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Experimental Investigation on the Important Factors on Structural Adhesive Joint Strength of Fiber-Reinforced Epoxy Composites

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Abstract

The static strength of fiber-reinforced epoxy composite structural adhesive lap joints was examined experimentally. Surface roughness and geometrical control parameters (adherent and adhesive kinds) were assessed for their effects. To examine load, elongation, and strength at failure, tensile tests were conducted. Cyanoacrylate glue outperformed SHCP 268 resin, and glass fiber-reinforced epoxy composites outperformed sisal fiber-reinforced epoxy composites. The study offers information on how to maximize adhesive bonding for lightweight multi-material design construction.

Keywords: Fiber-Reinforced Epoxy Composites, Adhesive Bonding, Tensile Strength, Geometric Parameters.

1. Introduction

In one way or another, composite materials have been incorporated into practically every industry. The usage of fiber composite materials and the proper application of their qualities are now linked to the creation of contemporary technology and technologies. In general, composite materials outperform conventional engineering materials in terms of strength-to-weight ratios. A system's weight can be lowered by up to 20% or 30% thanks to these characteristics. Energy savings or improved performance are the results of weight reduction.

Because of their high specific strength and stiffness, which enable the production of lightweight, high-performance vehicles, modern composite materials have become more and more popular in structural applications, especially in the transportation industry. Fastening and welding have historically been used to unite these structures, however, these techniques are not very suitable for composite constructions and provide challenges for integrating disparate materials. As a result, adhesives have become more popular for combining these structures, especially because of their capacity to link intricate multi-material systems. One benefit of adhesives is that they can achieve better stress distributions and greater joining strengths [1].

Over the last 20 years, an increasing number of researchers have been investigating structural adhesives [2] that are stronger, lighter, and have the capacity to endure impacts without sacrificing structural integrity [3]. Adhesively bonded joints are becoming more and more common in engineering applications, and they offer a variety of benefits over conventional mechanical fasteners. In comparison to traditional mechanical joints, they save weight and cost while offering a more even distribution of stress throughout the bonded area, increasing stiffness and improving load transfer.

Additionally, employing composite patches to restore structures is a good use for adhesive bonding, which allows for these repairs to be made without causing additional harm to the adherence [4]. Adhesive bonding reduces stress concentrations by offering a continuous and greater connection surface than mechanical joints, which depend on fasteners. However, because of the natural discontinuity of the materials at the bonding location, stress concentrations still occur in both the adhesive and the adherents. It has been demonstrated that the borders of the jointing area usually experience the highest stress levels [5]. Based on their actions, the primary stresses found in the adhesive and adherents are categorized as peel stress and shear stress. Peel stress has a greater impact on joint strength in joints with composite adherents because it loads the composite matrix directly and is unreinforced.

Fiber-reinforced epoxy composite adhesive joints are very effective for a variety of applications because they have notable tensile strength benefits. These connectors can sustain high tensile loads because epoxy resin and strong fibers, like glass or sisal, are combined. The fibers bear the majority of the stress. As a result of the fibers' ability to more evenly transmit tensile stresses and lessen localized stress concentrations, joints become stronger and more resilient. Additionally, under tensile loads, the composite materials' inherent stiffness offers superior resistance to deformation, guaranteeing the joint's structural integrity. Fiber-reinforced epoxy composites are lightweight despite having high strength, providing an exceptional strength-to-weight ratio that makes them perfect for sectors including automotive and aerospace where both strength and weight are critical factors.

With a focus on maximizing the performance of single-lap bonded joints, we experimentally examined the effects of geometrical and test condition parameters on the shear strength of these joints. For the experimental investigation, single-lap adhesive bonds were employed, and glass fiber and sisal fiber fiber-reinforced epoxy composites were utilized as adherents. Two adhesives, Cyanoacrylate glue, and SHCP 268 resin, were evaluated across three sample configurations.

2. Abbreviations and Acronyms

MMC	Metal matrix composites
CMC	Ceramic matrix composites
C/C	Carbon/carbon composites
PMC	Polymer Matrix Composites
AR-Glass	Alkali Resistant Glass
HDG	Hot-Dip Galvanized steel
SB	Secondary Bonded
VAF	Variable Amplitude Fatigue Loads
CFRP	Carbon Fiber-Reinforced Polymer
FRP	Fiber-Reinforced Polymer
FEM	Finite Element Method
CZM	Cohesive Zone Model
MWCNT	Multi-walled Carbon Nanotube
GFRP	Glass Fiber-Reinforced Polymer

GR-EP	Graphite/Epoxy Composite
MEPOXE	Methyl Ethyl Ketone Peroxide
ASTM	American Society for Testing and Materials
SLJ	Single-Lap Joint
SAJ	Structural Adhesive Joint
SGG	Glass fiber + Glass fiber composite
SGS	Glass fiber + Sisal fiber composite
SSS	Sisal fiber + Sisal fiber composite
UTM	Universal Testing Machine
Fig.	Figure
UV	Ultraviolet
e.g.	For Example
Vol.	Volume
No.	Number
et al.	And others
etc.	And so forth (Latin: et cetera)
avg.	Average
Tg	Glass Transition Temperature

3. Literature Review

Fiber-reinforced epoxy composites are structurally adaptable materials with benefits like corrosion resistance and a high strength-to-weight ratio, which makes them perfect for industries like construction and automotive. Thanks to developments in polymer science, adhesive bonding is now a widely used substitute for mechanical fastening, providing better results in some situations.

