Characterization of Sisal-Glass Fiber Reinforced Epoxy Hybrid Composite

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Abstract. Mathematical modeling of a unidirectional hybrid composite is performed using classical lamination theory. The effects of varying volume fractions of sisal and glass fibers on the mechanical properties of the hybrid composite are studied. Experimental results were obtained for seven samples of composite materials. Impact, tensile and three-point bending tests were performed for studying different characteristics of the hybrid composites. Variability in mechanical properties due to different volume fractions of the two fibers was studied. It is found that there was significant variability in tensile strength, flexural strength, and impact resistance properties of the hybrid composite materials due to the variation in volume fractions of sisal and glass fibers. Generally, the hybrid composite samples have better mechanical properties compared with pure sisal epoxy and glass-epoxy composite materials.

Keywords: Hybrid composites · Natural fiber · Synthetic fiber · Vacuum molding · Mechanical properties

1 Introduction

A composite material is a composition of two or more materials combined for a better mechanical and physical property. A composite material consists majorly two components, namely called a fiber and matrix. The matrix is the weak component of a composite material which helps to connect the fiber components while the fiber components are the strong and stiff part of the a composite material [1–4].

Composite materials can be used as a substitution for commonly used metallic materials [3, 6] due to their low density, higher strength- weight ratio and modulus to weight ratio [3, 5–7]. Due to better properties of fiber reinforced composite materials, composite materials are widely used in place of metallic materials in the automotive and aircraft industries for structural components to decrease the chance of structural damage, to reduce the vehicle weight which results in fuel efficiency, and to give more beauty to the vehicle body [8, 9, 11, 12].

Hybrid composites which are composed of two or more reinforcing fibers into a single matrix material usually have two or more reinforcing fibers by retaining the advantage

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of fiber components of the hybrid composites. The development of hybrid composites can be performed by combining different natural fibers together, or by a combination of different synthetic fibers, or by combining both natural and synthetic fibers [13, 14].

The reinforcing phase for the composite materials can be made from natural fibers, such as plant, animal as well as synthetic fibers such as glass, carbon, or aramid fibers [3, 5]. The matrix material,,used for the development of composite materials can be distinguished into plastic,which helps the fiber to be in a stable shape, metal, and ceramic matrix [1, 3, 16, 17]. The most commonly used resins in the production of polymer composite materials are epoxies, polyesters, nylons, phenolics, Polyamide-imide, Polyimides [3]. Matrix flow during the manufacturing process through the fiber architecture determines the contents of voids, fiber distribution, fiber wetting, dry area, and others in the final composite laminate, which also affect its properties and performance [18–22].

In synthetic/natural fiber reinforced hybrid composites a hybrid that consists of natural fiber and synthetic fiber can be combined targeting for the enhancement of the mechanical and thermal properties of natural fiber-reinforced composites. The hybridization of synthetic fibers with natural ones provides a balance between practical costs and the finest mechanical properties compared with those of single natural fiber materials [21]. For example, synthetic fibers such as carbon fiber or glass fiber have higher strength and stiffness, as well as enough resistance to water absorption compared to natural fibers. On the other hand, natural fibers are hydrophilic due to their porous structure, and their composites may swell because they may absorb large amounts of water. As a result, hybridization of chemically treated natural fibers and synthetic ones has been recommended as a solution since hybridization bids an effective method by adding another kind of hydrophobic fiber to the hydrophilic fiber composites [26, 27, 30].

Making a hybrid composite material by combining natural and synthetic reinforcing fibers will help to get superior mechanical properties, as well as cost-reduction advantages. For example, tensile strength, elastic modulus, impact strength, and rigidity in a laminar hybrid composite increases while the toughness property decreases due to the hybridization of cotton and glass fibers [25, 26]. Flax fiber is generally known for its damping properties and carbon fiber is registered for its brilliant performance and mechanical properties. So, by hybridizing these two fibers it has been used on an industrial level for manufacturing tennis rackets and bicycle frames. In this combination, hybrid flax-carbon composite has better impact absorption performance compared with flax fiber-reinforced composite material [27]. The studies on the hybrid flax-glass composite material show that the tensile strength and Young's modulus of flax fiber laminates increase due to the addition of more stiff glass fiber [28]. The hybrid kenaf–Kevlar epoxy composites have superior impact performance as compared to the other hybrid composites [29]. Making a hybrid composite of coir and glass fibers significantly improves tensile strength, impact resistance, flexural strength, and reduces moisture absorption of the composite material [30].

