Reinforced Polymer (FRP) composites (Naik, 1994; Ramzan and Ehsan, 2009). Tensile failure is a frequently observed mode of failure in laminated composite materials, particularly in many Fibers Reinforced Polymer (FRP) components. When weight is a crucial factor, designers turn to reinforced polymers. However, excessive design allowances to mitigate tensile failure can lead to added weight, undermining the original design intent. Hence, conducting a comprehensive analysis of the tensile failure behavior of the laminate intended for use in the component is essential.

2. Unidirectional Glass Fiber Mat

When a substantial portion of the fibers align in a single direction, the fabric is termed as unidirectional (UD). Introducing a small section of fibers or other material in an opposing direction, while it may provide structural benefits, serves primarily to secure the main fibers in place. While some producers of 0/90° fabric reserve the term "unidirectional" for fabrics with over 90% of the fiber weight in one direction, others apply the term to fabrics with just 75% of their weight in one direction. Weft UDs may position their main fibers at 90° to the roll length, unlike warp UDs, which typically orient them in the 0° direction (along the roll). Genuine unidirectional fabrics allow for the precise positioning of fibers within a component, ensuring they are placed exactly where needed and in the optimal quantity—neither more nor less than required. Furthermore, unidirectional (UD) fibers in these fabrics maintain their straight and uncurled form, maximizing the fiber properties for the manufacture of composite components. Regarding mechanical qualities, only prepreg unidirectional tape, which secures the unidirectional fibers without additional material, can surpass the performance of unidirectional fabrics. In these prepreg products, the resin system serves as the sole element responsible for holding the fibers in place.

3. Matrix

The term "matrix" refers to the principal phase known for its continuous nature. Usually softer and more ductile, the matrix falls into one of the three fundamental material categories: metals, ceramics, or polymers. It forms the predominant component.

3.1 Reinforcement

In a non-continuous configuration, the secondary phase is integrated into the matrix in two ways: particle-reinforced (either randomly distributed or with a specific orientation) and fiber-reinforced (either continuous or discontinuous, aligned, or randomly distributed). This dispersed phase, known as reinforcement, typically possesses greater toughness and strength than the continuous phase. It plays a vital role in improving the overall mechanical properties of the matrix and fortifying the composites. The strength of FRP/composites is predominantly influenced by the type, amount, and arrangement of the fiber reinforcement.

3.2 Glass Fiber

A fiber is a broad term encompassing any polymer, metal, or ceramic material drawn into a lengthy, slender thread. Commonly used reinforcements include glass, carbon, and aramid fibers. Glass fiber stands out as the primary reinforcing material for polymer matrix composites, valued for its cost-effectiveness, ease of manufacturing, and high stiffness and strength properties. Despite additional benefits like low density, chemical resistance, and insulation properties, glass is prone to breakage under prolonged exposure to high tensile stress. It remains resistant to breakage at higher stress levels for shorter durations. This characteristic diminishes the effective strength of glass, particularly when consistently bearing loads over extended periods. Tolerance levels of glass fibers are also influenced by factors such as loading time, temperature, moisture, and others. The study investigated the behavior affected by the temperature characteristics of the material, particularly in G11 laminated composites woven from glass fibers. The matrix was composed of epoxy resin, and unidirectional glass fibers were used as reinforcement. Unidirectional laminates were created through hand laying and were cured at room temperature for seven days before undergoing chopping. Tensile, compressive, and shear tests were performed on the unidirectional laminates at room temperature and lower temperatures.

The results indicated that both the tensile strength and Young's modulus of the laminates increased until reaching the point of breakage as the temperature decreased. Furthermore, brittleness increased rapidly at temperatures below freezing. This phenomenon was attributed to the interaction between the fibers and the matrix. Unidirectional laminates demonstrated insufficient curing under lower temperatures, especially in compressive stress, and this behavior was associated with the deformation of the polymeric matrix due to plasticity. In-plane shear stress measurements exhibited notably erratic behavior across all temperatures, with a slightly nonlinear relationship between shear stress and strain. Catastrophic failure consistently manifested in the ultimate stage, underscoring the intricate interaction within the fibers and matrix. As outlined by scientist, their investigation concentrated on analyzing the movement and material properties of glass fiber-reinforced composites under stationary and low ambient conditions. The study investigated how temperature characteristics affected the behaviour, particularly in G11 laminated composites made of glass fibres. The reinforcement was in the form of unidirectional glass fibers, and the matrix was epoxy resin.

The hand-laying method was used to create the unidirectional laminates, which were then allowed to cure for seven days at room temperature before being cut. These unidirectional laminates underwent several tests at room temperature and at lower temperatures, including tensile, compressive, and shear evaluations. The results showed that the laminates' tensile strength and Young's modulus increased until a breaking point was reached at a decreasing temperature. Furthermore, brittleness—which is related to the interaction between the fibers and the matrix—increased quickly at temperatures below freezing. Under lower temperatures, the unidirectional laminates showed inadequate curing, particularly in compressive stress, and this behaviour was linked to plasticity-related deformation of the polymeric matrix. Shear stress and strain showed a slightly nonlinear correlation, and in-plane shear stress measurements showed noticeably erratic behaviour at all temperatures. Catastrophic failure was always evident in the final phase, indicating the intricate relationship between the fibers and matrix. Sathishkumar et al. (2014) paper from three years ago states that glass-fiber-reinforced polymer composites were the focus of the investigation. The study investigated the mechanical, thermal, water absorption, and vibration properties of various glass-fibre-reinforced polymers (GFRP) and used a variety of processing technology procedures.