3.1 Research on Strength of Composite Joints: By putting a flexible adhesive at the overlap edges, Machado et al. (2018), who investigated the impact strength of composite joints in the automotive sector, demonstrated that employing two adhesives in a joint can lessen delamination. As a result, failure loads rise, and peel stresses decrease. When brittle, ductile, and tough adhesive combinations were tested, mixed-adhesive joints outperformed single-adhesive joints in terms of strength by 64% [6].

According to Cao and Wang's (2009) investigation into the temperature dependency of tensile strength in fiber-reinforced polymer (FRP) sheets, tensile strength remains constant above specific temperature ranges but declines as the glass transition temperature gets closer. It was discovered that the distinct dispersions of specimens at particular temperatures could be detected, as well as the clear temperature dependency of tensile strength [7].

In order to investigate the distribution of stress in adhesively bonded single-lap joints (SLJs) with functionally graded adherents, Guin and Wang (2016) created a theoretical model. Although the results were not quite equivalent to those of normal adherents or experimental validation, their three-parameter elastic foundation model demonstrated that applying a stronger layer close to the adhesive decreased peak peel stress by 27% [8].

Calvez et al. (2012) examined adhesion loss and metal surface corrosion in their investigation of the deterioration of epoxy adhesive/galvanized steel junctions. Their research suggested an aging model in which, after extended exposure, corrosion takes over from the early degradation at the metal/polymer interface [9].

The impact of co-cured and secondary bonded joints on mechanical strength under mode I and mixed-mode stress was investigated by Mohan et al. (2014). They discovered that secondary bonded joints (SB120 and SB180) were stronger than co-cured joints (CC180). Secondary bonded joints were cured at either 120°C or 180°C using a carbon fiber/epoxy prepreg that was treated at 180°C and an epoxy film adhesive that was cured at 120°C. Glass transition temperature (Tg) affects mechanical qualities, as demonstrated by the study; SB120 joints (Tg of 150°C) were stiffer than CC180 joints (Tg of 137°C). CC180 displayed the maximum strain at failure, but SB120 had the highest failure stress. The failure strains of SB180 tensile specimens were somewhat lower than those of CC180, while the failure stresses were similar [10].

The fatigue performance of scarf adhesive joints with a 3° taper angle in carbon-fiber-reinforced composite adherents under both constant and variable amplitude fatigue loads (VAF) was examined by Olajide and Arhatari (2017). They discovered that the main mechanisms for joint damage development were supported by constant amplitude fatigue, which made it possible to analyze the effects of fatigue and material factors on fatigue life. On the other hand, variable amplitude fatigue was used to investigate the hysteretic heating effect and damage progression over the joint's lifetime [11].

To address zero shear stress situations at the free edge of the adhesive layer, a feature overlooked by the traditional two-parameter model, Jailai et al. (2009) created a three-parameter elastic foundation model to study interface stresses in adhesively bonded joints. Compared to the findings of the finite element method (FEM), this model provides accurate predictions and satisfies equilibrium by accommodating various peel stresses at the interfaces [12].

Defects raise stress concentrations and cause early failure, according to Yousefsani et al. (2015)'s investigation of thermo-mechanical stresses in composite joints with interfacial voids [13].

The effectiveness of a flexible adhesive under impact loading in single-lap joints with high-strength steel adherents was investigated by Kadioglu and Adams (2015). They discovered that, in comparison to quasi-static loading, lap joint strength improves dramatically during impact, indicating a connection between loading speeds and joint performance [14].

Using two ductile adhesives at the ends and a brittle adhesive in the middle, Oz & Ozer (2017) examined bi-adhesive junctions and found that they were 40% stronger than joints constructed with individual adhesives, even if the ductile adhesive was stronger [15].

Khashaba et al. (2017) investigated fatigue and dependability in nano-modified scarf adhesive junctions, while Silva et al. (2012) investigated adhesive joint failures in composites. They discovered that certain nanofillers, such as SiC, significantly increased fatigue life, whereas Al2O3 resulted in decreased performance [16, 17].

Experiments on composite-to-composite bonded joints by Kweon et al. (2010) showed that thicker adherents and secondary bonding improve joint strength [18].

According to a 2009 study by Lee et al., peel stresses are higher in supported single-lap joints than in double-strap adhesive joints [19].

In their 2017 study, Rudawska et al. examined the adhesive qualities of graphite/epoxy composites and showed that stronger junctions are produced by thinner composites [20].

