

Research Article

Experimental Investigation on Effect of Weight Fraction of Sisal Fiber on Mechanical Properties of Sisal-E-Glass Hybrid Polymer Composites

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Currently, hybridizing natural fibers with synthetic fiber is considered as the best solution for reducing the environmental pollution and the cost of materials. This is due to the lower mechanical properties and high water absorption capacity problems of natural fiber reinforced composites and nonbiodegradability and high-cost problem of synthetic fibers that can be solved by hybridizing them. This article aims to investigate the influence of the weight fraction of the sisal fiber on the mechanical property of the E-glass-sisal fiber reinforced epoxy matrix composite. The sisal fiber was treated by 8% sodium hydroxide (NaOH) for three hours. The samples of five different weight fractions of fibers (0%, 20%, 30%, 40%, and 60%) with a constant weight fraction of epoxy matrix (40%) were prepared as per the ASTM standard prepared by the manual hand layup method at room temperature. The tensile, compression, and flexural tests of the samples were carried out on the WP 310 universal testing machine. From the experimental results, it has been observed that the increasing weight fraction of the sisal fiber greatly influences the mechanical properties (tensile, compression, and flexural) of E-glass-sisal hybrid reinforced epoxy matrix composites. From all the tested samples, those consisting of 60% E-glass and 0% sisal fibers with 40% epoxy matrix showed better mechanical properties than other hybrid samples with tensile, compressive, and flexural strengths of 464.03 MPa, 40.1 MPa, and 239.06 MPa, respectively.

1. Introduction

Nowadays, mixing natural fibers with synthetic fibers is a well-known approach to get more advantages over using only pure synthetic fibers. This is due to the fact that natural fibers have low cost, ease of availability, less health impact, and easy biodegradability. However, the mechanical properties of natural fibers are not good as compared with those of synthetic fibers. So, in order to improve the mechanical properties of natural fibers, researchers are always in search of solutions in various directions. Mixing/hybridization of synthetic fibers to natural fibers are taken as the effective and cheaper solution. The authors in [1] studied the mechanical properties of synthetic-natural fiber hybrid composites, in which carbon nanofiber (synthetic fiber) and rice husk

(natural fiber) were used as reinforcements and bisphenol was used as a matrix. From the results, it was observed that the mechanical properties (including tensile, compression, and flexural) were improved by 12% for the reason of adding rice husk fiber to carbon nanofiber. Reference [2] also investigated the hybridization effect of natural fibers on synthetic (glass fibers) fibers for application in the pipe industry by using natural fibers including Kenaf, hemp, and flax. The tensile and flexural behaviors of hybrid natural fiber/glass reinforced epoxy composites in the form of laminates and laminas were the primary features investigated in this study. From the result, it was observed that laminas that were made from glass fiber have greater mechanical properties than laminas made with natural fibers. Also, using natural/glass fiber results in a 20% and 23%

reduction in cost and weight, respectively, as compared to existing plastic and metallic pipes.

The most common problem of using natural fibers as reinforcements is poor adhesion bond with matrix due to the existence of hydrophilic properties in fiber and hydrophobic properties in polymer matrices. In addition, high water absorption capacity and relatively lower durability are other challenges that restrict their industrial application and production of natural fibers in the real world, and this is the root cause which reduces the mechanical properties of natural fibers [3, 4]. However, in order to change the characteristics of natural fibers for industrial application as reinforcement, many schemes and techniques have been used, including the incorporation of coupling agents and the use of different treatment methods.

On the other hand, in the study reported by [5], the mechanical properties (tensile strength, flexural strength, and modulus of elasticity) of hybrid composites of sisal fibers with glass fiber in an epoxy polymer matrix were evaluated. From the results, it has been observed that by mixing sisal and glass fibers, the tensile strength increased by 86% than that of pure sisal and the elastic modulus also increased by 64%. In the bending tests, the results showed a performance of 19% for the maximum stress and 38% in the breaking stress for the hybrid composites. The fibers were treated in a sodium hydroxide solution (10% by weight) and subjected to tensile tests in a universal testing machine. As stated by [6], mixing glass fiber to natural fibers improved the mechanical properties of natural fibers. In this study, epoxy was used as matrix and sisal fiber was treated by acetylene to increase the interfacial bonding between reinforcement and epoxy matrix. From the results, it has been observed that tensile and flexural strength of hybrid composite increased by 4% and 6%, respectively. In a similar manner, [7] investigated the mechanical properties including tensile, flexural, and impact strengths of natural fibers (sisal and jute) to glass fibers, in which sisal-jute-glass fiber reinforced polyester composites were manufactured by manual hand layup. The interfacial properties, internal cracks, and internal structures of the fractured surfaces were evaluated by using the scanning electron microscope (SEM). From the results, it has been observed that adding sisal and jute to glass fiber can improve its properties.

In the research conducted and reported by [8], the tensile, flexural, and impact properties of the composite improved when sisal fiber was mixed to glass fiber. The hybridization also reduced the environmental effects. In a similar manner, the authors in [9] reported that hybridization of natural fibers with glass fibers allowed a significantly improved heat transport ability of the composite. Furthermore, the authors in [10] stated that hybridization of natural fibers with small amounts of synthetic fibers makes natural fiber composites more suitable for technical applications such as automotive interior parts. For this study, injection-molded short hemp fibers and hemp/glass fiber hybrid with polypropylene was selected as a matrix material. From the results, it has been observed that both the impact and bending properties of the composites can be improved by adding glass fibers. In a similar manner, the thermal

properties and moisture resistance capacity of composites were modified by adding glass fiber into hemp/polypropylene composites.

Moreover, reference [11] studied the effect of hybridization of glass fiber with a flax fiber reinforced polypropylene matrix on the mechanical properties as well as the effect of treating flax fiber by chemicals on mechanical properties. From the study, they reported that the ratio of the fibers (glass/flax) has significantly affected both the tensile strength and the elastic modulus of hybrid composites. The other problem comes with using natural fibers as reinforcement in various applications includes durability and lower aging of natural fibers. This hinders the wider use of natural fibers. Reference [12] studied the effect of hybridizing bamboo fibers with glass fibers on the mechanical properties of hybrid composites. From this study, both the elastic modulus and tensile strength of glass/bamboo fiber reinforced polypropylene hybrid composites were greatly decreased after long period of time. Similar to [12], the effect of hybridizing natural fiber by synthetic fiber was also studied by [13] using curaua fibers and glass fibers as reinforcement. Tensile and flexural strengths were the parameters used for mechanical properties characterization. From the result, it has been observed that both the tensile and flexural properties of composites were improved by adding glass fiber for a higher volume fraction.