A range of production techniques, such as matrix blending, hydraulic presses, compression moulding, hot press techniques, and manual lay-up procedures, were used to create GFRP composites. The peak flexural strength and the tensile strength were measured at a 25% fiber volume fraction. The highest impact strength was observed at a 0% volume fraction of fiber. Curing pressure exhibited an increase with a nonsymmetrical arrangement, whereas a symmetric design led to a reduction in curing pressure. The flexible strain of the composites increased up to a 0.26 volume fraction with glass fiber and subsequently decreased with further increments in fiber volume fraction. The elastic modulus of the composite also rose with the glass fiber volume fraction. These properties were compared to those of steel and other composite materials using tensile and shear stresses. The investigation noted that an increase in the concentration of oligomeric siloxane resulted in higher natural frequencies for glass fiber-reinforced composites. According to Adekomaya and Adama (2017), their study delved into the impact of fiber loading on the tensile and impact strength of polymeric composite materials. A crucial aspect highlighted in their research is that both fiber loading and fiber direction dictate the characteristics of the composite. The study affirms that fiber loading affects the mechanical and corrosion-resistant properties of reinforcement composites, along with the stability of polymer composites. Moreover, raising the percentage of fiber volume in Glass Fiber Reinforced Polymer (GFRP) composites enhances strength and stiffness attributes.

In addition to the mechanical properties, an increase in the volume of fiber percentages improves the thermal conductivity of the composite material by 10% weight. During their experiments, manual lay-up techniques were utilized to produce fiber-reinforced composites, using woven E glass as the reinforcing material for epoxy resin (Ampreg-21). Five different composite sheets were generated, incorporating varying levels of fiber enhancement, and the resulting properties were influenced by the different ratios of loadings and orientations of the fibers. It was noted that irrespective of their orientation, an augmentation in fiber volume correlated with an increase in impact strength, providing a meaningful indication of the directional effect. According to El-Assal and Khashaba (2007), the research focused on examining the fatigue performance of glass-fiber-reinforced polymer composites exposed to combined bending and torsional loads under ambient temperature conditions. A thorough series of fatigue tests, specifically in torsion, was conducted to develop a failure model for glass-fiber composites using diverse failure theories. The study encompassed the analysis and comparison of data from pure tensile and fatigue tests with the Stress Amplitude Number (SAN) curves obtained. When compared to experimental results regarding pure bending fatigue strength, the findings suggested that unidirectional glass-fiber-reinforced polyester composites display reduced torsional fatigue strength. An increase in the fiber volume was noted to result in a higher number of stress cycles. The failure curves derived from the experimental data closely match the predictions at different cycles, furnishing valuable insights for designers.

Harizi et al. (2014) conducted a study utilizing passive laser thermography techniques to investigate the damage and thermomechanical performance of glass-fiber-reinforced polymer composite materials subjected to static tensile loads. Their research centered on a cross-ply glass fiber-reinforced polymer laminate created through 0/90 hand lay-up, employing sheets of E glass type fibers in the unidirectional orientation. Utilizing the CEDIP JADE III (MW) IR camera, they captured infrared radiation to observe the response of composite materials under elevated temperatures. This facilitated the generation of thermal maps, offering a detailed characterization of damage in the material, especially in mechanical components exposed to static loads of varying amplitudes. This parameter aids in identifying the state of material damage.

The research comprised an experimental evaluation and investigation of composite materials 275 reinforced with glass fiber under mechanical loads employing FEA software. The emphasis was on creating the front end for two-wheelers, utilizing materials composed of glass fiber and epoxy resin. Performance predictions under diverse mechanical loading scenarios were compared to those of steel axles. The experimental data for specific mechanical properties were subsequently compared with FEA data using ANSYS-R15. The pultrusion method was utilized in the fabrication of the composite wheel axle, which underwent testing for tensile strength, bending, impact resistance, and fatigue. The results were analyzed using FEA software and compared to those of traditional steel axles. Notably, the composite axle demonstrated superior performance in impact and fatigue tests, resulting in a substantial weight reduction of approximately 64% when replacing mild steel shafts with composite counterparts. While the tensile strength of the composite axles decreased, the impact strength and flexural strength increased.

As detailed by Sikarwar et al. (2014), they conducted an analysis on the influence of fiber orientations and thicknesses when incorporating glass-fiber-reinforced polymers in composite components, particularly those prone to impact conditions. The study aimed to evaluate the laminates' energy absorption capacity and establish their ballistic limit. The experiments involved an air cannon and a robust 9.5 mm diameter cone projectile weighing 7.5 g. To create the composite laminates, a combination of fiber-woven glass cloth and epoxy resin was employed. In experiments simulating the ballistic limit, a gas piston powered by pressurized air launched the projectile at various angles and velocities. Projectiles of different thicknesses and fiber orientations were fired to investigate the effects of thickness on the glass/epoxy laminated surface.

