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Study on Mechanical Properties of Sisal and Glass Fiber Reinforced Composites

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Abstract: ***Natural fiber reinforcements are finding a substantial potential for themselves in the current era of composite material development. One such fiber is obtained from Sisal plant (Botanical name: Agave Sisalana) which exhibits better mechanical properties compared to other natural fibers. In the present study, chemically treated and untreated sisal chopped fibers are used as reinforcements while epoxy (resin) is used a matrix material. The laminates are fabricated using hand layup technique. Various laminate specimens are prepared using different volume fractions and fiber lengths as variables. The resulting composite specimens are tested to find tensile, bending and hardness properties. It was found that the laminate with 0.7Vf epoxy resin + 0.3Vf sisal fiber, as its composition, had the highest practical Young's modulus of 17195.28Mpa.***

1. Introduction

All fibers which come from natural sources (animals, plants, etc.) classified as natural fibers. Plants, animals are the main sources for natural fibers. Some of the natural fibers like vegetable fibers are obtained from the various parts of the plants. They are provided by nature in ready-made form. It includes the protein fibers such as wool and silk, the cellulose fibers such as cotton and linen, and the mineral fibers asbestos. Stiff fiber traditionally used in making twine, rope and also dartboards. One such source of stiff fibers is Sisal plants. Sisal plants consist of a rosette of sword-shaped leaves about 1.5 to 2 meters tall. Young leaves may have a few minute teeth along their margins, but lose them as they mature. Sisals are sterile hybrids of uncertain origin; although shipped from the port of sisal in Yucatan the sisal plant has a 7–10 -year life-span and typically produces 200–250 commercially usable leaves. Each leaf contains an average of around 1000 fibers. The fibers account for only about 4% of the plant by weight. Sisal is considered a plant of the tropics and subtropics, since production benefits from temperatures above 25 degrees Celsius and sunshine. Fiber is extracted by a process known as decortication, where leaves are crushed and beaten by a rotating wheel set with blunt knives, so that only fibers remain where water is used to wash away the waste parts of the leaf. The fiber is then dried, brushed and baled for export. Proper drying is important as fiber quality depends largely on moisture content fiber is subsequently cleaned by brushing. Dry fibers are machine combed and sorted into various grades such as cotton and linen, and the mineral fibers asbestos.

The plants look like giant pineapples, and during harvest the leaves are cut as close to the ground as possible. The soft tissue is scraped from the fibers by hand or machine. The fibers are dried and the brushes remove the remaining dirt, resulting in a clean fiber. Sisal produces sturdy and strong fibers. Sisal fiber is one of the prospective reinforcing materials, that its use has been more experiential than technical until now. The use of 0.2% volume fraction of 25mm sisal fibers leads to free plastic shrinkage reduction. Agave Sisalana Perrini is a native species to the Yucatan peninsula, and known worldwide, the plant and also the fibers, as Sisal, belonging to the class of natural hard fibers. Presently, Sisal represents the first natural fiber in commercial application, in which it is estimated in more than half of the total of all natural fibers used. The Sisal plant is a monocotyledonous, whose roots are fibrous, emerging from the base of pseudo stem. The fibers of Sisal are made of elementary fibers of 4 to 12 μm diameter that are aggregated by natural bound forming small cells of 1 to 2 μm. Such arrays are placed along the length of the plant on a regular shape, with lengths of 45 to 160 cm. The leaves of Sisal are an example of natural composite with lingo-cellulosic material presenting in 75 to 80 % of the total weight of the leaves, reinforced by helical micro fibers of cellulose, which represent about 9 to 12 % the total weight. The composition of Sisal fiber is basically of cellulose, lignin and hemicelluloses. The failure strength and the modulus of elasticity, besides the lengthening of rupture, depend on the amount of cellulose and the orientation of the micro-fibers. As a natural product these characteristics have a wide variation from one plant to another. The Sisal fibers are found commercially in several formats: fabric, cords, strips, wire, rolls, etc. It is usually available in countries like East Africa, Bahamas, Antiqua, Kenya, Tanzania and India.