References [14–17] investigated the effects of adding glass fiber into sisal fiber by using a polymer matrix on tensile properties. As stated by [15], the tensile strength of the sisal/glass hybrid composite is greater than the tensile strength of individual fibers. In addition, this study reported that the tensile strength of the sisal/glass hybrid mainly depends on the weight fraction of glass rather than the sisal weight fraction. Reference [14] also stated that the mechanical properties of PALF and sisal fiber are improved by adding the glass fiber in to it. Furthermore, [18] conducted research on the effect of glass fiber hybridization on the physical properties of sisal-polypropylene composites. From the results, it was concluded that mixing glass fiber into the sisal fiber reinforced by polypropylene matrix composites can improve tensile, flexural, and impact strengths. In addition, adding glass fiber improved the thermal properties and water resistance of the composites.

The effect of chemical treatment on the mechanical properties of natural fibers is also one of the most investigated areas. This is because the major problem of natural fiber composites originates from the hydrophilic nature of the fiber and the hydrophobic nature of the matrix. The inherent incompatibility between these two phases results in weakening the bonding at the interface. The hydrophilicity of natural fibers results in high moisture absorption and weak adhesion to hydrophobic matrices. The natural fibers can be treated to improve the adhesion to matrix materials. In addition, most natural fibers have low degradation temperatures, which make them incompatible with thermosets that have high curing temperatures. This also restricts natural fiber composites to limit them to relatively low-temperature applications [19]. To solve this negative effect of natural fibers, the natural composites

should be treated. As stated by [20, 21], modifying the fiber surface by using chemical treatment can enhance bond strength between the fiber and the matrix. Chemical treatment is also an effective way to clean the fiber surface, chemically modify the surface, stop the moisture absorption process, and increase the surface roughness. In addition, as reported by [22], the overall mechanical properties of natural fiber reinforced polymer composites are highly dependent on the morphology, aspect ratio, hydrophilic tendency, and dimensional stability of the fibers used. The significance of chemically-treated natural fibers is seen through the improvement of the mechanical strength and dimensional stability of the resultant composites.

Effect of treating natural fibers and various methods of treating natural fibers have been researched by different researchers. As stated by [17], the interfacial adhesion between the matrix and the fibers mainly affects the tensile properties of natural fibers reinforced by either thermoset or thermoplastic matrix. Not only interfacial adhesion between matrix and fibers but also the tensile strength of natural fibers can be greatly affected by the weight fraction of fibers.

Reference [23] presented the effect of alkali treatment on the properties of natural fibers. Other properties including mechanical, physical, thermal, and tribological properties of biocomposites were also studied in this research. From the results, it was concluded that the properties of bio composite were improved by a great extent by alkali treatment. According to the study reported by [24], raw sisal and raw jute fiber reinforced epoxy matrix composites are treated by sodium hydroxide, where both jute and sisal fibers were treated with 20% sodium hydroxide for 2 hours. The aim of the study was to compare and analyze the mechanical properties of both treated and raw (sisal and jute) fibers. Furthermore, mechanical properties (tensile and flexural strength), water absorption, and morphological changes had been investigated on the prepared specimens. As indicated by the results, both treated jute and sisal fiber reinforced epoxy composites showed better properties than raw jute and sisal. Reference [25] also investigated the influence of fiber treatment on the mechanical characteristics of unidirectional sisal-reinforced epoxy composites. In this research, alkalization, acetylation, cyanoethylation, the application of a silane coupling agent, and heating were selected as natural fiber treating methods for the purpose of improving its properties. From this study, it has been observed that when the treated fibers were incorporated into an epoxy matrix, it improves the adhesion force between the fibers and matrix. In the same way, treatments can significantly lead to the easy entrance of the matrix resin into the fibers, blocking the pull-out of the cells.

From previous study, researchers tried to replace metallic materials by other advanced materials. Among their efforts, nowadays, replacing the existing metallic materials by composite materials is one of the widely adopted methods. Not only composite materials, but also light weight metallic materials like aluminum was used as solutions for the purpose of reducing the weight of components in previous times. However, the high cost of lightweight materials results in other problems and obstacles for using those

lightweight materials as alternative materials. Furthermore, researchers decided to use synthetic fibers including carbon, glass, and aramid fibers as alternative materials for metallic materials especially for reducing the weight of components. This achievement was not with zero disadvantage because of the nonrenewability, health risks, and high costs that accompany the inventions of synthetic fibers. The above listed problems can be solved by using natural fibers including the jute and hemp fibers. But, high water absorption and low mechanical properties of natural fibers limit their application.

Therefore, this article aims to investigate the effect of the weight fraction of natural fiber (sisal) on the mechanical properties of sisal/E-glass reinforced hybrid composites by mixing both synthetic (E-glass), and natural fiber (sisal) by collecting the high strength and stiffness advantages from E-glass and the low health risk and low-cost advantages from sisal fibers in order to solve the problem of using synthetic and natural fiber individually.

2. Materials and Methods

2.1. Materials. In this research, the E-glass (Figure 1(a)) was purchased from World Fiber Glass and Water Proofing Engineering in Addis Ababa, Ethiopia, and the sisal fiber (Figure 1(b)) was obtained from the Addis Ababa Science and Technology University campus. The basic characteristics of E-glass fiber [26] and sisal fibers [7, 26–28] are given in Tables 1 and 2, respectively.

Epoxy resin AY-105 with a brand name (“SYSTEM # 2000 EPOXY”) was used as matrix material in this article. This is since epoxy shows superior mechanical properties when compared to polyester. Epoxy is used very effectively as an adhesive and as a laminating resin for many engineering applications. It offers excellent moisture-barrier qualities when used in polymer composites. It binds extremely well to fibers for making fiber reinforced polymer composites [29]. It was obtained from Kadisco Paint and adhesive industry share company in Addis Ababa, and its properties are given in Table 3.