This research work will attempt to investigate the physical and mechanical properties of sisal-glass epoxy hybrid composite material, by varying the contents of sisal and glass fibers. The comparison is also made with the pure sisal epoxy and glass epoxy composites.

The novelty of this paper is the vacuum mold method was used for the manufacturing of the composite samples. The analysis was made by varying the contents of both sisal and glass fibers from 15% to 35% at a 5% volume fraction difference in order to obtain the finest proportions of the natural and synthetic fiber combination for the best physical and mechanical properties.

2 Materials and Experimental Methods

2.1 Materials

The materials used for this research work are sisal and E-glass fibers as a reinforcement, Epoxy resin as the matrix. The sisal fiber is extracted and collected from the local area around Bahir Dar city. The remaining materials E-glass and Epoxy resin are collected from the product suppliers. The resin system consists of KADILUX RM501 (epoxy resin) and KADILUX RM504 (hardener) which were provided by KADISCO Epoxy and Paint factory. The corresponding resin to hardener ratio was 2:1. printing area is 122 mm × 193 mm. The text should be justified to occupy the full line width, so that the right margin is not ragged, with words hyphenated as appropriate. Please fill pages so that the length of the text is no less than 180 mm, if possible.

2.2 Chemical Treatment

Natural fibers cannot be used directly to manufacture a composite material due to their hydrophilic surface in nature. However, to improve adhesion property between the fibers and the matrix by reducing their hydrophilic nature many researchers have found different types of chemical treatments. Alkali treatment, silane treatment, benzoylation treatment, peroxide treatment, isocyanate treatment, and acetylation treatment are the most widely used surface treatment methods [31]. Among those chemical treatments, alkaline treatment is one of the most common and simplest methods used for the chemical treatment of natural fibers. In alkali treatment, the natural fibers needed to be submerged in NaOH solution for a certain amount of time (as seen in Fig. 1.). Alkali treatment is used to disorder the hydrogen bonding and to remove the lignin, wax, and oil contents from the outer surfaces of natural fibers. This will create surface roughness by breaking down the cellulose into monomers and the hydroxyl group gets ionized to the alkoxide [31, 32].

2.3 Development of the Hybrid Composite

In order to swell raw sisal fibers and to separate fiber bundles into smaller fibers by removing more lignin amount, the sisal fiber was treated with a 2% NaOH solution for 12 h at room temperature. Then the sisal fibers were washed at first with tap water and then with distilled water several times to remove any NaOH sticking to the fiber surface. Lastly, these fibers were dried for 3 days in sunlight to completely remove the moisture.

The vacuum molding method was used to manufacture the hybrid composites in an open aluminum sheet mold at high pressure using a vacuum pump. Vacuum molding

Fig. 1. Sisal fiber surface treatment using NaOH.

has an advantage for improving the strength of composite laminates by reducing manufacturing defects when compared with other manufacturing techniques. The effects of the vacuum method on the reinforcements are good formability, good surface quality, high strength, wear-resistance, and density of the laminate is significantly lower than the commonly used compression molding technique. The fiber volume fraction (50%) was kept constant, is determined based on the literature survey, in order to avoid resin leakage to the pump during the vacuum bagging process [33, 34].

Hybrid fiber mat laminas of different ratios of sisal and E-glass (listed in Table 1) were mixed with epoxy resin for the preparation of composites. The epoxy resin was