2. Calculations

Rule of Hybrid Mixtures (RoHM), is used to determine the mass of sisal and glass fibers to be used in the composite as function of volume fraction of matrix and fibers. The formula for calculation is shown below. The Total volume of

the composite is

Density of composite is equal to the sum of products of density of each system and its respective volume fraction.

$$\rho_{comp} = [\rho_{sisal} \times V_f(sisal)] + [\rho_{resin} \times V_f(resin)] \quad ..1$$

Mass of the composite is product of density and its volume.

$$M_{comp} = \rho_{comp} \times V_{comp} \quad ...2$$

$$m_f(sisal) = \frac{\rho_{sisal} \times V_f(sisal)}{\rho_{comp}} \quad ...3$$

$$m_f(resin) = \frac{\rho_{resin} \times V_f(resin)}{\rho_{comp}} \quad ...4$$

$$M_{sisal} = m_f(sisal) \times M_{comp} \quad ...5$$

$$M_{comp} = M_{sisal} + M_{resin} \quad ...6$$

Where,
ρ_{comp} (kg/m^3), ρ_{sisal} (kg/m^3), ρ_{resin} (kg/m^3), ρ_{glass} (kg/m^3) are the densities of the composite, sisal fibers, resin and glass fibers respectively. $m_f(sisal)$ is the mass fraction of the sisal fibers, $m_f(resin)$ is the mass fraction of resin, $V_f(sisal)$ is the volume fraction of sisal fibers, and $V_f(resin)$ is the volume fraction of resin.

3. Experimentation

The experimental study was conducted to test the sisal and glass fibers reinforced composites. This included testing the composites for varying volume fraction and length of sisal & glass fibers while the base material being epoxy resin. The main objective of the investigation was to study the tensile, flexural behavior and hardness of sisal and glass reinforced composites. There were totally 4 samples for different volume fraction and length of sisal & glass fibers while reinforcing with epoxy resin base. Each sample had 3 tensile specimens and 3 bend specimens along the horizontal, vertical and diagonal direction respectively. Hardness test was carried out at various locations in the sample.

A. Specimens

To study the tensile, flexural behavior of sisal and glass reinforced composites, a total of four samples were prepared by varying the volume fraction of sisal & glass fibers. The compositions of the four samples are as listed below:

1) Sample 1- (0.9Vf epoxy resin + 0.1Vf sisal fibers)
2) Sample 2- (0.8Vf epoxy resin + 0.2Vf sisal fibers)
3) Sample 3- (0.7Vf epoxy resin + 0.3Vf sisal fibers)
4) Sample 4- (0.7Vf epoxy resin + 0.2Vf sisal fibers + 0.1Vf E-glass)

B. Pre-treatment of fibers

The processed sisal fibers obtained from the sisal plant leaves was initially cut into smaller length fibers of 2cm, 3cm and 4cm. These fibers were then soaked in 4% aqueous solution of Sodium Hydroxide (NaOH) for a time period of about 24 hours. Then, the fibers were washed with water to remove the excess NaOH and dried under Sun to remove any moisture content. By pretreating the sisal fibers, the wettability of the sisal fibers increases, hence increasing its bonding strength.

C. Preparation of the mold plate

A steel mold plate was used as the base upon which 4 spacer plates of 3mm thickness were attached using silicon sealants. Another steel mold plate was placed on top of the spacers in order to compress the composite and give uniform surface finish. The mold plates were cleaned thoroughly using acetone solution and a thin coat of mansion wax (releasing agent) was applied to facilitate the easy removal of the specimen.

D. Preparation of the sample

Hand layup method of preparing composites is adopted to prepare the samples. The details of this process are as follows. The pre-treated sisal fibers were weighed and the right amount of sisal fibers required to obtain the desired volume fraction of the specimen is calculated referring to the above mentioned formulae. The weighed amount of pre-treated fibers is then spread randomly in the mold and compressed for about 2 hours to take shape of the mold cavity.

The weighed amount of epoxy resin satisfying the desired volume fraction was heated over a flame until its viscosity reduces slightly. Calculated amount of hardener is added to the heated epoxy resin in the ratio of 1:10 and stirred vigorously for a while to attain proper mixing. This mixture of heated epoxy resin and hardener was carefully poured over the compressed fibers. A hand roller was used to evenly spread the resin within the mold, without disturbing the compressed shape attained by the sisal fibers. Once the resin was uniformly distributed, the mold was closed with the help of 'C' clamps.

Four 'C' clamps were used to clamp the mold plates together in place and to apply the necessary pressure in order to compress the mold plates while ensuring that the excess resin seeps out of the mold. The mold plates were kept undisturbed for a time period of 24-48 hours to ensure proper setting of the epoxy resin composite. The mold was then opened, the spacer plates attached to the base plates were removed and the specimen was carefully ejected from the mold.