Yang (2013) used T700/EXOPY laminates and braided composites to investigate how adhesives affect the strength of composite adhesive junctions. Uniaxial tension testing using J-272 adhesive film and J47 epoxy adhesives on single-lap adhesive junctions were part of the study. The failure shear strength of joints with higher shear strength increased by 27%, whereas junctions with lower adhesive shear strength had decreased strength. Crack propagation that starts at the overlap ends and leads to total joint failure [21].

3.2 Gap Analysis: In their review of adhesively bonded joints in composites, S. Budhea, M.D. Baneaa, S. de Barrosa, and L.F.M. da Silva emphasized the significance of environmental factors such as temperature and moisture on performance, which should be thoroughly discussed both before and after the bonding method because they directly affect the joints' performance [22]. Zhiwen Qin, Ke Yang, Jihui Wang, Lixin Zhang, Ji Huang, Haijun Peng, and Jianzhong Xu recommended using highly ductile adhesives instead of brittle ones and proposed adding a unidirectional lamina to wind turbine blades to avoid failure [23]. Fernando, D. In order to strengthen steel, J. G. Teng, T. Yu, and X. L. Zhao concentrated on the best surface-adhesive combinations. They recommended a minimum acceptable surface energy and a range of fractal dimensions for the surface topography. The surface must first be cleaned with the proper solvent to get rid of any surface impurities [24]. After reviewing the tensile tests of epoxy composite reinforced with bamboo fiber, R. S. Wani and R. R. Shitole proposed that increasing the volume percent of fiber could improve the composite's tensile properties [25]. According to Anna Rudawska, Dana Stančeková, Nadezda Cubonova, Tetiana Vitenko, Miroslav Müller, and Petr Valášek, a structure can be useful when paired with other technological aspects to create adhesive joints [26]. Chuanxi Li, Lu Ke, Jun He, Zhuoyi Chen, and Yang Jiao suggested cohesive zone models for simulating bond behavior and advocated against depending exclusively on adhesive tensile strength for determining maximum shear stress [27]. After conducting experiments on the fatigue and fracture behavior of adhesively bonded composite structural joints, A.P. Vassilopoulos and T. Keller proposed that stiffness degradation data and fracture mechanics measurements may be utilized to determine dependable design allowable. Damage-tolerant design procedures can be developed with the use of stiffness and real damage, which can eventually be utilized as useful damage metrics [28].

4. Methodology

4.1 Reinforcing Component: Sisal Fiber: Sisal is a sturdy, coarse cloth made from the leaves of agave plants. The plant's leaves are the source of sisal fiber. After harvest, the newly picked agave leaves are compressed in a machine to extract the fibers. Following their separation, the fibers undergo cleaning, bleaching, sun drying, and brushing with revolving brushes. Just 4% of the leaf's weight is composed of dry fiber. Sisal fiber has a diameter of 1 mm and a length of 80 mm. Sisal fiber is beneficial in a variety of applications due to a number of significant mechanical characteristics. It is a light material with a density of 1.33 to 1.5 g/cm^3. Because of its tensile strength, which ranges from 400 to 700 MPa, it can bear a lot of pulling power without breaking. With Young's modulus ranging from 9.0 to 38.0 GPa, it exhibits stiffness and resistance to bending under stress. Finally, its 98.7 KJ/m^2 work of fracture indicates that it can absorb a considerable amount of energy before breaking. Sisal fiber is a strong and eco-friendly choice for reinforcing materials because of these characteristics.

4.2 Reinforcing Component: Glass Fiber: One particular kind of synthetic fiber is glass fiber. This substance, which is made up of many incredibly fine glass fibers, is also referred to as fiberglass. The fiber is really robust. In addition to desired fiber qualities like strength, flexibility, and stiffness, glass fibers have practical bulk qualities including hardness, transparency, stability, inertness, and resistance to chemical assault. Glass fibers are utilized in the production of printed circuit boards, structural composites, and several other special-purpose goods. Glass fiber's significant mechanical qualities make it a material that is utilized extensively in many different sectors. With a tensile strength between 400 and 3,000 MPa, it can sustain considerable force despite being heavier than natural fibers due to its density of roughly 2.5 g/cm³. Good stiffness and resistance to bending are indicated by its Young's modulus, which ranges from 30 to 80 GPa. It has some flexibility but barely stretches 2% to 5% before breaking. Although glass fiber is more brittle than certain alternatives, its work of fracture is approximately 10 to 20 KJ/m2, indicating that it can absorb energy before collapsing. Because of these qualities, glass fiber can be used in construction, automotive, and aerospace applications where durability and strength are crucial.

4.3 Matrix Materials: Epoxy Matrix: In this work, epoxy matrix was utilized as the matrix material. These are composites, which are essentially materials based on epoxy resin mixed with reinforced fiber. The curing agent is the hardener. Hard, thermoset materials are produced when curing agents react with epoxy resins. Epoxy resins were chosen with the appropriate hardener. Epoxy resin SHCP 268 and MEPOXE (Methyl Ethyl Ketone Peroxide) were used in this work to manufacture the epoxy composites. Ortho phthalic-grade SHCP 268 is a thixotropic, fast-curing unsaturated polyester resin used for general laminating. Methyl Ethyl Ketone Peroxide is a component of the catalyst MEPOXE. Like acetone peroxide, methyl ethyl ketone peroxide (MEKP) is an organic peroxide with a strong explosive power. In contrast to acetone peroxide, which is a white powder at STP, MEKP is an oily, colorless liquid that is more stable in storage and somewhat less susceptible to shock and temperature changes.