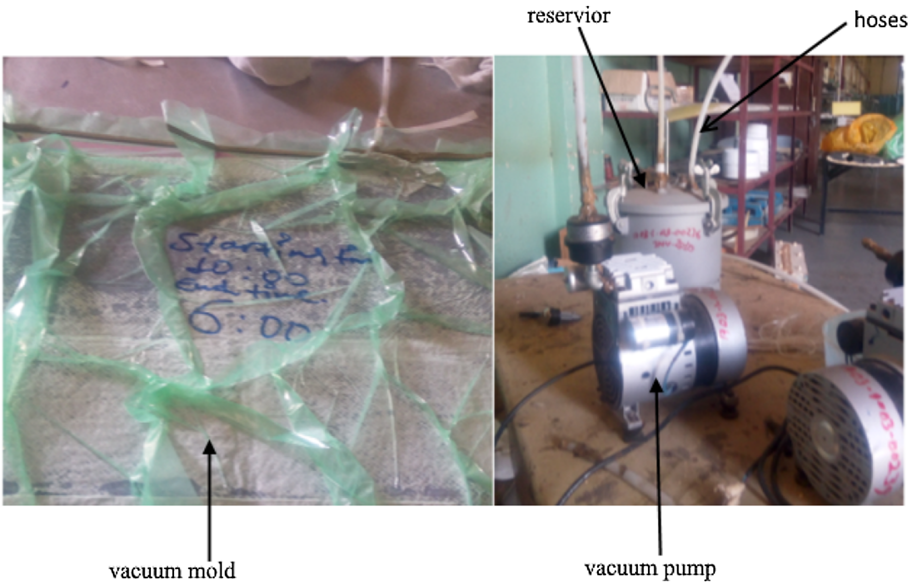

Fig. 2. The vacuum bag molding set-up.

prepared by mixing the resin and hardener at a ratio of 2:1 for 2 min. Figure 2 shows the vacuum molding set up used to manufacture the composite laminates. Each sample contains four layers of laminas prepared with a dimension of 200mm x 200mm molding size. The bottom surfaces of the aluminum sheet were cleaned and coated with wax for easy release of the composite samples from the mold. After arranging the fiber mats uniformly, they were mixed with the epoxy resin and compressed for 12 h in the mold using a vacuum pump. Finally, the composite samples cured for 72 h in sunlight before subjected to experimental tests.

Table 1. Samples of the hybrid composite at a different volume ratio of sisal and E-glass fibers.

Samples	Fiber volume fraction	Resin volume fraction
Sample 1	25% sisal + 25% E-glass	50%
Sample 2	20% sisal + 30% E-glass	50%
Sample 3	15% sisal + 35% E-glass	50%
Sample 4	30% sisal + 20% E-glass	50%
Sample 5	35% sisal + 15% E-glass	50%

The main materials and devices used for the vacuum mold are a vacuum pump, breather materials, a vacuum bag, and a vacuum tap.

2.4 Experimental Tests

Density Measurement. The densities of the hybrid composites were calculated using the Archimedes principle. In this method, the test specimens were tightly warped with cling warp to avoid the sucking of water. Cling wrap is used since it could easily take on the geometry of the test specimens and allow for precise volume measurement. Once the cling wrap is completed the waterproof specimens are dipped into a measuring container filled with water. After the specimen was fully immersed in the water the rise in the water level was recorded to get the specimen volume. From the mass and volume of the specimens, the density was determined using Eq. (1).

$$\rho = \frac{m}{v} \tag{1}$$

Where ρ is the density of the composite, m is the mass of a single specimen and v is the volume of the displaced water when a specimen is immersed. The density of different samples obtained is depicted in Table 2.

Table 2. The density of the composite materials.

Composite samples	Density (g/cm3)	Density (kg/m3)
Sample 1	1.1205	1120.5
Sample 2	1.0696	1069.6
Sample 3	1.1389	1138.9
Sample 4	1.2189	1218.9
Sample 5	1.0019	1001.9

The density of the composites ranges from 1 g/cm3 to 1.3 g/cm3. Increasing the glass fiber content in the hybrid composites promote an increase in density, as shown in Table 2 due to the higher density of glass fibers relative to the sisal fibers.

Impact Test. The Charpy impact test is carried out based on the national standard JBS-500B impact testing machine. In this experiment, an automatic drop pendulum hammer

Fig. 3. Impact test specimens of the different composite samples.

Charpy impact testing machine was used to perform an impact test on a specific composite specimen at an impact speed of 5.4 m/s. The dial gauge displays the impact strength values of the composite material in Joules. All the test specimens have a dimension of 65 x 10 x 5 mm (length x width x thickness) based on ASTM D256 standard [35]. The Charpy impact test specimens of different composite samples are shown in Fig. 3.

