Review on Mechanical, Thermal and Morphological Characterization of Sisal Fibre Composite

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Abstract. Growing worldwide ecological risks and energy crisis, fibers from different plants reinforced into composites made up of polymer have initiated extraordinary research interest leading to their quality of acting as an alternate substitute for synthetic composites made up of fiber. Comparing it with commonly used carbon fibers or glass fibers, fibers from plants have numerous advantages like environmental kindly, renewable, less in weight, minimal cost, and good specific mechanical performance. Seeking to the existing situation the globe is hunting for sustainable and substitutable resources, therefore one of such natural fiber which is ordinarily being used across the world is sisal fiber.

Keywords. Sisal Fibre; mechanical properties; morphological properties; Thermal properties.

1. Introduction
Sisal fibers can be gathered from the plant leaves which belongs to the agave family of plants. The fiber from sisal plant is scratched out from leaves extracted from stronger and stiffer plants, with a little bit of elasticity. Sisal fiber have several applications and multiple traditional uses like; ropes, twine, yarn and string, and also can be woven into mats, carpets and numerous handicrafts. Also sisal cloth has proved its use in polishing few materials. Moreover, sisal has a great prospective as its reinforcement in polymer composites because of its comparatively low density. Major benefit of the composites is that their strength to their weight ratio, which is usually tends to be high and providing good strength. Moreover sisal fibers are also used in multiple industries such as in automotive for making components and also in making of furniture. Furthermore the left-out waste after the making of composite from sisal and its extraction is generally being used for producing ingredients in pharmaceutical, biogas and material manufactured for building. Sisal biomass consist of good proportion of cellulose, and its mash is further useful as an alternative for fibers from wood and being used in the paper manufacturing industry. Tremendous research is being conducted for validating it to the cementitious and polymeric grounds as reinforcement. For studying further in detail, a wide range of datum of test results of various different composites made up of sisal fiber were explored to reach out a certain conclusion.

2. Tensile Strength
To achieve continuous and unidirectional sisal reinforced composites. Characteristics such as dependence of tensile property and flexural properties, sisal volume fraction, impact strength mechanical properties, and tensile strength were assessed and compared. Relation between reinforced natural fiber composites and tensile strength was observed to rise along with the fiber composite to a level of optimization and then begins to decrease.

| Paper number | Composition | Tensile strength (MPa) |
|--------------|-------------|------------------------|
| 3            | Short sisal tensile properties: 95% Benzylated and 5% sisal (vol %) | 20                      |
### Table 3
30% Benzylated and 70% sisal

| Tensile properties of unidirectional sisal: | 20 |
|------------------------------------------|----|
| 11% Benzylated and 89% sisal             | 30 |
| 40% Benzylated and 60% sisal             | 69 |

### Table 7
Mechanical and physical properties: (B-banana fiber, G-glass, S-sisal)(vol %)

|                  | 29% | 21% S, 9% G | 15% S, 13% G | 16% B, 15% S | 12% B, 11% S, 8% G |
|------------------|-----|-------------|--------------|-------------|-------------------|
|                  |     |             |              |             |                   |

### Table 14
Tensile strength of PE, PEox, PE/sisal and PEox/sisal composites

|                  | PE/S10 | PEox/S5 | PE/sac5 | PEox/sac10 |
|------------------|--------|---------|---------|------------|
|                  | 21.1   | 18.5    | 19      | 18.2       |

### Table 16
Relation between sisal fiber content on tensile results of PP and MAPP matrix composites (tensile strength)

| Fiber content (wt%) with PP | 10% | 20% |
|----------------------------|-----|-----|
| 29% S                      | 30  | 32  |
| 21% S, 9% G               |     |     |
| 15% S, 13% G              |     |     |
| 16% B, 15% S              |     |     |
| 12% B, 11% S, 8% G        |     |     |

### Table 25
The relation between the tensile strength along with some glass fibers in the composite made up of sisal–glass hybrid. Glass fiber content (vol %) for 5% volume

|                  | 25 | 100 |
|------------------|----|-----|
| 29% S            | 21 | 34  |
| 21% S, 9% G      |    |     |
| 15% S, 13% G     |    |     |
| 16% B, 15% S     |    |     |
| 12% B, 11% S, 8% G|    |     |