4.4 Specimen Preparation: **Fabrication of composites:** Wetting, mixing, or saturating the reinforcement material with the matrix are some of the steps involved in the creation of composite materials. The matrix fuses the reinforcement into a solid structure using heat or chemical reactions. Depending on the necessary properties of the composite, this procedure usually occurs in an open or closed mold using various techniques. Only the outer mold line (OML), or surfaces in direct contact with the mold, are regulated by open molds; the inner mold line (IML) is uncontrolled. However, all of the composite part's surfaces are controlled by closed molds. The characteristics of the matrices and reinforcements, the product's size and shape, and its intended use all have an impact on the fabrication technique selection.

4.5 Specimen Preparation: **Mold Preparation:** Six specimens in all, of two types—three composed of glass fibers and three of sisal fibers—were created. These specimens needed to be molded, therefore two wooden frames—one for each type of material—were made. Each frame had dimensions of 160 x 140 mm and was 10 mm thick. In order to minimize sticking during the casting process, wax was put into the molds as a release agent prior to the material being poured.

4.6 Mixing of Epoxy and Hardener and Adding Reinforcement: The hardener MEPOXE and unsaturated polyester resin SHCP 268 were combined in a 10:8 weight ratio. The mixture was first made in a large container, and from this batch, the amount needed for each mold was transferred to a smaller container. The resin mixture was poured straight into the glass fiber mold. After that, glass fibers were added by laying a layer of glue on top and then arranging the fibers at random. Until the required fiber-to-resin ratio was reached, another layer of resin was applied, and so on. The sisal fiber mold was made similarly. After pouring the resin mixture, layers of sisal fibers and resin were alternated in the mold, with the fibers arranged at random. This went on until the necessary ratio was obtained. Three examples were taken from each mold after cutting and additional processing, for a total of six specimens: three made of glass fibers and three made of sisal fibers.

Figure 1: Fabricated Specimen Epoxy Composites [a) Sisal Fiber, b) Glass Fiber]

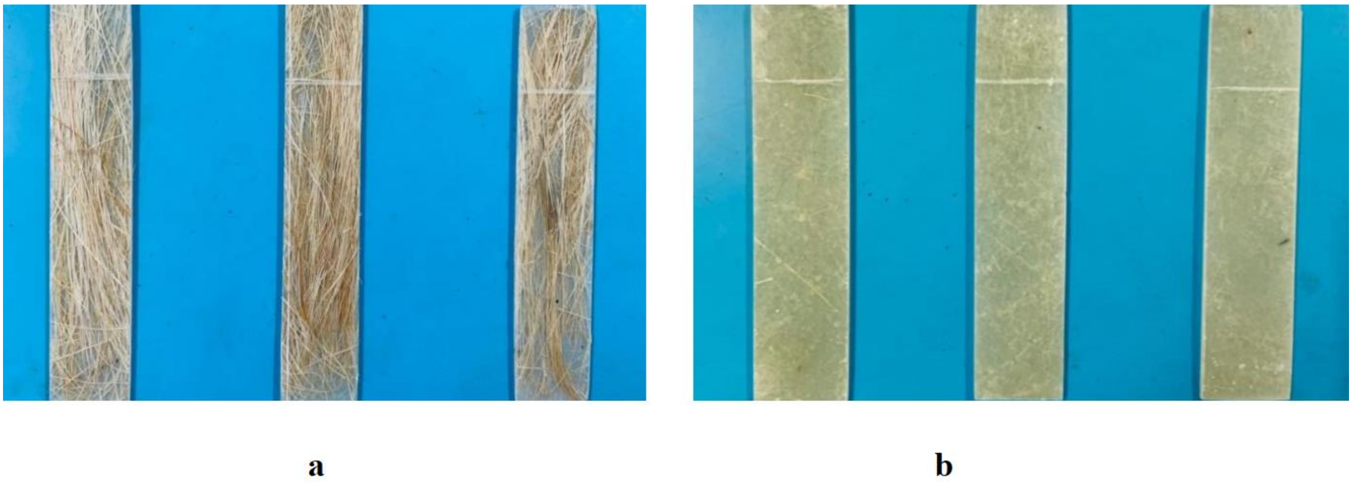


Table 1: Mixing Ratios of Epoxy, Hardener and Reinforcement

	Fiber Type	**Fiber Quantity**	**Epoxy Resin + Hardener (10:8)**
Specimen 1	Glass Fiber	20%	80%
Specimen 2	Glass Fiber	20%	80%
Specimen 3	Glass Fiber	20%	80%
Specimen 4	Sisal Fiber	10%	90%
Specimen 5	Sisal Fiber	10%	90%
Specimen 6	Sisal Fiber	10%	90%

4.7 Adhesive joint production: Among all the adhesive joints, the single lap joint (SLJ) is the easier configuration to predict the strength and durability of the adhesive bonded joints. So in this experiment, we used single-lap joints (SLJ) as adhesive joints.