While the projectile created an indentation in the plate at slower speeds, it did not penetrate. Regarding the modulus of elasticity at higher strain rates, both experimental and mathematical analyses indicated that glass/epoxy composites displayed greater consistency and a more favorable response to impact loading. Increasing projectile speed resulted in a reduction in the damage area at velocities above the ballistic range. The laminates' ability to absorb energy and their ballistic limit increased with the growth of dynamic Young's modulus and failure strain.

According to Bhat et al. (1994), their study focused on the development of fatigue-fracture within composite components, influenced by various breakdown techniques, each contributing uniquely to the damage. These breakdown techniques provide a means to monitor and assess the progression of damage as it occurs. The experiments demonstrated the capability to identify and mitigate three distinct fault mechanisms leading to damage at specific locations. El-habak (1991) conducted a study on how the geometrical makeup of composite materials influences their structural properties, particularly emphasizing impact properties on woven fabric composites.

Instrument-based Izod and Charpy investigations were carried out on these composite materials. Scientist conducted a study on the effects of stress levels, concentrated stresses, and fatigue endurance of Glass Fiber Reinforced Polymer (GFRP) composites using GFRP composite laminates as test materials. The tests included static tensile tests and fatigue tests at various loads, amplitudes, and frequencies on an MTS machine to assess the final strength, tensile, and rigidity for each sample. Erden et al. (2010) studied the mechanical properties of woven roving E-GF-reinforced unstable composites of polyester using the matrices change method. They introduced oligomeric siloxane into the polyester resin at levels of 1%, 2%, and 3% wt. The mechanical characteristics of the polyester resin, such as inter-laminar shear, bending and tension strength, young modulus, and vibration values, improved with the addition of oligomeric siloxane. The glass/polyester composite with a 3% weight percent oligomeric siloxane showed improved mechanical performance compared to other combinations.

Yuanjian and Isaac (2008) conducted a study on the low-velocity impacts and tensile breakdown properties of glass fiber-reinforced polyester composite using two fiber geometries, at 42% wt for fiber and [0/90] at 47% wt for fiber. The tensile strength and stiffness dropped as the impact energy increased, and fatigue analysis revealed longer fatigue lives at lower impact energy. Karakuzu et al. (2010) investigated the behavior of impact on unidirectional E-glass epoxy plate composites with stacked orders of [0/30/60/90]. The study involved various impact energies and masses, demonstrating that for the same impact energy, a sample treated with the same mass could absorb less energy than a specimen subjected to equal velocity. EI-Assal and Khashaba (2007) studied the fatigue behavior of unidirectional glass fiber-reinforced orthophthalic polyamide matrix composite under ambient temperatures with torsion and combination flexural force. Different fiber volume fractions (Vfs) were used, indicating that as fiber Vf increased, the quantity of stress cycles and stress magnitude also increased, with the torsional fatigue toughness being less than the bending fatigue strengths in the composite specimen.

4. Experimental

4.1 Materials

In this research, the composite material utilized for manufacturing incorporated a unidirectional glass fiber fabric with a thickness of 0.3mm as the reinforcing element. The experimental setup involved the use of unidirectional glass fiber with a grade of 400gsm. Unidirectional glass fiber is characterized by being lightweight, highly robust, and powerful. While its strength properties are comparatively lower than carbon fiber, and it is less rigid, it typically exhibits significantly reduced brittleness, and the raw material costs are substantially more economical. The selected matrix material for this study comprised epoxy resin

(LLY556) and hardener (HY951), both sourced from Herenba Instrument and Engineers, Pudur, Amttarpur, Chennai. The thermosetting polymer epoxy, commonly referred to as polyepoxide, is formed through the reaction of an epoxy resin with a polyamine hardener. The materials utilized in the experiment are depicted in the **Figure 1**.

Figure 1. (a) Epoxy (b) Hardener (c) Glass fiber.

4.2 Fabrication of Composite

Composites can be manufactured using various methods, including resin transfer molding, compression molding, vacuum molding, and pultruding. One popular technique for combining resin and fabric components is the hand lay-up production process as shown in **Figure 2**. This method allows for the manual placement of fiber reinforcement into a single-sided mold, followed using hand rollers to impregnate the fiber matting with resin. One of the main advantages of the hand lay-up method is its ability to produce large, intricate parts with shorter manufacturing times. Additionally, the hand lay-up technique relies on simple and cost-effective tools and equipment compared to other manufacturing processes. All composite specimens in this study were created using the hand lay-up method.

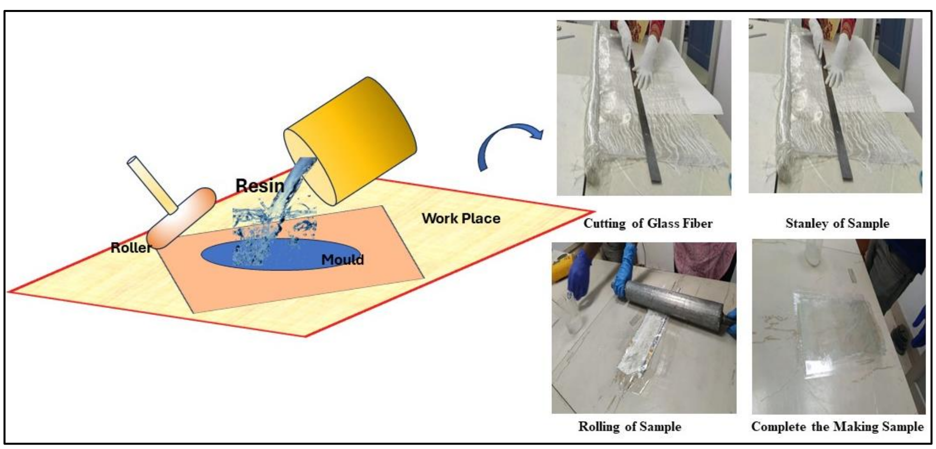

Figure 2. Fabrication of composite through hand lay-up process.