Then the impact energy of five specimens from each sample was recorded and the average values of the impact energy were taken and reported for each sample. Figure 4 illustrates the Charpy impact pendulum testing machine.

Fig. 4. The Charpy impact pendulum testing machine.

Tensile Test. Tensile test specimens of the different samples were subjected to a tensile test and the test was conducted as per **ISO 527–1 standard.** Prepared tensile test specimens of the different composite samples are shown in Fig. 5. The tensile properties

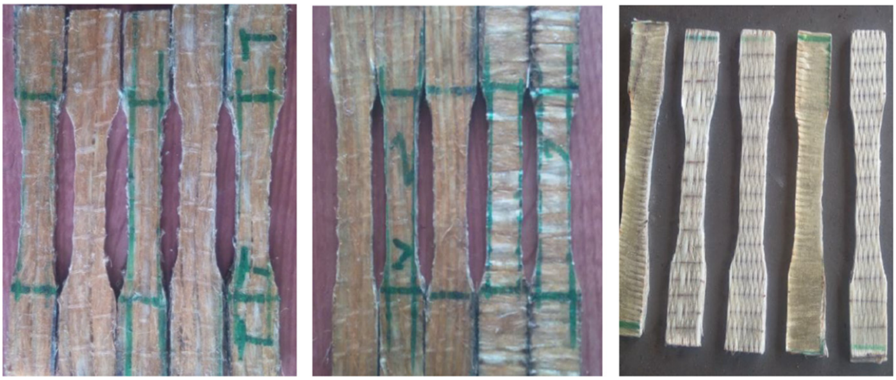

Fig. 5. Prepared tensile test specimens.

of the seven composite samples were studied by testing the specimens using the WAW-600D tensile testing machine. Figure 6. shows the tensile and three-point bending test set up. The cross-head speed for tensile testing was 10 mm/min and each specimen was loaded up to failure. The dimensions of the specimens for tensile testing were 120 x 20 x 5 mm (length x width x thickness). Five specimens of each sample were tested for tensile testing and the average values were taken and reported for each sample of the composite.

Fig. 6. WAW-600D universal tensile testing machine.

Flexural Test. Flexural test specimens of the different samples were subjected to a three-point bending test and the test was conducted as per ISO 14125 standards for fiber-reinforced composite materials. During the three-point bending test, the load was applied at the middle between the supports with a cross-head speed of 10 mm/min. The dimensions of the specimens for flexural testing were 120 x 20 x 5 mm (length x width x thickness). Prepared three-point bending test specimens of the different composite samples shown in Fig. 7.

3 Results

3.1 Impact Strength

After the completion of the impact test impact energy of five specimens from each sample was recorded and the average values were taken and reported for each individual sample. Table 3 shows the impact test results. The impact test results show that increasing

Fig. 7. Prepared three-point bending test specimens.

the volume fractions of glass fiber in the hybrid composite marks in the enhancement of impact resistance properties. But impact resistance properties decrease when the volume fractions of sisal fiber in the hybrid composite increases.

Table 3. Impact energy of the seven composite samples.

Composite samples	Impact energy (J)	Impact energy (J/m^2)
Sample 1	14.6633	45117.9487
Sample 2	15.7933	48594.8717
Sample 3	13.83	42553.8461
Sample 4	10.4867	32266.6667
Sample 5	8.8167	27128.2051
Sample 6	15.1533	46625.6410
Sample 7	11.27	34676.9231

From the impact test results, it can be concluded that the glass-epoxy composite material has the highest impact damage resistance property. Relatively the pure sisal epoxy composite material has lower impact resistance property. For an equal amount of sisal and glass fibers i.e., 25% sisal and 25% glass fiber the impact energy is 14.6633 J.

when the glass fiber content is increased by 5% the hybrid composite shows 4% enhancement in its impact resistance property compared with the glass epoxy composite material and 8% improvement when compared with the hybrid composite containing an equal amount of sisal and glass fibers. But when the glass fiber content is increased from 30% to 35% the impact resistance property of the hybrid composite is again decreased by 12%. In the hybrid composite, the impact resistance property decreases by 40% as the sisal fiber content is increased by 10% i.e., impact energy decreases from 14.6633 J to 8.8167 J. Figure 8 and Fig. 9 shows the variation of impact energy at different contents of sisal and glass fibers.