4.7.1 Surface preparation of composites (for adhesion): Surface preparation is vital for creating strong adhesive bonds and enhancing performance. The adhesive must fully wet the surfaces being joined, but contaminants like dust, oils, and grease can hinder adhesion. If not removed, these can lead to bond failure. A common method is to degrease, abrade, and then degrease again. Other techniques, such as corona discharge, flame, laser, and plasma treatments, can also improve the surface of composites for better adhesion.

4.7.2 Adhesive selection and application: Achieving strong, long-lasting connections and preserving cost effectiveness need careful adhesive selection. The choice of adhesive is influenced by a number of variables, such as clamping time, surface area, surface type, and material. In light of these considerations, two adhesives were chosen: cyanoacrylates, also known as "Crazy Glue" or "Super Glue," which include fast-bonding adhesives appropriate for a variety of materials, such as metal, plastic, and skin, and SHCP 268 resin, a thixotropic, quick-curing unsaturated polyester resin perfect for general laminating. In the presence of moisture, these adhesives, which are made from ethyl cyanoacrylate and similar esters, rapidly polymerize to create robust connections. Each type of adhesive has a different application technique; paste adhesives need more cautious handling, whereas liquid adhesives cover joint regions with ease. Three samples were created from six specimens during the joining process: two glass fiber-reinforced epoxy composites were first joined together using cyanoacrylate glue, then a glass fiber-reinforced epoxy composite was bonded to a sisal fiber-reinforced epoxy composite using SHCP 268 resin, and finally, two sisal fiber-reinforced epoxy composites were joined together using SHCP 268 resin.

4.7.3 Assemble and fixture of the joint: Due to a number of significant geometrical parameters, such as overlap length, adhesive thickness, adhesive spew fillets, and the alignment of the joined components, assessing adhesive characteristics for single-lap joint bonding can be challenging. During the assembly and fastening stages, it is crucial to properly regulate these elements. The overlap length and adhesive thickness in this study were 25 mm and 1 mm, respectively.

4.7.4 Adhesive curing process: Curing the adhesive, a chemical procedure that turns the glue from a liquid to a solid and increases its strength, is the last stage in creating a lap joint. The sample is prepared for testing after this curing process is finished.