### Table 29
The consequences of exposing untreated sisal fiber to boiling water in terms of tensile strength, CTDIC-treated composites of sisal fiber. At zero hours

|                  | Untreated | Treated |
|------------------|-----------|---------|
| 29% S            | 12.5      | 16.9    |
| 21% S, 9% G      |           |         |
| 15% S, 13% G     |           |         |
| 16% B, 15% S     |           |         |
| 12% B, 11% S, 8% G|           |         |

### Table 30
Change in tensile properties of sisal fiber to its test length (Ø of fiber: 200µm). Test Length (in mm)

|                  | 15 | 65 |
|------------------|----|----|
| Observations (MNm²) | 793.80 | 620.81 |

### Table 30
Change in tensile properties of sisal fiber to its speed of testing (Ø of fiber: 200µm; test length: 50mm). Testing speed (mm/min)

|                  | 1 | 500 |
|------------------|--|-----|
| Observations (MNm²) | 481.00 | 441.60 |

The linear correlation between tensile strength and fiber loading was observed as far as 60 vol % in sisal. Also, unidirectional fibers show long tails after the major damage that was concluded by the brittle failure theory. This
improves the safety of use as it must be related to the interfacial failure characteristics and post-failure crack propagation resistance. Which means, the generalized shear deformation of the ductile material is brought due to the reinforcing fiber, which causes the phenomenon. So, with an increase of interaction of solid in the present laminates would result in a higher elongation breaking point.

3. Impact Test
Impact test determines qualities of the material such as brittleness or ductility. In order to do that the net energy consumed by a material during fracture has to be calculated. This energy depicts material’s toughness and helps to evaluate temperature-dependent brittle-ductile transition. The capability of the fiber to tolerate sudden load is termed as its impact strength. Izod impact test rig was used here in this case to conclude the impact strength of the laminates. The purpose of the test was to measure the kinetic energy that is needed to initiate the fracture and also to break the specimen completely. The standard dimension for the Izod test is ASTM: D4812. The specimen was held vertically upwards with the help of jaws and the pendulum swung from one side and struck the fiber with kinetic energy. Energy being consumed by the material prior to its fracture point was verified on the scale which concluded the ductility and toughness of the material. The table below shows some Impact test on different composites made from sisal fiber;

| Paper Number | Composition | Impact Test |
|--------------|-------------|-------------|
| 3            | 100% Benzylated fir sawdust 70% Benzylated fir sawdust 30% sisal | charpy (kJ/m^2) 5.8 4.4 |
| 7            | Mechanical and physical properties: (B-banana fiber, G-glass, S-sisal) (vol %) 16% B, 14% G 29% S 15% S, 13% G 7% B, 6% S, 14%G | Izod impact test - Impact energy (J) 12.5 8.4 13.3 12.8 |
| 14           | PE- polyethylene; PP- polypropylene; PEox- oxidized polyethylene matrix; S- sisal fibers; 10- 10 wt%; Sac - acetylated sisal fibers as reinforcement. PE/S10 PEox/S5 PE/Sac10 PEox/Sac10 | Izod impact strength J/m 63 55 64 56 |
| 11           | Compositions of the SF (Sisal fiber) /MA-g-PP (maleic-anhydride-grafted polypropylene) /PP (polypropylene) were studied composites. Sisal fiber (wt%) MA-g-PP (wt%) PP (wt%) 10SF 10 9 81 2.25 4.5 6 or 5.9 | Izod impact strength (kJ/m²) at no immersion in water |
| 16           | Change of sisal fiber content on the Charpy impact strength of PP(Polypropylene) and MAPP (maleic-anhydride -polypropylene) composites with change in percent of Sisal Fiber Sisal Fiber content (wt%) PP matrix MAPP matrix 0% 3.25 3.5 10% 3.60 2.4 20% 4.7 3.2 | Charpy impact strength (kJ/m³) for; |
| 19           | Composites with different patterns of layers, with the Ratio of Volume Fraction of Banana (B) and Sisal (S) 4 : 1 B/S S/B/S B/S/B | Izod impact (kJ/m²) 34 30 33 |
23 Polypropylene grafted with maleic anhydride (PP-g-MA)  
PP, Sisal fiber, Glass fiber, PP-g-MA (wt%) (wt%) (wt%)  
PP/sisal  70  30  3  
PP/sisal/PP-g-MA  70  10  20  3  
PP/10sisal/20GF/PP-g-MA  70  10  3  

| Izod impact (kJ/m²) | 12.78 | 14.42 | 20.01 |

24 Magnesium hydroxide (Mg(OH)₂), zinc borate (Zb), ammonium polyphosphate (APP), and Zb in sisal and combination of APP with Mg(OH)₂ fiber/polypropylene (PP) composites  
PP/30sisal  
PP/30sisal/40APP  
PP/30sisal/40Mg  
PP/30sisal/40Zb  
PP/30sisal/30APP/10Mg  
PP/30sisal/30APP/10Zb  

| Izod impact | Impact strength (kJ/m²) |
|-------------|-------------------------|
| 14.02± 0.52 | 10.49± 0.31 |
| 11.22± 0.54 | 12.96± 0.20 |
| 10.49± 0.31 | 10.72± 0.37 |