Among all fabrication techniques, the hand lay-up method is one of the oldest and most cost-effective compared to others. Also known as the wet lay-up technique, this process is suitable for producing a limited number of parts and is not well-suited for mass manufacturing. It is commonly employed for the cost-effective production of items like ducts, pools, furnishings, shells, and panels. After preparing the mold, fibers are manually laid in various orientations based on the desired characteristics. The matrix material is then introduced, and the composite undergoes heating and high-pressure treatment to bond with the fibers. The composite is allowed sufficient time to cure or set.

4.3 Material used to Fabricate Pure Epoxy Sample and Pure Epoxy Fabrication

There are certain materials which are used for the fabrication of Epoxy Mould and their composites, Such as Mold, Epoxy, Hardener, Releasing Agent, Wax. First, a mold is used to make the entire epoxy sample. The mold is made of mild steel. The mold take has a tolerance of 2mm so that the sample come out easily. Epoxy and hardener are used to make complete epoxy samples, whose ratio is 2:1. Both Epoxy and mold is shown in **Figure 3**.

Figure 3. (a) Pure epoxy tensile (b) Pure epoxy flexural sample.

4.4 Test Specimen and Flexural/Bending Test

The Test specimen and Bending test machine is shown in **Figure 4**. The composite samples were manufactured in a rectangular shape following ASTM standards. For the bending test, ASTM D790 specifications were adhered to, resulting in samples with dimensions of 60x15x1.42mm. For the tensile test at 0 degrees, ASTM-D3039 guidelines were followed, producing samples with dimensions of 250x15x1mm. Additionally, for the tensile test at 90 degrees, ASTM-D3039 specifications were applied, resulting in samples with dimensions of 175x25x2mm.

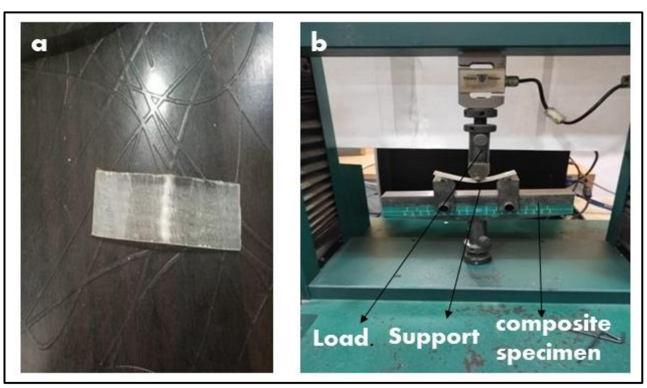

Figure 4. (a) Test specimen (b) Flexural (Three-point bending) test on autograph machine.

The bending or flexural test was conducted on composite specimens with dimensions of 60mm x 15mm using an Autograph machine at room temperature, following the guidelines of ASTM D-790. The test began by applying weight to the specimen at a predetermined rate. A gauge positioned beneath the specimen, in direct contact with its midpoint over the support span, was utilized to measure the deflection. The flexural testing apparatus for the different composites is illustrated.

5. Result and Discussion

5.1 Flexural Strength Test

Flexural strength, also known as the modulus of rupture, bending strength, or fracture strength, is a mechanical property of materials that denotes their ability to withstand deformation under bending stresses and it is well explained in **Figure 5**. The transverse bending test is the most common method used to evaluate this property. In this test, a rod specimen with a circular or rectangular cross-section is subjected to bending until fracture occurs, following a three-point flexural test procedure. The flexural strength of a material signifies its maximum stress-bearing capacity now of rupture.