4.7.5 Experimental Specimens: Three samples were found for testing.

Figure 2: Experimental Samples

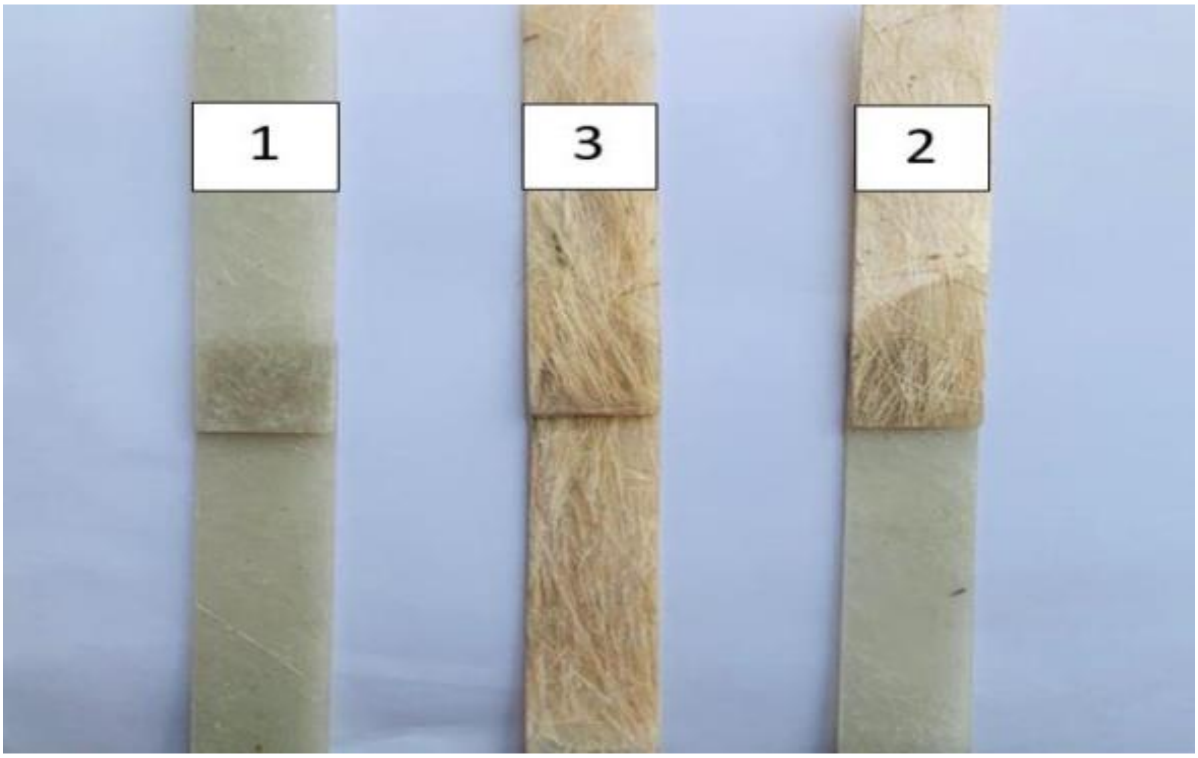


Table 2: Experimental Specimens

	Fiber	**Adhesive**
Sample 1 (SGG)	Glass Fiber + Glass Fiber	Cyanoacrylate Glue
Sample 2 (SGS)	Glass Fiber + Sisal Fiber	SHCP 268 Resin
Sample 3 (SSS)	Sisal Fiber + Sisal Fiber	SHCP 268 Resin

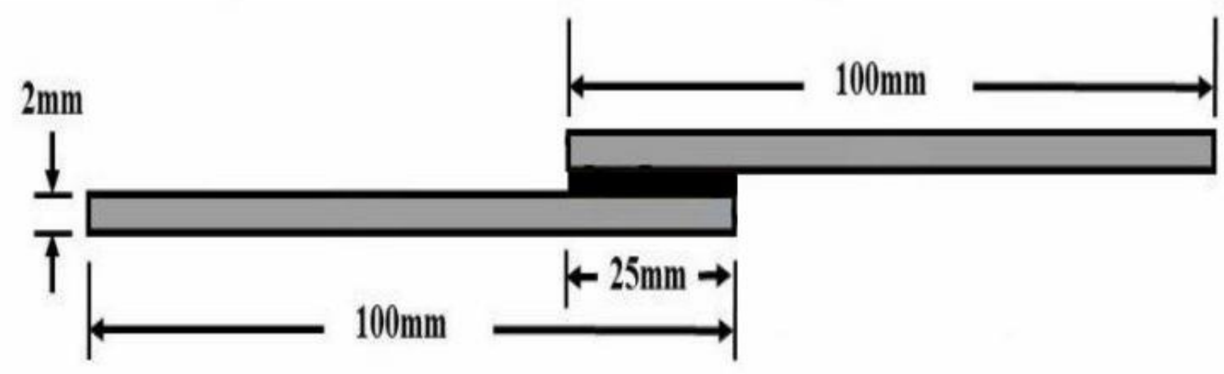
5. Experimental Setup

5.1 Specimen size:

Two specimens, each measuring 100 x 25 mm, are adhered to one another in such a way that the overlap is adequate to cause failure in the adhesive rather than the substrate. Usually, there is a 25 mm overlap.

The application of adhesives follows the guidelines provided by the adhesive manufacturer. The following represents the specimen size in accordance with ASTM D5868:

Figure 2: ASTM D5868 Standard Specimen for Tensile Test



5.2 Tensile testing:

The ASTM D5868 has been followed in the tensile test. The Universal Testing Machine "Hounsfield" was used to assist with the test. A 100mm gage length was maintained. The testing speed was 1.3 mm/min, and the maximum load was set at 10,000 N. A universal testing machine holds the test specimens, and they are dragged at a speed of 1.3 mm/min (0.05 in/min) until they break. The slope of the stress-strain curve's first straight-line section is known as Young's modulus. It can be computed using the equation that follows:

$$E = \frac{PL}{\delta A} \qquad (1)$$

$$E = \frac{\sigma L}{\delta} \qquad (2)$$

Here, δ = Deflection at the initial portion of the curve
σ = Corresponding deflection
L = Gage length
E= Young's Modulus

6. Result and Discussion

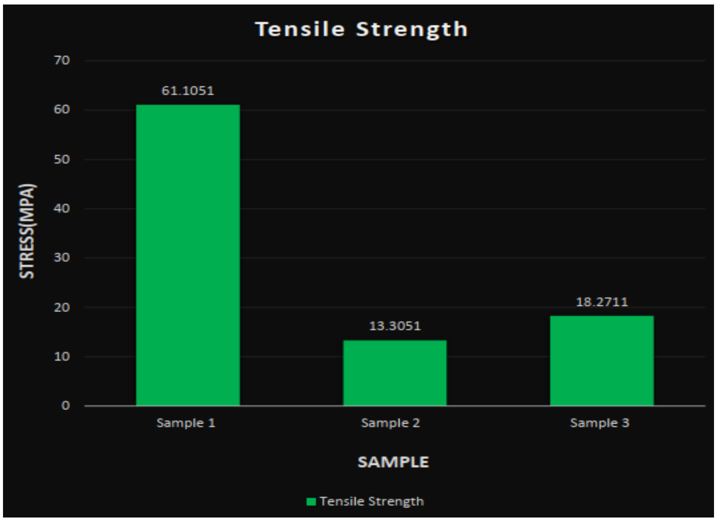
Tensile strength, Young's modulus, maximum rate of strain, failure load, and deflection have all been determined using tensile testing. The previous equation has been used to compute Young's modulus.