The composite mold dimension was approximately 150 X 160 X 3.5 mm. Furthermore, the test samples are cut in longitudinal (A), transverse (B) and diagonal (C) direction to calculate average properties of the composite. Thus, sample 1A, for example, represents the composite specimen having 0.9Vf epoxy resin + 0.1Vf sisal fibers and is cut in the longitudinal direction. Similar analogy can be used to understand the mechanical and directional properties of the remaining test samples.

E. Tensile test on composite

A thin, flat dumb-bell shaped strip of composite material having a rectangular cross section is hand cut and machined as per ASTM D 638-03 standard. The tensile specimen is mounted between the grips of a servo hydraulic Nano Universal Testing Machine (UTM) of 25KN capacity, BiSS make.

The test specimen is subjected to a gradually increased axial load until failure occurred. The specimen elongated in a direction parallel to the applied load. The gauge length of the specimen is 25mm and the width of narrow gauge section is 6mm. Elongation was measured using an extensometer and the maximum tensile strength of the composites is determined from the maximum load carried before failure.

Three tensile test specimens were cut along horizontal, vertical and diagonal directions from each sample. The speed of testing for tensile strength was 0.2mm/sec.

F. Bending test on composite

A thin, flat strip of composite material having a constant rectangular cross section is hand cut and machined as per ASTM D 790-03 standard. The bending test specimen of rectangular cross section is placed on two supports and is loaded by means of a loading nose from midway between the supports. A support span-to-depth ratio of 16:1 is used. A span length of 60mm is used while the overall length being 120mm. The specimen is allowed to deflect until rupture is observed at in the outer surface of the test specimen. The flexural stress and strain is calculated by noting down the maximum load taken by the specimen before rupture. The rate of crosshead motion for 3-point bending test was 0.02 mm/sec.

G. Rockwell Hardness test on composite

A Rockwell Hardness Number (RHN) is a number derived from the net increase in depth impression as the load on an indenter is increased from a fixed minor load to a major load and then returned to a minor load. Rockwell hardness test was conducted on the composite material as per ASTM D785-98 standards of testing composite materials.

L-scale was selected as it is applicable to plastic materials, Bakelite and vulcanized fibers. It applies minor load of 10kgf and major load of 60kgf (589N). A steel ball indenter of 6.35mm diameter is used and the red dial was observed for determining the Rockwell hardness number. Rockwell hardness number was determined with a ball indenter because the total surface area of the ball indenter in contact with the sample is much more than a diamond indenter.

Composite specimen is placed on the anvil of the Rockwell hardness tester and the capstan screw is turned until the small pointer is at a zero position and the large pointer is within 65 divisions of B 30 or the "set" position on red scale. This adjustment applies without shock, a minor load of 10 kg, which is built into the machine. Final adjustment of the gage to "set" is made by a knurled ring located on some machines just below the capstan hand wheel. Within 10 seconds after applying the minor load and immediately after the "set" position is obtained, apply the major load by releasing the trip lever. Remove the major load 15 seconds after its application. Read the Rockwell hardness on the red scale to the nearest full-scale division after 15 seconds of removal of the major load.

4. Results and Discussions

From the above mentioned tests conducted on various specimens, sample 3 was found to have the highest average Young's modulus. The results of sample 3C are as shown below.

Sample 3- (0.7Vf epoxy resin + 0.3Vf sisal fibers) has a volume fraction of 70% epoxy resin and 30% pre-treated sisal fibers of length 4cm. The results along the diagonal direction have been tabulated.

a) Tensile test

The tensile test results of sample 3C are shown in table 1. The stress v/s strain graph and load v/s displacement graph of sample 3C is shown in figure 1 and figure 2 respectively.

Table 1: Tensile Test Results of Sample 3c

Peak Load (KN)	1.4
Maximum displacement (mm)	0.879954
% Elongation (%)	1
Tensile Stress (MPa)	58.139
Tensile Strain	0.01
Young's Modulus (MPa)	5813.95

The maximum load was found to be 1.4 KN and its corresponding maximum displacement was 0.879954mm. The tensile stress and tensile strain was found to be 58.139MPa and 0.01 respectively. The percentage elongation and young's modulus was 1% and 5813.95MPa respectively.

The highest load withstood by sample 3 was along its diagonal direction and also has a high modulus of elasticity. The practical young's modulus is 11753.3MPa which is lesser than its theoretical value of 12355MPa. The average tensile test result of Sample 3 is shown in table 2.