To convert the epoxy resin and monomer component from a liquid to a solid form, a hardener was used, which acts as a curing agent and catalyst so that it cures the epoxy into a strong adhesive. For this research, hardener HY-951 (curing agent) with the brand name (“SYSTEM # 2060 HARDENER”) was obtained from Kadisco painting and adhesive company. The volume ratio of resin to hardener was determined as 2:1 for better dimensionally stable laminates with free residual internal stresses. In addition, mold releasing agent (brand name HONEY WAX 250), which can prevent materials from sticking, was obtained from the local market (World Glass Fiber and Water Proofing PLC).

2.2. Experimentation Method

2.2.1. Sisal Fiber Extraction Process. To extract the sisal fibers, hand/manual extraction process was used due to the unavailability and high cost of mechanical decortication. The

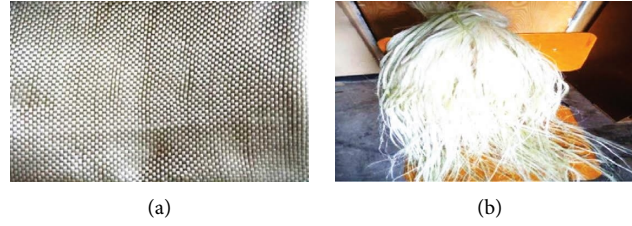


FIGURE 1: Fibers selected for research: (a) E-glass fiber and (b) sisal fiber.

TABLE 1: Properties of the E-glass fiber [26].

Parameters	E-glass fiber	Units
Density ρ	2.54	g/cm^3
Longitudinal modulus, E_{1f}	85	GPa
Transversal modulus, E_{21f}	85	GPa
Axial shear modulus, G_{12f}	30	GPa
Transverse shear modulus, G_{23f}	30	GPa
Poisson's ratio (ν_{12f})	0.23	—

TABLE 2: Properties of the sisal fiber [7, 26–28].

Physical properties	Values	Units
Density ρ	1.41	g/cm^3
Elongation at break	6-7	—
Cellulose content (%)	60–65	—
Lignin content (%)	10–14	—
Tensile strength	511–635	MPa
Longitudinal Young's modulus	9–22	GPa
Transversal Young's modulus	3.85 ± 0.87	GPa
Poisson's ratio	0.175	—
Diameter	205–230	μm
Lumen size	11	μm

TABLE 3: Properties of epoxy resin [45].

Parameters	Values	Units
Density ρ	1.108	g/cm^3
Young's modulus, E_m	3.4	GPa
Shear modulus, G_m	1.26	GPa
Poisson's ratio ν_{mf}	0.36	—
Tensile strength, σ_{tm}	80	MPa
Compressive strength, σ_{cm}	104	MPa
Shear strength, G_{12}	40	MPa
Coefficient of thermal expansion, α_{1f}	62	$10^{-6}/^\circ\text{C}$

manual sisal extraction process also has advantages over mechanical decortication for extracting natural fibers because the method does not require a special tool, a skilled operator, or a low cost. Moreover, this method can be used in rural areas where there is no electric power.

After cutting the leaves of the sisal plant at their base with the help of a sickle as shown in Figures 2(a) and 2(b), the leaves were trimmed into two or three parts depending on the size of leaves in the longitudinal direction. This is done for ease of the fiber extraction process. Then, the peel was clamped between the wood plank and knife and hand-pulled gently in a longitudinal direction in order to remove the

resinous material as shown in Figure 2(c). After the extraction process, the extracted sisal fiber was washed with pure water in order to remove and separate unwanted dusts from the fiber and it was dried in the sun. Eventually, the required fine fibers were obtained as shown in Figure 2(d).

2.3. Sisal Fiber Treatment Process. Several research activities have been conducted to improve fiber adhesion properties with the matrix through chemical treatments, because chemical treatments on reinforcing fiber can reduce its hydrophilic tendency and thus improve compatibility with the matrix [30]. Due to its broad availability, good modification characteristics, improved mechanical qualities, strong impact strength, and low cost, NaOH is the most often used chemical for treating natural fibers. When treating the natural fibers, the percentage of NaOH that is mixed with distilled water needs serious attention. This is due to the fact that percentages of alkali concentration affect the mechanical properties of natural fibers. When the percentage of NaOH is increased, it affects the fibers properties by reducing the adhesive, and bonding capacity during preparation of the composite samples [31]. The appropriate ratio of sodium hydroxide and distilled water is important parameters and need attention during treatment of natural fibers because treatment of natural fibers has direct effect on mechanical properties of natural fibers. On the other hand, the immersing time of natural fibers in sodium hydroxide and distilled water solution also has direct effect on mechanical properties of natural fibers. Excess of chemical solution (10%) did not only remove part of the boundary layers of the natural fibers but also causes some deterioration to the fiber particles themselves that can reduce the overall tensile strength. On the other hand, if the percentages of sodium hydroxide are minimum, (below 4%) boundary layers of the raw fiber are not completely removed. Hence, some weakness is observed in the strengths [32]. In this article, based on several literature, the average value of 8% NaOH and 92% distilled water (that was obtained from atomic laboratory and teaching material PLC, Kirkos subcity, Addis Ababa) was mixed at room temperature was used.

After agitating the sodium hydroxide in distilled water, the sisal fiber was then immersed in the solution (NaOH and distilled water) for three hours, and the bucket was covered with a plastic sheet in order to avoid the interaction of sodium hydroxide with environments. Then, it was washed several times with distilled water to neutralize it. Lastly, the fibers were allowed to dry in sun

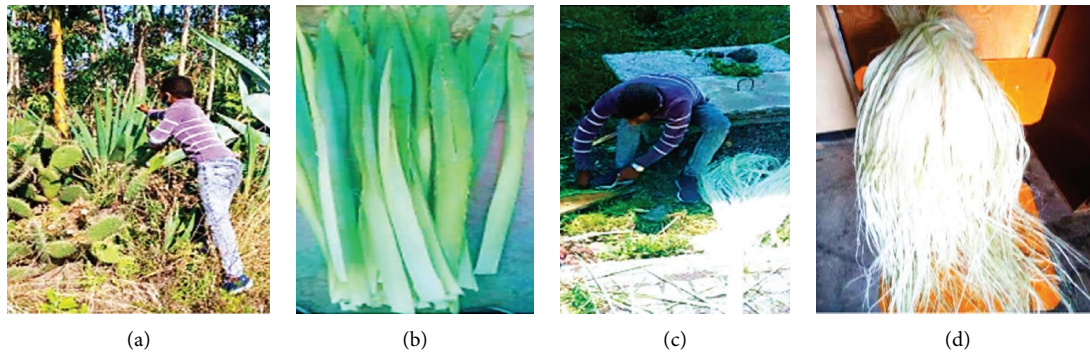


FIGURE 2: Sisal fiber extraction process, (a) harvesting the sisal plant, (b) collecting the sisal plant, (c) fiber extraction process, and (d) extracted sisal fiber.

light for 3 days. The whole treatment process is shown in Figure 3.