Table 3: Tensile Properties of Specimens

	Tensile Strength (MPa)	Maximum Strain (%)	Young's Modulus (MPa)	Failure Load (N)	Type of Failure	Maximum Deflection (mm)
Sample 1 (SGG)	61.1051	1.77462	3438.206	3365.23	Adhesive Failure	2.096
Sample 2 (SGS)	13.3051	0.64416	2065.491	686.795	Adhesive Failure	1.135
Sample 3 (SSS)	18.2711	1.06612	1713.790	938.641	Adhesive Failure	3.153

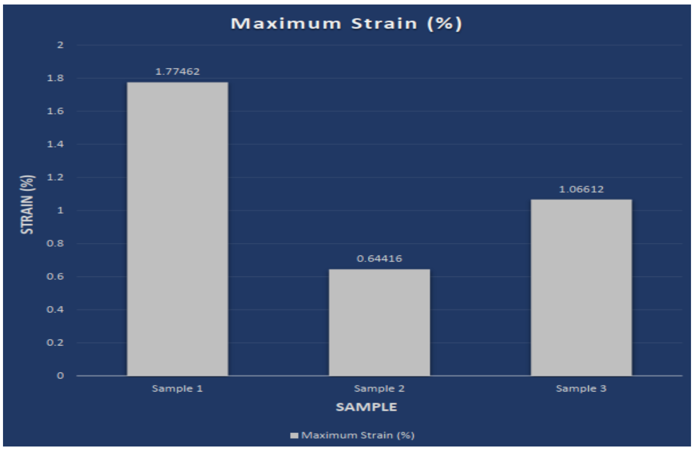
6.1 Comparative analysis of tensile properties: Among the glass fiber and sisal fiber composites, Sample 1 had the maximum strength, according to the experimental study. In this example, two glass fiber-reinforced epoxy composites were joined using cyanoacrylate glue. Sample 2, on the other hand, had the lowest strength since it used SHCP 268 resin to fuse a glass fiber-reinforced epoxy composite with a sisal fiber-reinforced epoxy composite.

Figure 3: Comparative Analysis of Tensile Strength



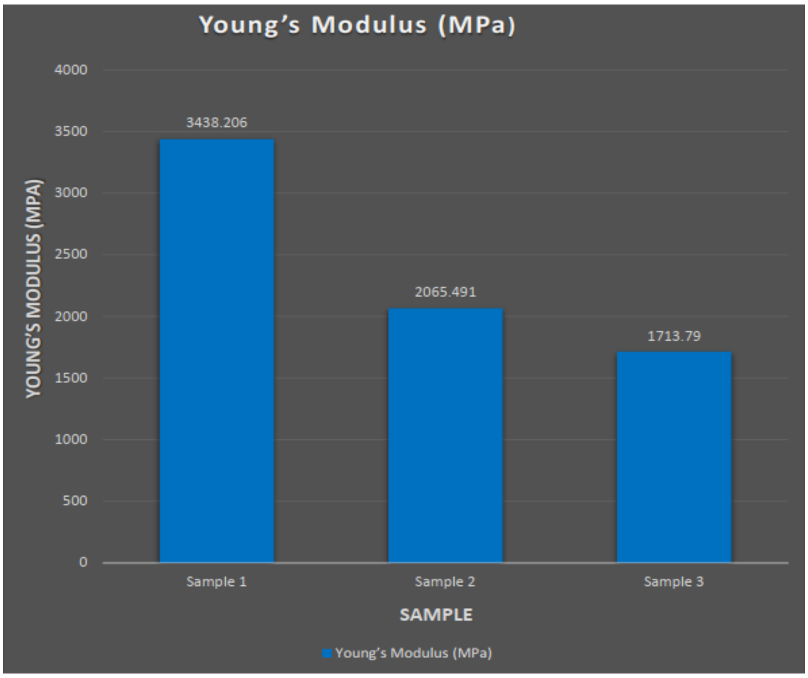
According to the experimental findings, of the glass and sisal fiber composites, Sample 1 exhibits the highest strain rate. This example used cyanoacrylate glue to join two glass fiber-reinforced epoxy composites. However, Sample 2, which bonded a glass fiber-reinforced epoxy composite with a sisal fiber-reinforced epoxy composite using SHCP 268 resin, exhibited the lowest strain rate.