Table 2: Average Tensile Test Results of Sample 3

	3A	3B	3C	Average
Maximum Load (KN)	1.325	1.062	1.4	1.262
Displacement (mm)	0.9103	0.81798	0.87995	0.8694
Tensile Stress (MPa)	55.024	44.102	58.139	52.422
Tensile Strain	3.2X10-3	3.6X10-3	0.01	0.0056
% Elongation (%)	0.32	0.36	1	0.56
Young's Modulus Practical (MPa)	17195.2	12250.8	5813.9	11753.3
Young's Modulus Theoretical (MPa)	-	-	-	12355

The average tensile test results of all samples are tabulated below in table 3. We can infer from the result table that as the volume fraction and length of sisal fibers increased, the maximum load it bears before its failure also increased for first three samples. Similarly, its corresponding displacement, tensile stress and tensile strain showed an increase. The results of the last sample which consists of 10% glass fibers were not as expected. Consistent tensile results can be obtained by testing at least five samples of the same composition.

Table 3: Average Tensile Test Results

	Sample1	Sample2	Sample3	Sample4
Maximum Load (KN)	0.617	0.9586	1.262	0.545
Displacement (mm)	0.6381	0.7379	0.8694	0.523
Tensile Stress (MPa)	28.7535	41.988	52.422	22.652
Tensile Strain	6.4x10-3	0.0226	0.0056	0.0092
% Elongation (%)	0.64	2.267	0.56	0.92
Young's Modulus Prac (MPa)	5489.96	1879.16	11753.3	3651.68
Young's Modulus Theo (MPa)	5885	9120	12355	16155

b) Bending test

The bending test results of sample 3C are shown in table 4. The load v/s deflection graph of sample 3C is shown in fig 3.

Table 4: Bending Test Results of Sample 3c

Peak Load(KN)	0.3345
Maximum Deflection (mm)	5.0623
Slope (N/mm)	100.1
Flexural Stress (MPa)	146.99
Flexural Strain	0.03374
Flexural Modulus (MPa)	6599.04

The average bend test results of sample 3 and the average bend test results of all samples are tabulated table 5and 6. We can infer from the results of table 6 that as the volume fraction and length of sisal fibers increased, the maximum load it bears before its failure also increased for first three samples. Similarly, its corresponding deflection, flexural stress and flexural strain showed an increase. The results of the last sample which consists of 10% glass fibers were not as expected. Consistent flexural results can be obtained by testing at least five samples of the same composition.

Table 5: Average Bending Test Results of Sample 3

	3A	3B	3C	Average
Maximum Load (KN)	0.2395	0.2464	0.3345	0.27346
Deflection (mm)	5.7525	4.3443	5.0623	5.053
Load/ Deflection (N/mm)	66.906	81.606	100.1	82.874
Flexural Stress (MPa)	105.249	108.28	146.99	120.173
Flexural Strain	0.03835	0.028962	0.03374	0.033684
Flexural Modulus Prac (MPa)	4410.307	5379.301	6599.04	5462.88
Flexural Modulus Theo (MPa)	-	-	-	6873

Table 6: Average Bending Test Results

	Sample1	Sample2	Sample3	Sample4
Maximum Load (KN)	0.0981	0.1199	0.27346	0.1836
Deflection (mm)	4.2172	5.0	5.053	30.811
Load/ Deflection (N/mm)	30.41	48.226	82.874	75.532
Flexural Stress (MPa)	57.658	58.398	120.173	70.0923
Flexural Strain	0.02593	0.03165	0.033684	0.02729
Flexural Modulus Prac (MPa)	3064.71	3707.833	5462.88	4023.54
Flexural Modulus Theo (MPa)	4551	5712	6873	-

5. Rockwell Hardness test

The hardness value of the composite samples with different volume fraction and different sisal fiber length was determined. After applying and releasing the major load of 60kgf, Rockwell hardness value was noted. The number of times the larger pointer passes through zero on the red scale on the application of the major load is counted. Subtract from this the number of times the larger pointer passes through zero upon the removal of this load. If this difference is zero, record the value as the reading plus 100. If the difference is 1, record the reading without change, and, if the difference is 2, record the reading as the scale reading minus 100. Five trials were conducted on different locations of the sample and the average values are tabulated.