54 Glass fiber + sisal fiber composite  
Glass fiber + jute fiber + sisal fiber composite  

| Charpy impact test | 18 | 12 |

37 Fiber content banana / sisal  
100/0  
0/100  

| Impact strength kJ/m² | 13.25 | 22.54 |

After evaluating the impact ability and losses of energy in different laminates with the help of Izod impact test. Impact results for the glass fibers are much better than the natural fibers. The specimen starts to break with a crack due to impact which further propagates because of loss of adhesion among fibers and matrix which eventually results in initiating the fiber breakage and pullout. Therefore, it is observed that there is a steep rise in the impact characteristics with increase in glass fibers content along with the natural fibers. Impact results are improved by 34%, 39% and 53% for the two-layer glass ply addition as extreme ply to the banana (G/B/G), sisal (G/S/G) and banana–sisal (G/BS/G) laminates. Best results for impact test are observed for three-layer glass fiber samples with sisal fiber (G/S/G/S/G) which is 3.1% and 6.4% greater than the glass hybrid banana (G/B/G/B/G) and banana–sisal fiber (G/BS/G/BS/G) laminates.

4. Differential scanning calorimetry

Differential scanning calorimetry (DSC) was used to investigate the behavior of sisal fiber that undergo solid-liquid phase transitions. It is performed to conclude the declination in crystallinity and breaking down of natural plant cellulose. The outcome of this test is found by analyzing first exothermic peak (decomposition) observed in DSC which associates with the data collected with the help of second endothermic peak which is stronger than the first peak, generally tends to be around 350°C to measure the thermal degradation of crystallites in plant fibers.

| Paper number | composition | DSC |
|--------------|-------------|-----|
| 36           | DSC thermo grams of untreated sisal Temperature (°C) 100 500 | Heat Flow (W/g) |
|              |             | -0.4 | 0.3 |
| 36           | DSC thermo grams of alkalized sisal Temp. (°C) 100 500 | Heat Flow (W/g) |
|              |             | -0.9 | -0.4 |
The results demonstrated that the degradation procedure relies upon the atmospheric conditions. In dormant climate, the DSC curves presented definite peaks for sisal fiber and its constituents, though in normal room conditions the thermal curves exhibited two exothermic peaks for each of the constituents. The degradation of cellulose in dormant conditions happened by endothermic procedures though, in atmospheric conditions, it happened by exothermic procedures.

### 5. Hardness Test

The material hardness was tested with the use of a shore-A hardness tester at room temperature, with the help of test method (Durometer) ASTM D-2240-81.

| Page number | Composite | Hardness |
|-------------|-----------|----------|
| 37          | SBR-1502” (Styrene-butadiene rubber) 100 A- sisal -, length -0mm | 43 |
|             | H- sisal -20, length -6mm | 71 |
| 34          | MMA-methyl methacrylate Untreated %%v MMA-Length | 71.4 |
|             | 10 | 71.8 |
|             | 40 | 71.6 |
|             | 0.025%v MMA-Length | 72.1 |
|             | 10 | 72.5 |
|             | 40 | 72.75 |
|             | 0.050%v MMA-Length | 72.1 |
|             | 10 | 72.8 |
|             | 40 | 72.8 |
|             | 0.075%v MMA-Length | 72.1 |
|             | 10 | 72.8 |
|             | 40 | 72.8 |
|             | 0.100%v MMA-Length | 72.1 |
|             | 10 | 72.8 |
|             | 40 | 72.8 |

The observation indicates that the hardness properties is directly proportional to the fiber length and composites made up from ad micellar-treated sisal filaments additionally had higher hardness and impact strength. The mechanical
characteristics of short sisal-fiber-strengthened composite of SBR have been evaluated as length of fiber, direction, stacking, and a holding specialist.