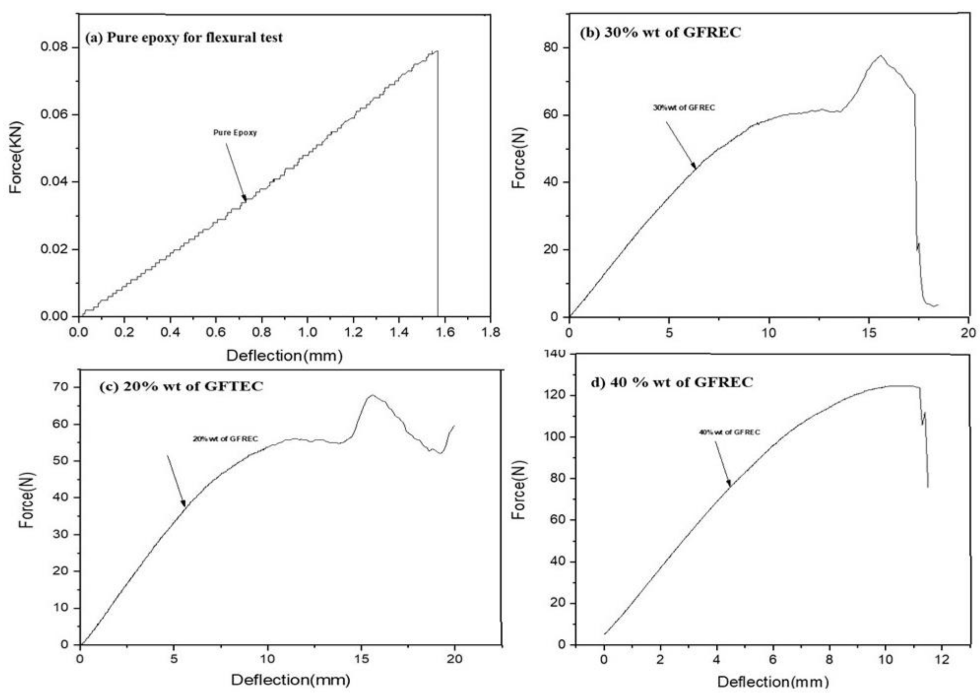

Figure 5. Flexural strength test of different composite.

The flexural test results are represented by a force versus deflection graph for P.E, GFREC of 20%wt, GFREC of 30%wt, and GFREC of 40%wt fractions, as shown in the **Figure 5**. A comparison of the flexural tests for all specimens is presented in the figure. The plot illustrates that the flexural strength may increase or decrease with an increase in fiber content in epoxy. The presence of porosity and surface defects in the specimen is the primary reason for the observed decrease in results.

5.2 Tensile Test

5.2.1 Zero-degree Unidirectional

The Autograph machine is employed for conducting tensile tests. These tests are conducted at room temperature using 250mm x 15mm rectangular specimens as shown in **Figure 6**.

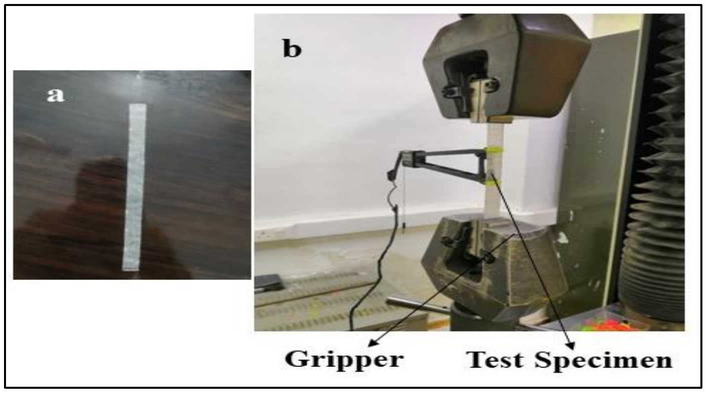

Figure 6. (a) Tensile Sample (0^0 degree) and (b) Tensile Test on Autograph Machine (0^0 degree).

The specimens are inserted into the grips and subjected to tension until they fracture. In the tensile test method where are two sample made such as, we take fiber orientation to be zero degree unidirectional whose dimensions are,

1.	Overall length	250mm(10.0in)
2.	Width	15mm(0.5in)
3.	Thickness	1.0mm(0.04in)
4.	Tab length	56mm(2.25in)
5.	Tab thickness	1.5mm(0.062in)
6.	Tab bevel angle	7 to 90 degrees

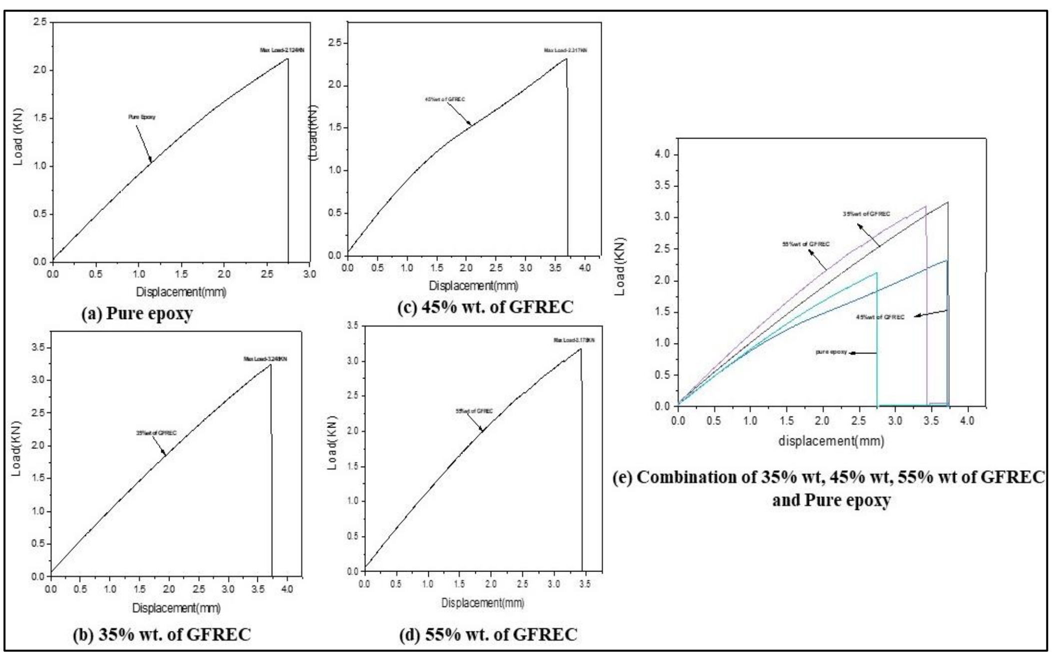

Figure 7. Zero - degree unidirectional tensile test for different composite.