Nowadays, the automotive and construction industries are the largest segments for natural fiber composite applications [33]. In addition, natural fiber reinforced composites are also most promising and interesting for decking (furniture application), railing, plywood, plastic lumber, and window/door applications [34]. Moreover, applications of natural fibers including paper products, building materials, absorbents, and animal feeds [20].

2.4. Experimental Design. In this research, the effect of fiber weight fraction on mechanical properties such as tensile, compression, and bending (flexural) strengths were considered. Properties of the E-glass/sisal hybrid were calculated by the rule of mixtures approach. This was done due to the fact that the rule of mixtures is a method for estimating composite material properties based on the idea that a composite property is the volume-weighted average of the matrix and fiber phases. It approximates parameters such as elastic modulus, mass density, and ultimate tensile strength, theoretically. The mechanical properties of a fiber reinforced composite are directly related to the amount of fiber and matrix in the composite. Due to manufacturing characteristics, the fiber volume ratios for the fabrication of composites lie between 50% and 65%. This is because an extremely high fiber volume can lead to more delamination between the fibers. Due to a shortage of space for the matrix to properly surround and connect with the fibers, too much fiber volume may also reduce the composite's strength. Therefore, 60% fiber (E-glass and sisal), and 40% epoxy resins were selected as reinforcement and matrix, respectively, for this study. The weight fraction selected in this article is shown in Table 4.

2.5. Fabrication of Hybrid Specimen. There are different fabrication methods of composite laminates including, hand lay-up, autoclave molding, filament winding, pultrusion, and resin transfer molding. In some cases, the fabrication methods determine the shape and application of the composite. For instance, filament winding is generally used for making pipes and tanks to handle chemicals, autoclave

forming is used to make complex shapes and flat panels for structures in which low void content and high quality are important, and resin transfer molding is extensively used in the automotive industry because short production runs are necessary [35]. Among these, the hand lay-up process is selected for this article because it is the simplest and most widely used fabrication process of composite materials, and this method is commonly used when there is no need of special equipments for production of samples. It also requires low costs. Hand lay-up is widely used for thermoset composites, and it involves a manual mixing procedure of the fiber and the matrix. In this process, the uniformity of the composite in terms of thickness, fiber to matrix ratio, and void content throughout the sample depends on the workmanship skill [22]. In addition, manually hand lay-up is mainly used for the fabrication of natural composite samples due to the problem of natural fibers with flow in injection molding machines, and it has lower elongation properties [36].

After deciding the method of composite laminate fabrication, the next task is preparing the mold that is used for the fabrication of laminates. The mold may be made of wood, plastics, or metals depending on the number of parts, cure temperature, pressure, etc. In this research, the mold was made from wood (Figure 4(a)). After completing the preparation of the mold, Figure 4, the reinforcements (sisal and E-glass fibers) were cut as per the mold size and measured on the digital weighting machine (Figures 4(c) and 4(d)) to mixing appropriate fibers with matrix. Then epoxy resin AY-105 and hardener HY-951 (curing agent) were mixed thoroughly for at least 5 minutes (Figure 4(e)).

After spraying the releasing agent (wax) (Figure 4(f)), epoxy was placed on the mold surface as shown in Figure 4(g). Then, the first layer of the fibers was placed at the surface of the mold (Figure 4(h)). The main objective of applying the wax on the mold surface is to avoid the sticking of epoxy to the mold surface and to facilitate the removal of the finished part. The epoxy is uniformly distributed with the help of the brush. The second layer of fibers is then placed on the epoxy surface, and a roller was moved with a mild pressure on the fiber-epoxy layer to remove any air trapped as well as the excess epoxy present (Figure 4(i)). The overall process is repeated for each layer of epoxy and fibers, till the