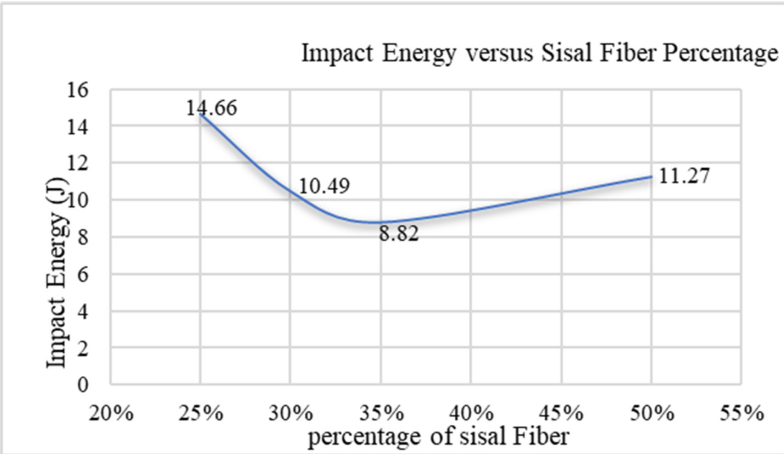

Fig. 8. Impact energy versus sisal fiber percentage.

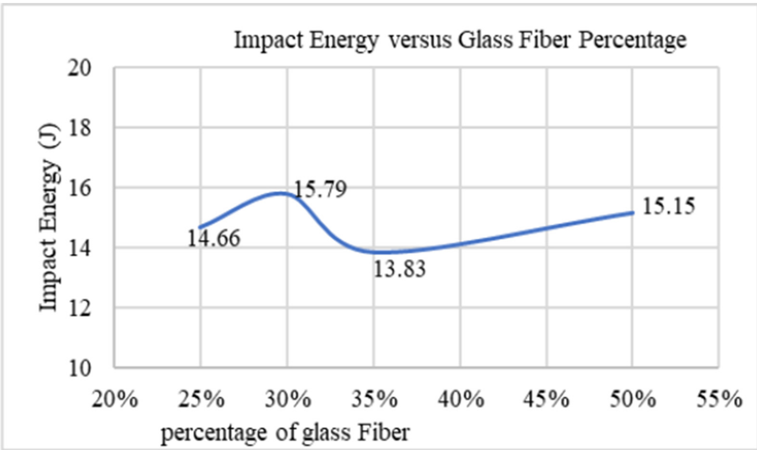

Fig. 9. Impact energy versus glass fiber percentage.

3.2 Tensile Strength

After the tensile test, it was found that sample 5 of the hybrid composite performed best under tensile load amongst all. Sample 5 has a tensile strength of 72.1334 MPa and a yield strength of 37 MPa. The tensile strengths of the seven composite samples are depicted in Table 4. The tensile test results show that increasing the volume fractions of both sisal and glass fibers in the hybrid composite marks in an increase of the tensile strength. At equal percentages of sisal and glass fibers which is sample 1, the tensile strength is 53.7669 MPa. However, when the volume fraction of glass fiber content is increased from 25% to 35%, and sisal fiber content is decreased from 25% to 15% the tensile strength is increased by 7%. Whereas, when the volume fraction of sisal fiber content is increased from 25% to 35%, and glass fiber content is decreased from 25% to 15%, tensile strength rises to 72.1334 MPa which is an increment of 34%.

Table 4. Tensile test results.

Composite samples	Yield strength (MPa)	Tensile strength (MPa)
Sample 1	29.7	53.7669
Sample 2	32.93	54.3067
Sample 3	33.9	57.3667
Sample 4	39.9	70.7667
Sample 5	37	72.1334
Sample 6	27.6	52.5888
Sample 7	36.9	63.0667

The yield strength increases by 14% when the volume fraction of glass fiber content is increased from 25 to 35% and sisal fiber content is decreased from 25% to 15%. On the other hand, the yield strength increases from 29.7 to 39.9 MPa as volume fractions of sisal fiber content is increased from 25 to 30% and glass fiber content is decreased from 25% to 15%. But as the volume fractions of sisal fiber increased by 5% the yield strength of the hybrid composite decreases from 39.9 to 37 MPa.