Ultimate tensile strength (UTS), commonly known as tensile strength (TS), refers to the maximum stress a material can endure when subjected to stretching or pulling before necking or noticeable cross-sectional compression occurs well explained with the help of **Figure 7**. Being an intensive characteristic, its value is influenced by factors beyond the size of the test specimen, including specimen preparation, the presence of surface imperfections, and the temperature of the test environment and material. The tensile strength of a fiber-reinforced composite (Tsc) is determined by the bonding between the fibers and the matrix. The matrix's role is to transfer stresses to the load-bearing fibers.

The experimental results of the tensile test at a 0-degree angle are presented in **Table 1**. The tensile strength values derived from various composite specimens are illustrated in Fig. As per the experimental results in **Table 1**, an increase in fiber content corresponds to an increase in tensile strength compared to pure epoxy. The experimental results for the tensile test at a 0-degree angle, including Max. Force, Modulus of Elasticity, and Tensile Strength, are detailed in **Table 1**.

Table 1. Experimental results of 0 degree tenisile test.

S. No.	Composites	Max Force (KN)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)
1.	Pure Epoxy	2.124	3.246	36.87
2.	GFREC 35%wt	2.272	19.95	221.893
3.	GFREC 45%wt	2.317	15.734	170.751
4.	GFREC 55%wt	3.33	17.402	228.704

5.2.2 Ninety Degrees Unidirectional

These tests are conducted at 90^{o} temperature using 250mm x 15mm rectangular specimens. The required sample and machine setup is shown in **Figure 8**.

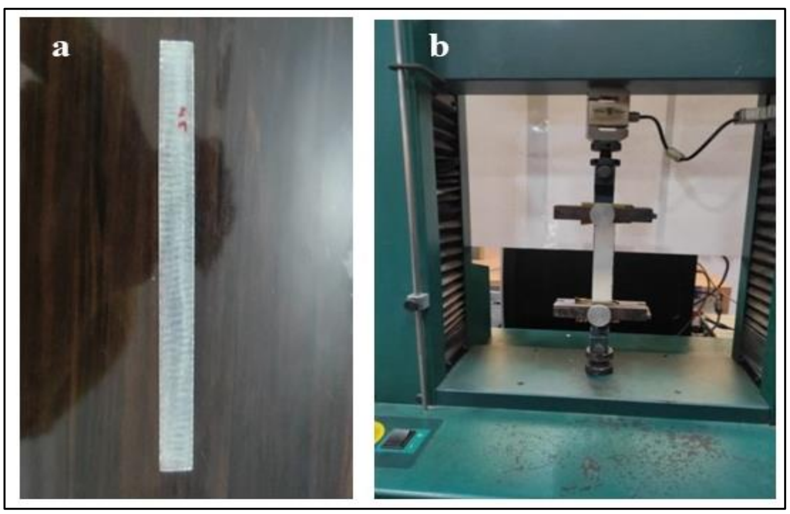

Figure 8. (a) Tensil sample of 90^0 degree angle (b) Tensil test on autograph machine (90^0 degree).

We take fiber orientation to be 90 degrees unidirectional whose dimensions are

1.	Overall length	175mm(7.0in)
2.	Width	25mm(1.0in)
3.	Thickness	2.0mm(0.08in)
4.	Tab length	25mm(1.0in)
5.	Tab thickness	1.5mm(0.062in)
6.	Tab bevel angle	90 degree

Ultimate tensile strength (UTS), also referred to as tensile strength (TS), denotes the maximum stress a material can withstand when subjected to stretching or pulling before necking, or when the specimen's cross-section begins to noticeably compress. It is an intensive characteristic, and as such, its value is determined by factors beyond the size of the test specimen. These factors include specimen preparation, the presence of surface imperfections, and the temperature of the test environment and material. The bonding between the fiber and the matrix plays a crucial role in determining the tensile strength of a fiber-reinforced composite (Tsc). The matrix's primary function is to transfer stresses to the load-bearing fibers. Experimental results of the tensile test at a 90-degree angle are detailed in **Table 2**, and the corresponding tensile strength values from various composite specimens are presented in **Figure 9**.