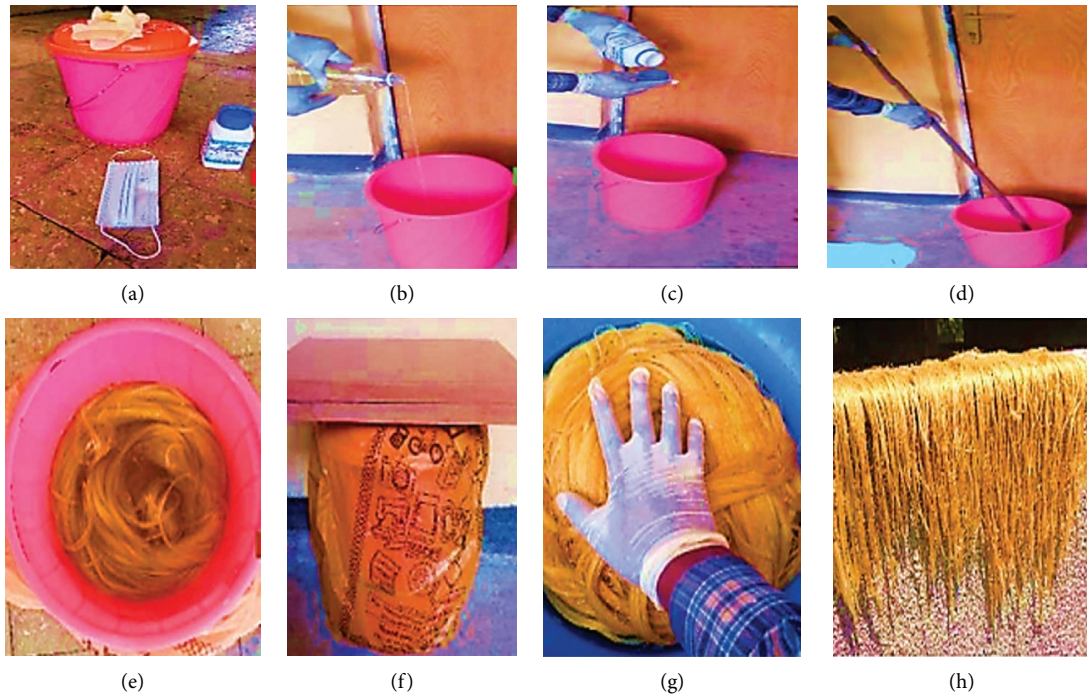


FIGURE 3: Sisal alkali treatment process, (a) apparatus required for treatment, (b) adding the distilled water to bucket, (c) adding the NaOH to distilled water, (d) preparing solution of NaOH and distilled water, (e) immersing the sisal fiber in to solution, (f) covering the bucket with plastic sheet, (g) washing the sisal fiber by distilled water, and (h) drying the treated sisal fiber in sun.

TABLE 4: Fibers versus matrix weight fraction.

Hybrids	Fibers weight fraction		Matrix weight fraction
	Sisal	Glass	Epoxy
H1	0.00	0.60	0.40
H2	0.20	0.40	0.40
H3	0.30	0.30	0.40
H4	0.40	0.20	0.40
H5	0.60	0.00	0.40

required layers were obtained. After all required thickness was obtained, the mold cover was placed on the top of the mold and 5 MPa pressure was applied on it by using hydraulic pressing machine (Figure 4(j)) for the purpose of curing and to increase the bonding force between epoxy and fibers (E-glass and sisal fibers). After curing for a period of 24 hours, the mold was opened, and the fabricated sisal/E-glass hybrid composite specimen was taken out from the mold (Figure 4(k)) and cut into the required dimension based on ASTM standard specifications and prepared for further tests.

2.5.1. Secting Sample Sample Size. In order to study any property of a material, including mechanical properties, material should be sized according to the recommended standards (ISO, ASTM, etc.). This is since the specimens are cut according to the standards to get the required dimensions. Among the available standards, ASTM (American standard for testing material) is a well-known standard and

many researchers use this standard. There are various ASTM standards for testing composite materials and for this article ASTM D3039, ASTM D3410, and ASTM D709 were selected. This is because these standards are widely selected by various researchers. As reported by [37, 38], for tensile test, flexural test, and compression test, ASTM D3039, ASTM D3410, and ASTM D709, respectively, are convenient for testing composite materials. The size of the sample used for this study, as recommended by ASTM standards, is shown in Table 5.

3. Results and Discussion

3.1. Tensile Test Results. The tensile test is the fundamental material characterization method for engineering applications in which the samples prepared as per ASTM standards were subjected to controlled tension force. In this research, the tensile test was performed by preparing three specimens of a hybrid E-glass/sisal hybrid of five different weight fractions of (0%, 20%, 30%, 40%, and 60%) of E-glass fibers with (60%, 40%, 30%, 20%, and 0%) of sisal fibers, while the weight fraction of the epoxy matrix was kept constant at 40%.

3.1.1. Stress versus Elongation of Hybrid Composites. The stress-elongation (strain) is the basic parameters that are recorded during longitudinal tensile test on a universal testing machine. But, due to many factors including testing conditions, temperature effects, manufacturing errors since the specimens were fabricated by manual hand layup, and personal errors, the values of all specimens were not exactly