Based on the tensile test results it can be concluded that the sisal-glass epoxy hybrid composite material shows an increase in tensile strength up to 37% when compared to composites made from only pure glass fiber and the tensile strength increases up to 17% when compared to pure sisal epoxy composite material. Generally, the sisal-glass fiber epoxy hybrid composite material has a better tensile and yield strength than either the pure glass epoxy or pure sisal epoxy composite materials. Figure 10 and Fig. 11 illustrates the variation of the ultimate tensile strength and the yield strength of the seven composite samples.

3.3 Flexural Strength

The flexural properties of the seven samples are studied by testing the specimens using the WAW-600D universal tensile testing machine shown in Fig. 6. the same machine

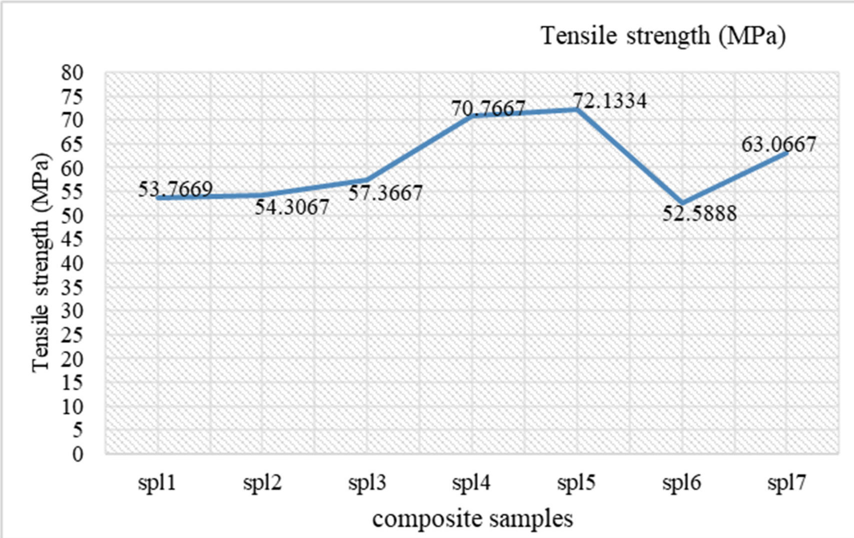

Fig. 10. The variation of the tensile strength for different amounts of sisal and glass fibers.

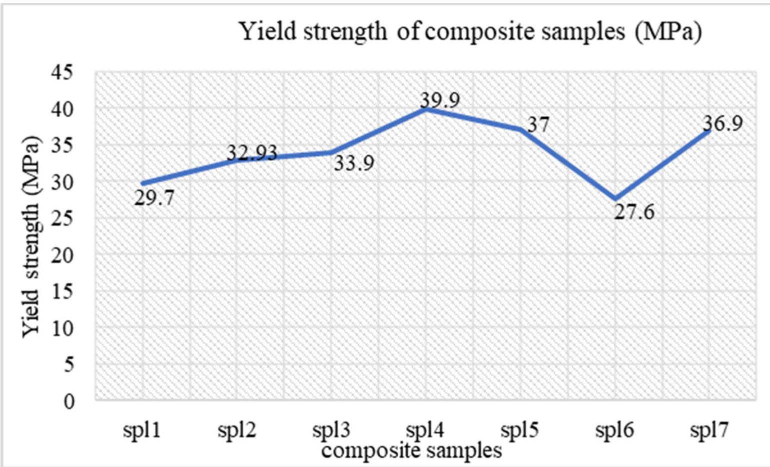

Fig. 11. The variation of the yield strength for the seven composite samples.

used for the tensile test. After the test, it was found that sample 4 of the hybrid composite performed best under the bending load amongst all and has a flexural strength of 87 MPa. The bending strengths of the seven samples of the composites are tabulated in Table 5. The flexural test results show that increasing the volume fractions of both sisal and glass fibers in the hybrid composite marks an increase of the flexural strength.