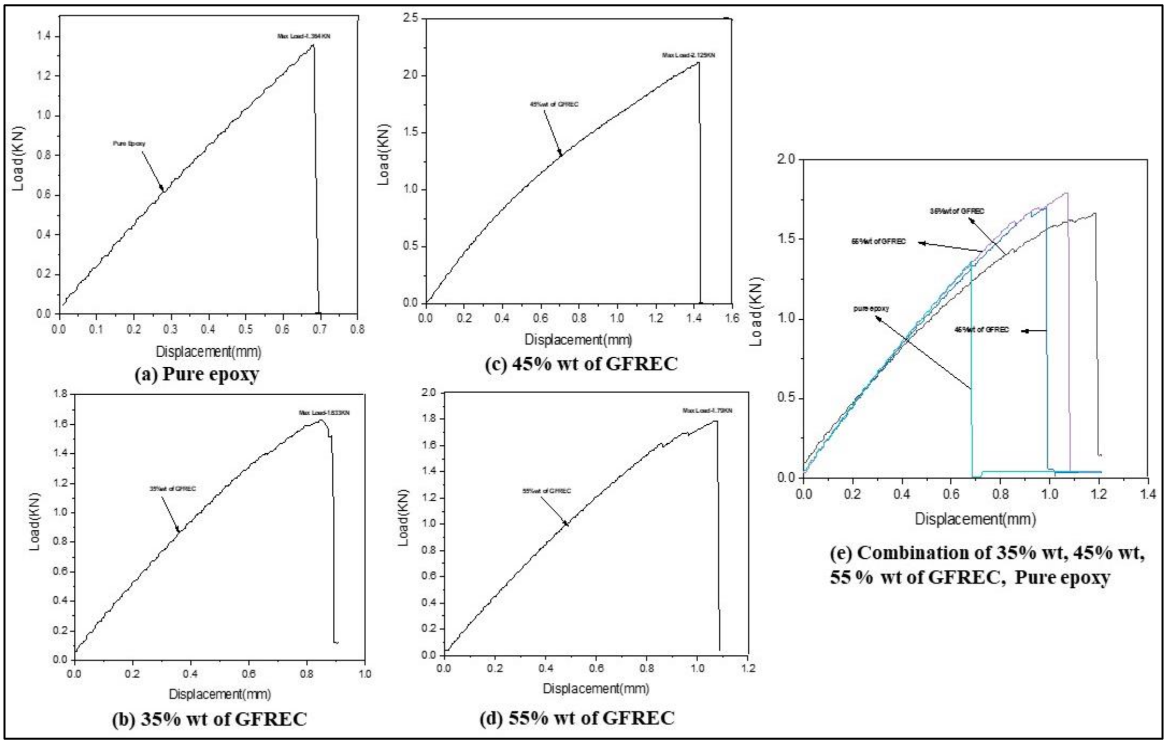

Figure 9. Ninety - degree unidirectional tensile test for different composite.

According to the experimental results in **Table 2**, an increase in fiber content leads to a corresponding increase in tensile strength. This is attributed to glass fibers serving as the main load-carrying members, while the matrix acts as a stress transfer medium. As the load increases, the stress also reaches its maximum. Additionally, **Table 2** reveals that tensile strength increases with the increasing load. The Young modulus of elasticity also exhibits an increase with the rise in weight fraction of the material.

Table 2. Experimental results of 90-degree tensile test.

S. No.	Composites	Max force (KN)	Modulus of elasticity (GPa)	Tensile strength (MPa)
1.	Pure Epoxy	1.364	3.331	14.705
2.	GFREC 35%wt	1.666	8.235	45.097
3.	GFREC 45%wt	1.687	9.351	47.778
4.	GFREC 55%wt	1.79	9.319	51.807

6. Conclusion

The current investigation into the mechanical behavior of unidirectional glass fiber-reinforced epoxy composites reveals a significant influence of the fiber content/weight fraction of reinforcement in the matrix on the tensile strength. Reinforced composites exhibit higher tensile strength at both 0 degrees and 90 degrees of unidirectional glass fibers. The tensile strength increases with a 55% weight fraction of glass fiber over the pure epoxy. The Young modulus of elasticity also shows an increase with an augmented weight fraction of the material. However, the flexural strength does not increase with an increase in fiber content, displaying a decreasing trend in the experimental results. This decline may be attributed to surface defects and poor surface finish. Additionally, the presence of porosity could contribute to the observed decrease in flexural strength. In tensile tests, maximum stresses occur at the center of the specimen, marking the initiation of fracture.

Conflict of Interest
There is no conflict of interest.

Acknowledgments
There is no acknowledgment.

References

Adekomaya, O., & Adama, K. (2017). Glass-fibre reinforced composites: the effect of fibre loading and orientation on tensile and impact strength. *Nigerian Journal of Technology*, *36*(3), 782-787. http://dx.doi.org/10.4314/njt.v36i3.17.

Alam, S., Habib, F., Irfan, M., Iqbal, W., & Khalid, K. (2010). Effect of orientation of glass fiber on mechanical properties of GRP composites. *Journal of the Chemical Society of Pakistan*, *32*(3), 265-269.

Aramide, F.O., Atanda, P.O., & Olorunniwo, O.O. (2012). Mechanical properties of a polyester fibre glass composite. *International Journal of Composite Materials*, *2*(6), 147-151.

ASTM-D3039. Standard test method for tensile properties of polymer matrix composite materials. USA: ASTM, International.

Avci, A., Arikan, H., & Akdemir, A. (2004). Fracture behavior of glass fiber reinforced polymer composite. *Cement and Concrete Research*, *34*(3), 429-434.

Bhat, M.R., Majeed, M.A., & Murthy, C.R.L. (1994). Characterization of fatigue damage in unidirectional GFRP composites through acoustic emission signal analysis. *NDT & E International*, *27*(1), 27-32.

Chandra, R., Singh, S.P., & Gupta, K. (1999). Damping studies in fiber-reinforced composites–a review. *Composite Structures*, *46*(1), 41-51.