Table 7: Rockwell Hardness Test Results

	RHN					
Trial No.	**1**	**2**	**3**	**4**	**5**	**Average**
Sample 1	92	92	85	91	92	**90**
Sample 2	87	81	95	97	92	**90**
Sample 3	92	94	91	90	93	**92**
Sample 4	48	70	53	60	58	**58**

The average Rockwell hardness test results are tabulated as shown in table 7. Consistent hardness test results can be obtained by testing at least five samples of the same composition.

6. Conclusions

- Pre-treating the sisal fibers in 4% aqueous sodium hydroxide (NaOH) solution gives a better bonding strength by removing the moisture content in the fibers and thereby improving the wettability of fibers. It shows a better tensile and flexural behaviour.
- The ratio of epoxy resin is to hardener plays an important role in making the composite more ductile. As ductility increases, percentage elongation increases.
- By increasing the volume fraction of the pre-treated sisal fibers in the sisal fiber reinforced with epoxy resin composite, there has been a great improvement in their tensile and bend results.
- Increasing the length of pre-treated sisal fibers in the sisal fiber reinforced with epoxy resin composite, there has been a great improvement in their tensile and bend results.
- As the maximum load bearing capacity of the composite increased with increase in volume fraction of pre-treated sisal fibers in the composite, its displacement, tensile stress, tensile strain and young's modulus also increased.
- As the maximum load bearing capacity of the composite increased with increase in volume fraction of pre-treated sisal fibers in the composite, its deflection, slope of load to deflection, flexural stress, flexural strain and flexural modulus also increased.
- Randomly distributed pre-treated sisal fibers give a better tensile and bend strength in all three directions compared to unidirectional distributed fibers.
- By reinforcing the pre-treated sisal fibers with glass fibers, we should get much better tensile and bend strength results. But, since we tested only one sample, results are not consistent. By testing more number of samples of the same composition would give a better result.

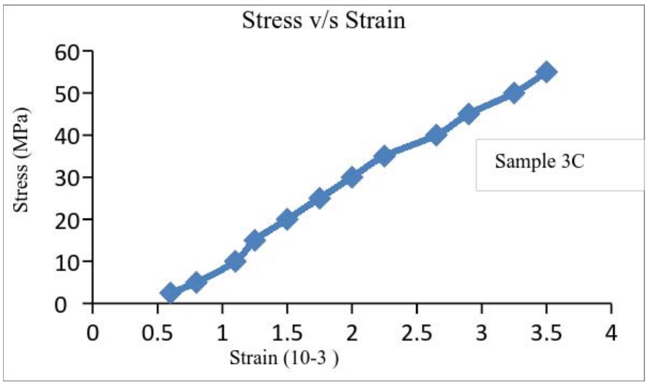

Figure 1: Load v/s Strain of Sample 3C

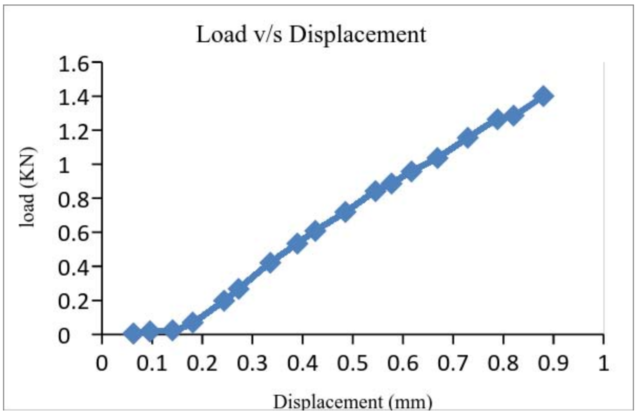

Figure 2: Load v/s Displacement of Sample 3C

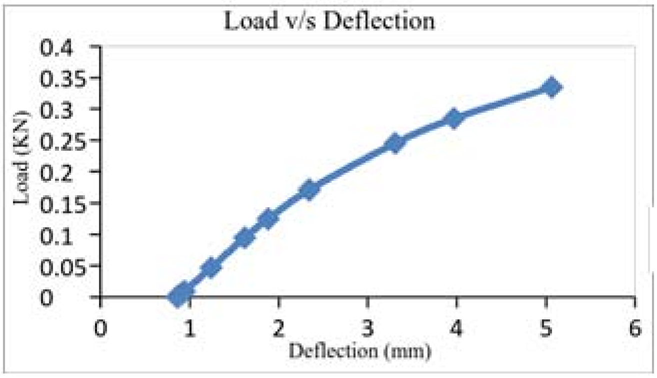

Figure 3: Load v/s Deflection of Sample 3C

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