At equal percentages of sisal and glass fibers, the flexural strength is 80.2 MPa. It is notable that when the volume fraction of sisal fiber content is increased from 25 to 30%, the flexural strength of the composite is increased from 80.2 MPa to 87 MPa which is an 8% increment. But when the volume fraction of sisal fiber content is increased from 30 to 35%, the flexural strength of the composite is decreased from 87 MPa to 85.6 MPa which is a 2% decrement. On the other hand, when the volume fraction of glass fiber content is increased from 25 to 35%, the flexural strength increases to 84.6667 MPa which is a 6% increment.

Table 5. Three-point bending test results.

Samples	Fiber volume fraction	Flexural strength (MPa)
Sample 1	25% sisal + 25% E-glass	80.2
Sample 2	20% sisal + 30% E-glass	81.2
Sample 3	15% sisal + 35% E-glass	84.6667
Sample 4	30% sisal + 20% E-glass	87
Sample 5	35% sisal + 15% E-glass	85.6
Sample 6	Pure E-glass fiber	64.8
Sample 7	Pure Sisal fiber	62.4667

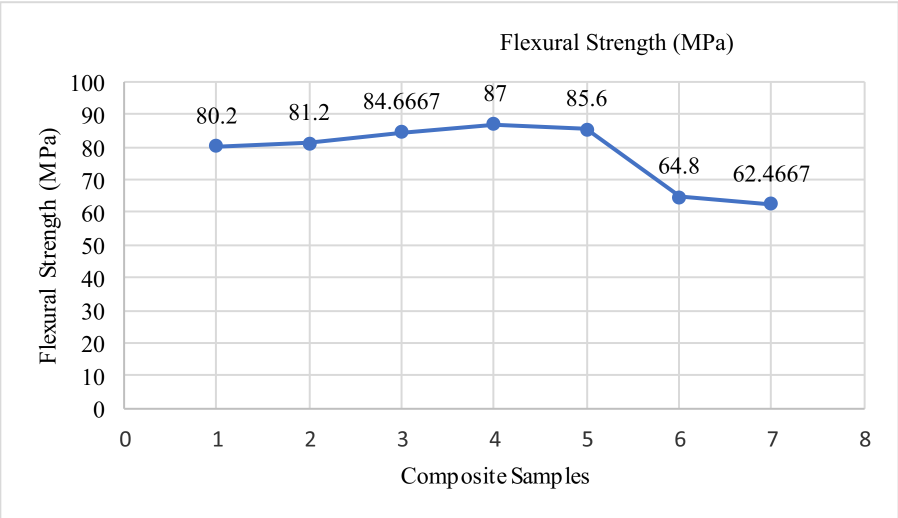

Fig. 12. The variation of the flexural strength for the seven composite samples.

Based on the flexural test results the sisal-glass epoxy hybrid composite material shows an increase in flexural strength up to 31% when compared to composites made from only pure glass fiber. The flexural strength increases by up to 39% due to the hybridization effect when compared to pure sisal epoxy composite material. Generally, the sisal-glass epoxy hybrid composite material has better flexural strength than either the pure glass epoxy or pure sisal epoxy composite materials. The results plotted in Fig. 12 shows the variation of the flexural strength for different composite samples.

4 Conclusion

Based on the observations from the experiments, the hybrid composite sample 2 possesses maximum impact strength and can hold up to 15.7933 J followed by pure glass-epoxy composite sample which is holding the impact strength of 15.1533 J. Sample 5 of the hybrid composite which contains 35% sisal fiber and 15% glass fiber by volume has the poorest impact resistance capacity with a maximum impact load of 8.8167 J. The tensile test results show that increasing the volume fractions of both sisal and glass fibers in the hybrid composite results in an increase of both tensile and yield strength. The sisal-glass epoxy hybrid composite material shows an increase in tensile strength up to 37% when compared to composites made from only pure glass fiber and the tensile strength increases up to 17% when compared to pure sisal epoxy composite material. The sisal-glass epoxy hybrid composite material shows an increase in flexural strength up to 31% when compared to composites made from only pure glass fiber. The flexural strength increases by up to 39% due to the hybridization effect when compared to pure sisal epoxy composite material.

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