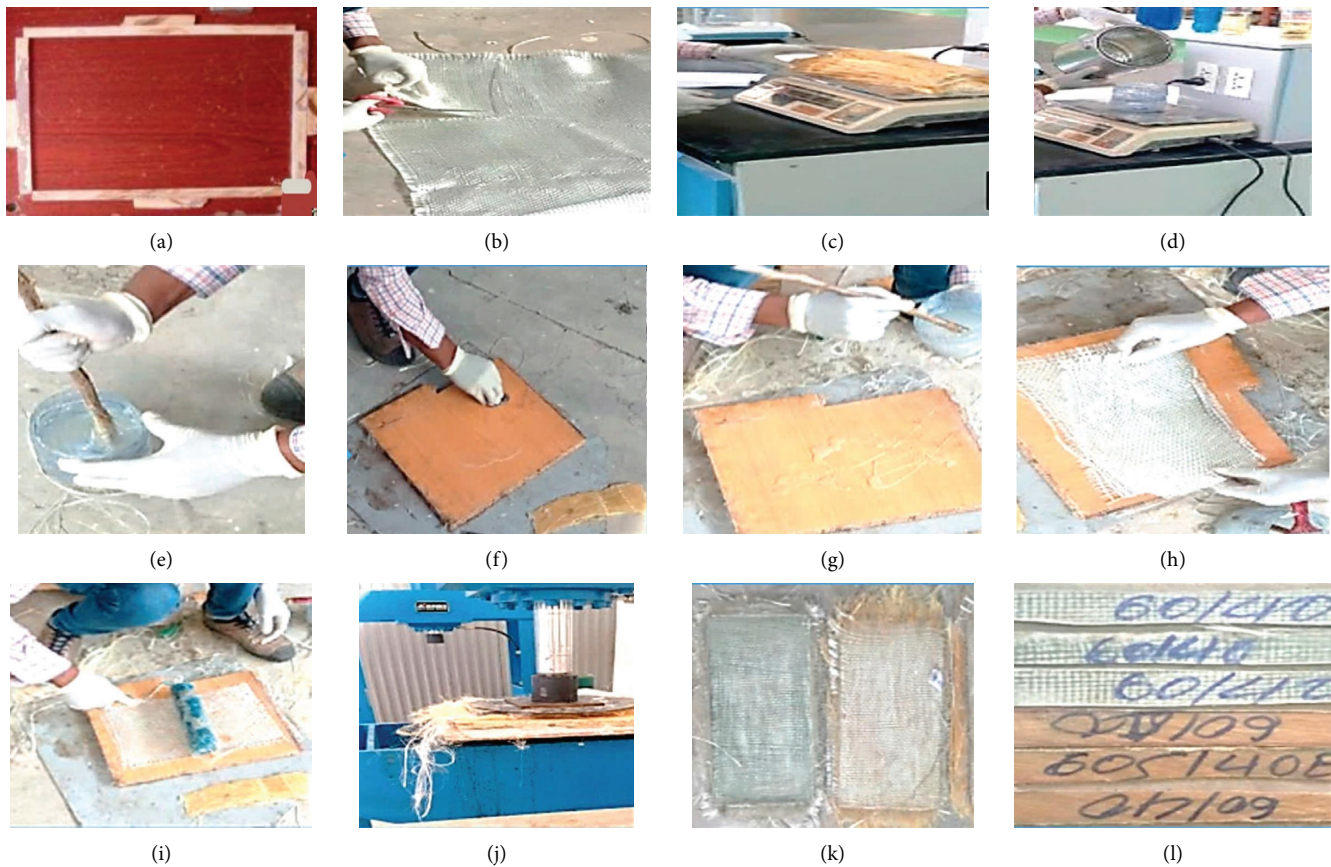


FIGURE 4: Laminates preparing procedure: (a) mold preparation process, (b) cutting the fibers in required dimension, (c and d) measuring the fibers and epoxy, (e) mixing the hardener and epoxy, (f) spraying the wax to the mold surface, (g) placing the epoxy resin on mold surface, (h) placing the fibers in the mold, (i) applying pressure to provide good contact of fiber and epoxy by roller, (j) curing the laminates under HPM, (k) removing the laminates from mold, and (l) cutting the laminates under pressing machine, in to ASTM standard dimension by hack saw.

TABLE 5: ASTM standard size of samples.

Mechanical properties	Sample size (length \times width \times thickness)	Standards
Tensile strength	220 \times 25 \times 4	ASTM D3039
Compression strength	50 \times 50 \times 4	ASTM D3410
Flexural (bending) strength	150 \times 20 \times 4	ASTM D709

the identical. Therefore, to overcome the above listed problems, the average values of longitudinal tensile strength were used in this article, and the test results are plotted in Figures 5(a) and 5(e). The plots clearly indicate the influence of sisal fiber on the hybrid composite. The tensile strength is at its highest value (about 464 MPa) in the absence of sisal fiber (Figure 5(a)), while the highest weight fraction of sisal fiber, i.e., lowest (zero) weight fraction of E-glass fiber, has the lowest tensile strength (Figure 5(e)). In other words, the tensile strength decreases with an increasing weight fraction of sisal fiber.

The tensile strength results of the five different weight fractions of the composites are shown in Figure 6. From the bar graphs of the tensile strength results, the weight fraction of sisal fiber mixed to E-glass fiber did affect the longitudinal

tensile strength of the E-glass/sisal hybrid samples. The tensile strength improved with decreasing sisal fiber weight fraction and an increasing weight fraction of the E-glass fiber. The results reported in this work agree with the result reported by [39] which stated that the hybrid composites with a higher weight fraction of glass fiber layers achieve higher values of tensile strength. In the article reported by [40] it is also reported that by incorporating 20% of glass fiber by weight improves the tensile strength of bamboo/glass fiber reinforced hybrid composites by 7%. Their conclusion indicates that the tensile strength properties of the fabricated hybrid composite increased as the weight fraction glass fiber content increased and decreased as the weight fraction of sisal increased. This is due to the fact that natural fibers have lower mechanical properties than synthetic fibers. Generally, this report agrees with the results reported by [41], which stated that natural fiber composites are not having sufficient strength to replace the conventional materials and that the hybrid combinations of natural fibers are preferred for applications like automotive interior parts.

The maximum longitudinal tensile strength was 464 MPa which occurred for the composites of 0% sisal and 60% E-glass with a 40% epoxy matrix. The minimum longitudinal