6. Flexural test

Flexural test was conducted for sisal fibers to measure the force required to bend the sisal fiber. Tensile stress and compressive stress were subjected to the sisal fibers respectively which in result created shear stress for bending the material. Three point bending and tensile strength tests took place using an LWK-5 universal tester at 1 and 5 millimeters per minute crosshead speeds.

| Paper number | composite                                                                 | Flexural test (MPa) |
|--------------|---------------------------------------------------------------------------|---------------------|
| 3            | Benzylated fir sawdust composites short sisal considered as a function of sisal content. Sisal vol % | 35                  55 |
| 7            | ASTM: D790 standards. Where; G- glass fiber, S-Sisal fiber, B-banana fiber, BS-banana sisal fiber. Laminates | 175                 185 190 |
| 9            | ASTM D-790; Sisal fiber-reinforced rubber seed oil-based polyurethane     | 53.2 (+-13.9)       96.1 (+-7.9) |
| 20           | Isophalic polyester resin HSR 8131. Volume fraction of fiber sisal         | 45.5                52.0 |
| 23           | PP- Polypropylene; MAPP - Maleated polypropylene; Polypropylene-PP       | 55.40               60.80 |
| 26           | cobalt naphthenate and Methyl ethyl ketone peroxide; Volume of sisal fibers; Sisal rest is glass fiber (5% total fiber content) | 32.06               80.80 50.21 110.03 |
| 32           | Sisal content in %vol in Benzylated fir sawdust                           |                     |
Sisal composite fibers displayed maximum results in tensile and flexural properties when a concentration of up to 30 weight percentage of sisal fiber was used. The results drastically improved when tested unidirectionally.

7. Thermal gravimetric analysis

Thermal gravimetric analysis (TGA) usually is used for the observation of the decomposition attribute and also the constituent phase of the composites in high temperature. TGA being done with the help of Perkin–Elmer TGA-7 thermo gravimetric analyser. Wherein samples were ranging between 5 to 10mg being heated at 25 up till 600°C and also at 20°C for 1 minute in flowing nitrogen.

| Paper number | Composition                                                                 | TGA     |
|--------------|-----------------------------------------------------------------------------|---------|
| 27           | TGA curves of untreated and Benzylated sisal fiber. TEMP. (°C) for Untreated | 90g 05g |
|              | 100                                                                         |         |
|              | 500                                                                         |         |
|              | TEMP. (°C) for Benzylated                                                   | 94g 00g |
|              | 100                                                                         |         |
|              | 500                                                                         |         |
| 24           | TGA curves of sisal fiber TEMP. (°C)                                        | 94 18   |
|              | 100                                                                         |         |
|              | 600                                                                         |         |
| 16           | Temp. (°C) for He                                                           | 91g 19g |
|              | 100                                                                         |         |
|              | 400                                                                         |         |
|              | Temp. (°C) for He + O₂                                                      | 95g 18g |
|              | 100                                                                         |         |
|              | 400                                                                         |         |

Observing various datum the thermal decomposition of every specimen happens in the fixed temperature varying between 50–600°C. Talking about sisal fiber, weight lost between the range of 60 and 100°C matches to vaporization taking place of the water molecules present in the specimen. Another loss of weight which takes place about 325 °C in because of thermal polymerization of the hemicellulose and in addition to the glucosidal cleavage of cellulose links. For EVA, the decomposition is being observed in two steps. The initial step consist of VA group degradation, step two involves degradation of the main chain. From the datum we can analyses that the fiber starts to degrade before the EAV matrix, plus the composites tend to be stable that EAV and other fiber. The strength of the composite do not rely much on the quantity of sisal in it, this is because in maximum cases the decomposition of sisal takes place first and then EVA decomposes.

8. Conclusion

Application of the fiber sisal as a good reinforcing material in compounds based on the polymers, after studying, analyzing various aspects and also desiring a future with a natural fibers in common, properties and construction of
fiber sisal, surface alteration, mechanical and physical qualities of sisal fiber grounded on their composites made up of polymer. Sisal fiber got an impressive potential as polymer reinforced composites. Having a good specific characteristics of sisal fiber and low in density, the composites made using sisal fibers tend to have a considerable implications in multiple sectors like transportation and automotive industries. Furthermore, reduced apparatus, scrape and successive reduction of re-tooling costs which makes composites made up of sisal fibers prone to become a better choice. Raw material in plastic industries being replaced by sisal fibers as an alternative source does not only makes it a sustainable resource, but also is able to produce a non-traditional path towards economic growth and development for sectors like agriculture for the farmers.

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