Figure 4: Comparative Analysis of Tensile Strength



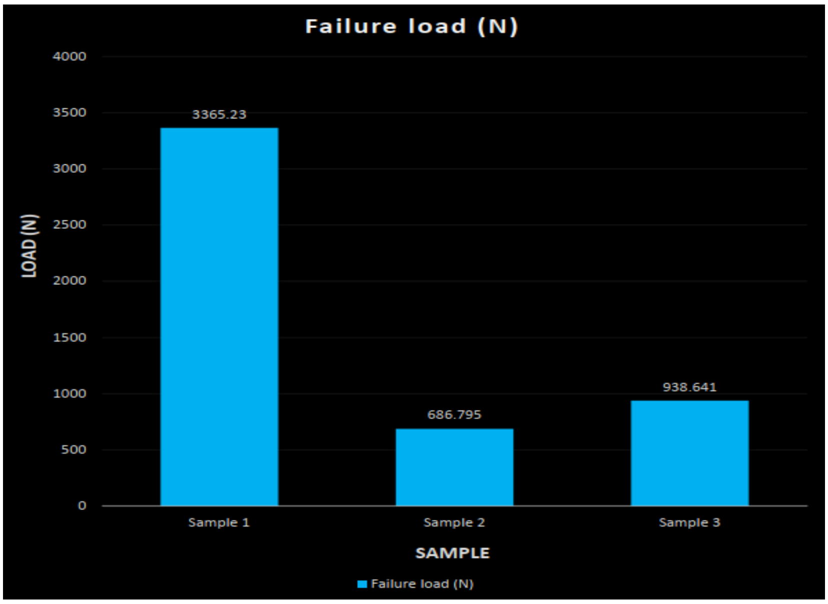
Young's modulus is highest at sample 1 among the glass and sisal fiber composites, according to experimental research. In sample 1, glass fiber-reinforced epoxy formed an adhesive bond with glass fiber-reinforced epoxy composites. As an adhesive, cyanoacrylate glue was employed. Young's modulus is at its lowest in sample 3. In sample 3, sisal fiber-reinforced epoxy formed an adhesive bond with sisal fiber-reinforced epoxy composites. As adhesives, SHCP 268 resin was utilized.

Figure 5: Comparative Analysis of Young's Modulus



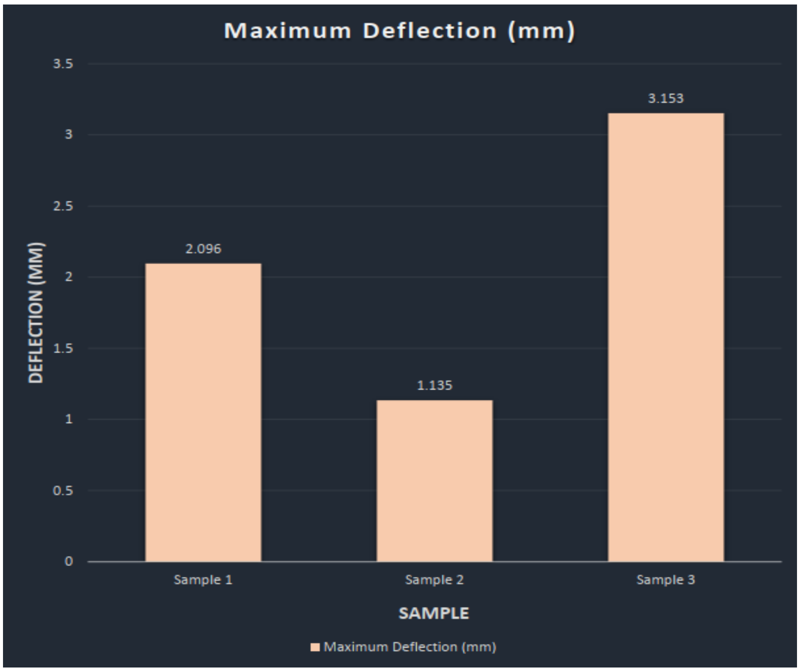
Among the glass and sisal fiber composites, Sample 1 achieves the highest failure load, according to the experimental study. This sample uses cyanoacrylate glue to create an adhesive link between two glass fiber-reinforced epoxy composites. However, using SHCP 268 resin as the adhesive, Sample 2 shows the lowest failure load due to the adhesive bond that forms between glass fiber-reinforced epoxy and sisal fiber-reinforced epoxy composites.

Figure 6: Comparative Analysis of Failure Load



According to the experimental analysis, of the glass and sisal fiber composites, Sample 3 shows the greatest deflection. SHCP 268 resin is used in this sample to create an adhesive bond between two sisal fiber-reinforced epoxy composites. In contrast, Sample 2, which also uses SHCP 268 resin as the adhesive, exhibits the least amount of deflection. This is because it creates an adhesive contact between glass fiber-reinforced epoxy and sisal fiber-reinforced epoxy composites.

Figure 7: Comparative Analysis of Maximum Deflection



7. Conclusions and Recommendations

Using a structural adhesive based on epoxy that can be used for a variety of purposes, this experiment examines the strength of fiber-reinforced epoxy composites in adhesively bonded structural joints. Sample 1 had the highest tensile strength, maximum strain rate, failure load, and Young's modulus, according to the data. Cyanoacrylate glue was more successful than SHCP 268 resin, and glass fiber-reinforced epoxy composites performed better than sisal fiber composites in these characteristics. Using high-strength fibers and raising the fiber volume percentage are two suggestions for improving tensile properties. Other suggestions include making sure the surface is properly prepared before bonding and using adhesives with the right qualities. It is also advised to perform fatigue analysis and further testing, like peel and impact tests, in order to assess how well adhesive bonding works in crashworthiness applications.

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