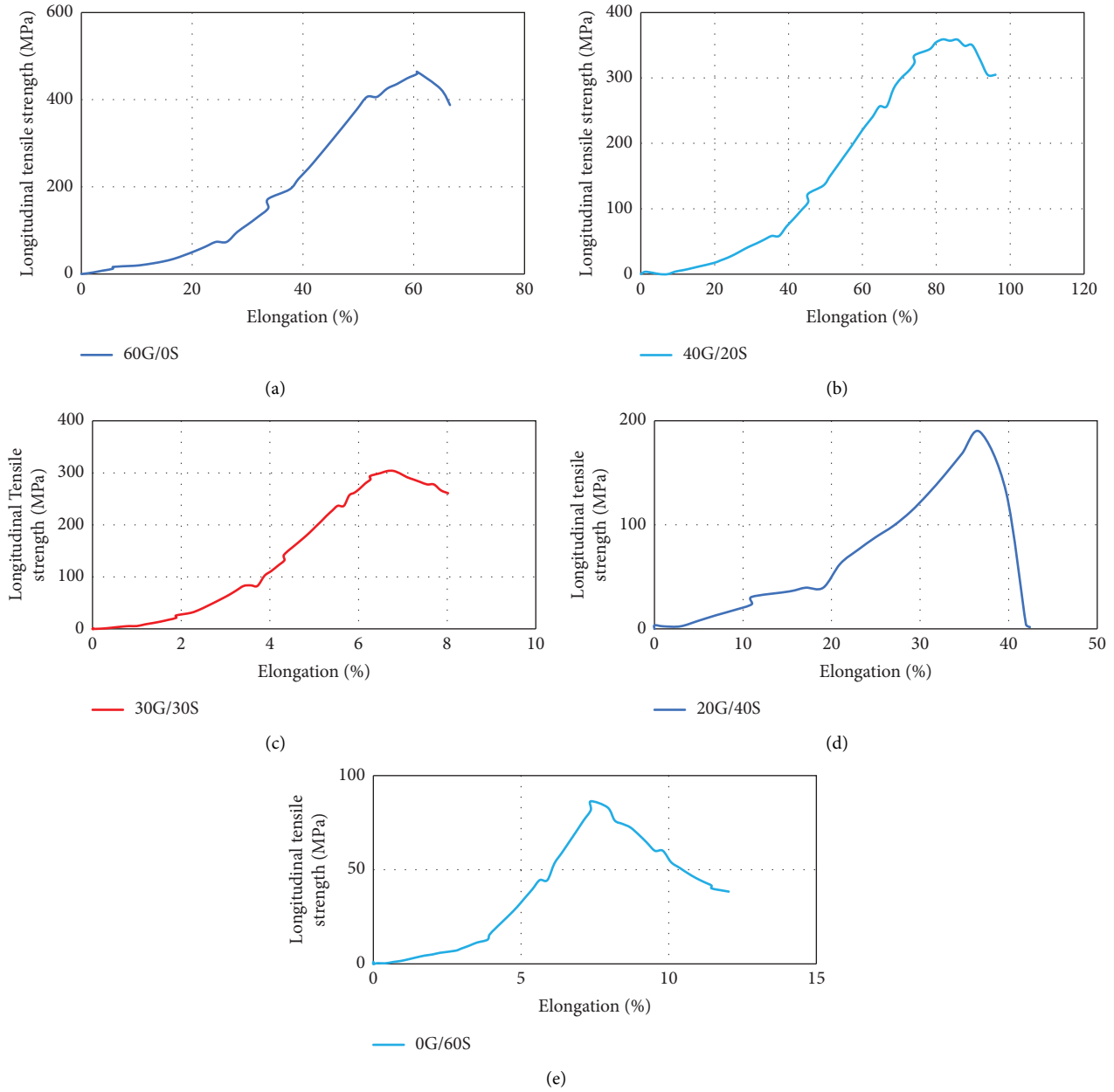


FIGURE 5: Stress versus elongation for various weight fraction of E-glass/sisal hybrid composites.

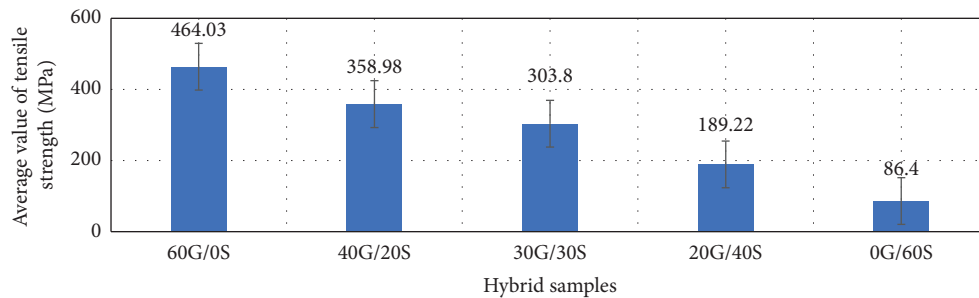


FIGURE 6: Average longitudinal tensile strength for hybrid laminates.

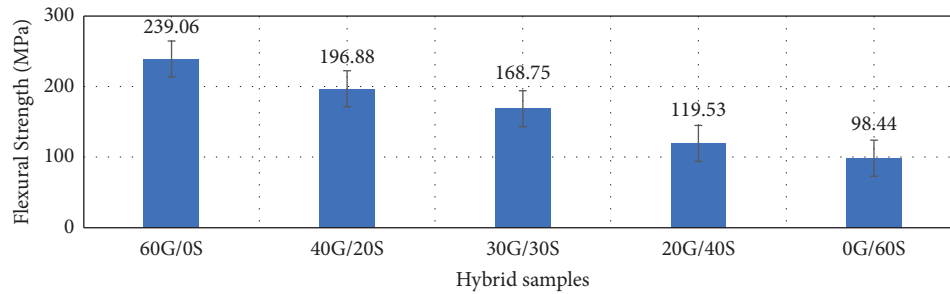


FIGURE 7: Flexural strength of hybrid composites.

tensile strength was 86 MPa which occurred for the composites of 60% sisal, and 0% E-glass with 40% epoxy. From the tensile test results, it is easily observed that the longitudinal tensile strength of 60% sisal and 0% E-glass fiber reinforced composites tensile strength was decreased by about 81% when compared to the tensile strength of 0% sisal and 60% E-glass fiber reinforced epoxy matrix composites. In addition, the longitudinal tensile strength of 20S/40G, 30S/30G, and 40S/20S were decreased by 23%, 36%, and 59%, respectively, from longitudinal tensile strength of 0S/60G composites. As seen from the results, the longitudinal tensile strength of E-glass/sisal hybrid reinforced epoxy matrix composites decreases in a linear manner with an increasing weight fraction of sisal fiber. This decrement in longitudinal tensile strength results from the lower bonding between sisal and E-glass fiber. Moreover, the tensile strength of natural fibers (in this case, sisal) has lower tensile strength than synthetic (E-glass) fiber. The weight fraction of the matrix (epoxy) was kept constant at 40% throughout the test.

3.2. Flexural Test Results. Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. For the three-point bending test, three specimens for five different weight fractions of E-glass and sisal fiber with a constant weight fraction of matrix (epoxy) were prepared by manual hand layup as per ASTM D790 standard with the dimension of 150 mm × 20 mm × 4 mm.

The flexural properties of sisal/E-glass hybrid reinforced composites of different weight fraction of sisal and E-glass fibers are shown in Figure 7. It is observed from the plots that the flexural characteristics of the composites are affected by the weight fraction of sisal fiber. This result agrees with the result reported in [31]. The glass hybrid laminates have better flexural properties than the pure natural laminates, and the properties seem to be increasing with the addition of the weight fraction of glass fibers. Furthermore, as reported in [28], the hybrid composites with a higher weight fraction of glass fiber have higher flexural properties than pure sisal composites.

The plots in Figure 7 also show that the maximum flexural strength of 60G/0S is maximum, and its value is about 239 MPa, while the flexural strength of hybrid composites with 0G/60S is found to be about 98 MPa. From the

flexural test results, it is easily observed that the flexural (bending) strength of 60% sisal and 0% E-glass fiber reinforced composites strength decreased by 59% when compared to the bending strength of 0% sisal and 60% E-glass fiber reinforced epoxy matrix composites. In addition, the flexural strength of 20S/40G, 30S/30G, and 40S/20S are decreased by 18%, 29%, and 50%, respectively, when the results compared with the flexural strength of 0S/60G composites. This decrement in flexural strength properties results from the lower flexural properties natural (sisal) and the lower bonding between natural (sisal) and synthetic (E-glass) fibers. Also, as seen from the results, the flexural strength of E-glass/sisal hybrid reinforced epoxy matrix composites decreases in a linear manner with an increasing weight fraction of sisal fiber. From these results, we conclude that flexural (bending) stress decreases as the weight fraction of sisal fiber increases.