Chou, T.W., & Ko, F. (1989). *Textile structural composites. Introduction to textile structures and their behavior*. Elsevier Science Publishing Company, New York.

El-Assal, A.M., & Khashaba, U.A. (2007). Fatigue analysis of unidirectional GFRP composites under combined bending and torsional loads. *Composite Structures*, *79*(4), 599-605.

El-Habak, A.M.A. (1991). Mechanical behaviour of woven glass fibre-reinforced composites under impact compression load. *Composites*, *22*(2), 129-134.

El-Sonbaty, I., Khashaba, U.A., & Machaly, T. (2004). Factors affecting the machinability of GFR/epoxy composites. *Composite Structures*, *63*(3-4), 329-338.

Erden, S., Sever, K., Seki, Y., & Sarikanat, M. (2010). Enhancement of the mechanical properties of glass/polyester composites via matrix modification glass/polyester composite siloxane matrix modification. *Fibers and Polymers*, *11*, 732-737.

Ferdous, W., Manalo, A., Peauril, J., Salih, C., Reddy, K. R., Yu, P., Schubel, P., & Heyer, T. (2020). Testing and modelling the fatigue behaviour of GFRP composites–Effect of stress level, stress concentration and frequency. *Engineering Science and Technology, an International Journal*, *23*(5), 1223-1232. https://doi.org/10.1016/j.jestch.2020.01.001.

Ghassemieh, E., & Naseehi, V. (2001). Prediction of failure and fracture mechanisms of polymeric composites using finite element analysis. Part 1: Particulate filled composites. *Polymer Composites*, *22*(4), 528-541. https://doi.org/10.1002/pc.10557.

Harizi, W., Chaki, S., Bourse, G., & Ourak, M. (2014). Mechanical damage assessment of glass fiber-reinforced polymer composites using passive infrared thermography. *Composites Part B: Engineering*, *59*, 74-79. https://doi.org/10.1016/j.compositesb.2013.11.021.

Hsiao, H.M., & Daniel, I.M. (1998). Strain rate behavior of composite materials. *Composites Part B: Engineering*, *29*(5), 521-533.

Husić, S., Javni, I., & Petrović, Z.S. (2005). Thermal and mechanical properties of glass reinforced soy-based polyurethane composites. *Composites Science and Technology*, *65*(1), 19-25. https://doi.org/10.1016/j.compscitech.2004.05.020Get rights and content.

Jones, R.M. (2018). *Mechanics of composite materials*. CRC press, New York.

Karakuzu, R., Erbil, E., & Aktas, M. (2010). Impact characterization of glass/epoxy composite plates: An experimental and numerical study. *Composites Part B: Engineering*, *41*(5), 388-395. https://doi.org/10.1016/j.compositesb.2010.02.003.

Kaw, A.K. (2005). *Mechanics of composite materials*. CRC press, New York.

López, F.A., Martín, M.I., Alguacil, F.J., Rincón, J.M., Centeno, T.A., & Romero, M. (2012). Thermolysis of fibreglass polyester composite and reutilisation of the glass fibre residue to obtain a glass–ceramic material. *Journal of Analytical and Applied Pyrolysis*, *93*, 104-112.

Naik, K.N. (1994). Woven fabric composites. Technomic publishing company, Inc., Lancaster, PA, USA. Now, CRC Press, Boca Raton, Florida, USA

Putić, S., Bajčeta, B., Vitković, D., Stamenović, M., & Pavićević, V. (2009). The interlaminar strength of the glass fiber polyester composite. *Chemical Industry & Chemical Engineering Quarterly*, *15*(1), 45-48. https://doi.org/10.2298/CICEQ0901045P.

Ramzan, E., & Ehsan, E. (2009). Effect of various forms of glass fiber reinforcements on tensile properties of polyester matrix composite. *Journal of Faculty of Engineering & Technology*, *16*, 33-39.

Sanjay, M.R., Arpitha, G.R., & Yogesha, B. (2014). Investigation on mechanical property evaluation of jute-glass fiber reinforced polyester. *IOSR Journal of Mechanical and Civil Engineering*, *11*(4), 50-57.

Sathishkumar, T.P., Satheeshkumar, S., & Naveen, J. (2014). Glass fiber-reinforced polymer composites–a review. *Journal of Reinforced Plastics and Composites*, *33*(13), 1258-1275. https://doi.org/10.1177/0731684414530790.

Sikarwar, R.S., Velmurugan, R., & Gupta, N.K. (2014). Influence of fiber orientation and thickness on the response of glass/epoxy composites subjected to impact loading. *Composites Part B: Engineering*, *60*, 627-636. https://doi.org/10.1016/j.compositesb.2013.12.023.

Srivastava, V.K. (2012). Impact behaviour of sandwich GFRP-foam-GFRP composites. *International Journal of Composite Materials*, *2*(4), 63-66.

Torabizadeh, M.A. (2013). Tensile, compressive and shear properties of unidirectional glass/epoxy composites subjected to mechanical loading and low temperature services. *Indian Journal of Engineering & Materials Sciences*, *20*, 299-309.

Yuanjian, T., & Isaac, D.H. (2008). Combined impact and fatigue of glass fiber reinforced composites. *Composites Part B: Engineering*, *39*(3), 505-512.