3.3. Longitudinal Compression Test Results. The stress-elongation (strain) is the basic parameter that is recorded during the longitudinal compression test on the universal testing machine. The longitudinal compressive strength-elongation of E-glass/sisal hybrid laminates for each weight fraction of fibers is shown in Figure 8 below. Due to the same reason for the tensile test, however, the values of maximum longitudinal compressive stress for all specimens are not exactly the same, so the average value of the longitudinal compressive stress of those specimens is used in this article.

For the compression test, three specimens with five different weight fractions of E-glass and sisal fiber were prepared as per ASTM 3410D. The dimension of the specimens was 50 mm long × 50 mm wide × 4 mm thickness. The results of the average compressive strength of the three composites types are shown in Figure 8. As depicted, the composite 0G/60S has the lowest compressive strength, which is 17.1 MPa, whereas the composites of 60G/0S has the highest compressive strength which is equal to 40.1 MPa. From the compression test results, it is easily observed that the compressive strength of 60% sisal and 0% E-glass fiber reinforced composites compressive strength was decreased by 57.4% when compared to the tensile strength of 0% sisal and 60% E-glass fiber reinforced epoxy matrix composites. In addition, the compressive strength of 20S/40G, 30S/30G, and 40S/20S were decreased by 12.7%, 19%, and 40%,

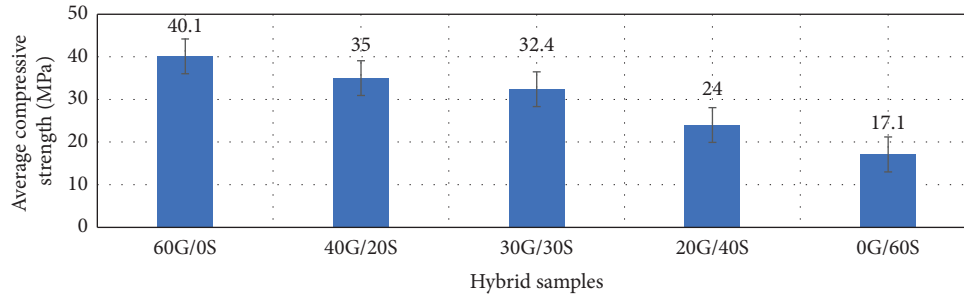


FIGURE 8: Longitudinal compressive stress of various weight fraction of fibers.

TABLE 6: Mechanical properties of sisal/glass hybrid composite.

Sample designation	Tensile strength (MPa)	Flexural strength (MPa)	Reference
0G/60S	86.4	98.44	Current work
0G/33S	23	61	
17G/22S	52	159	[44]
23G/15S	93	184	

respectively, when the results are compared with the compressive strength of 0S/60G composites. As seen from the results, the compressive strength of E-glass/sisal hybrid reinforced epoxy matrix composites decrease in linear manner with an increased weight fraction of sisal fiber. This agrees with the study reported by [42] on the mechanical property of E-glass/sisal hybrid reinforced composites has the higher compressive strength than pure sisal composites. In addition, as stated by [43], the incorporation of natural fibers such as sisal/jute with glass fiber composites has gained increasing applications both in many areas of engineering and technology.

For the sake of validation of the results of this study, the tensile strength and flexural strength results are summarized in Table 6 and compared with published work on the same topic. Though the proportions of sisal fibers are different, the comparison shows that a higher weight fraction of sisal fiber influences (lowers) both the tensile and flexural strengths.

4. Conclusion

Research progress on the mechanical behavior and performance of composite materials reinforced with natural fibers has been a topic of interest in the past decades. This article investigates the effect of the weight fraction of the sisal fiber on mechanical properties (tensile, compression, and flexural) of E-glass/sisal hybrid reinforced epoxy matrix composites. The ultimate tensile strength, tensile modulus, and ultimate compressive strength of samples prepared as per ASTM standards were obtained experimentally. In order to improve the surface roughness and increase the adhesive bond capacity with matrix, the sisal fiber was treated by 8% percentages of sodium hydroxide (NaOH) for three hours.

Based on the experiments conducted (tensile, compression, and flexural), the following conclusions can be drawn:

- (1) Weight fraction of the sisal fiber added to the E-glass fiber affects the mechanical properties in tensile, compression, and flexural tests.
- (2) From tensile test results, adding the sisal fiber to the E-glass fiber decreases the tensile strength of hybrid laminates. But if the weight fraction of sisal mixed to E-glass fiber increases, the tensile strength of the hybrid composite decreases.
- (3) From the flexural test, adding the sisal fiber to the E-glass fiber affects the flexural properties of hybrid samples. But the effect of the weight fraction of the sisal fiber has not shown a significant change in flexural properties.
- (4) From the compression test, mixing the sisal fiber to the E-glass fiber reduces the compression properties of hybrid composites. Therefore, the longitudinal compressive stress of the E-glass/sisal hybrid sample greatly affects the compression properties of the hybrid composites.
- (5) Generally, all samples consisting of 60% E-glass and 0% sisal fibers with a 40% epoxy matrix showed better mechanical properties than other hybrid samples. The longitudinal tensile strength, longitudinal compressive strength, and the flexural strength of 60% E-glass, 0% sisal, and 40% epoxy matrix were observed to be 464 MPa, 40 MPa, and 239 MPa, respectively.
- (6) Also, the lower mechanical properties were obtained in the samples that are made from 0% E-glass and 60% sisal fiber with a 40% epoxy matrix. Their tensile, flexural, and compression values are 86.4 MPa, 98.4 MPa, and 17.1 MPa, respectively. This is due to the fact that natural fibers have lower mechanical properties when compared to synthetic fibers.

This article is only limited to the mechanical properties including the tensile, compression, and flexural strength of sisal-E-glass hybrid reinforced composites and epoxy matrix composites. Possible future works in this research include conducting microstructure studies using scanning electron microscopy (SEM).

Data Availability

The tensile, flexural, and compression test data used to support the findings of this study are included within this article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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