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Mechanical Characterization of Bio-Char Made Hybrid Composite

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ABSTRACT
Material discoveries and development have always been the cause of the growth and development of a nation and the need of naturally made materials is the need of hours. Thus this paper takes you to the development of a hybrid composite made of sisal fiber with epoxy as the matrix intertwined with softwood bio-char. Softwood chip bio-char, produced by slow pyrolysis, has a porous structure improving its nutrient absorbing capacity, surface area and thus a potential substituent. Bio-char has an appreciable carbon sequestration value i.e. a carbon absorbing product. The orientation of sisal fiber are changed and studied in longitudinal and orthogonal direction indicating superiority of longitudinal fiber orientation .It also addresses the variation in mechanical characteristic (tensile flexural and impact) with different constituent of the new composite and its position in material selection charts with a direction for further work.
Keywords: Sisal, Bio-char, Epoxy, Mechanical properties, Material selection chart

I. INTRODUCTION

History tells that ages have always been named on the basis of material predominant over time. The need of today's world is to focus on the use of natural fiber and organic compounds that are environment friendly materials for caring the environment. Natural plant fibers are the cell walls that occur in stem and leaf parts and are comprised of cellulose, hemicelluloses, lignin and aromatics, waxes and other lipids, ash and water-soluble compounds. The area of natural fiber composite and organic compound interconnects several scientific disciplines (agriculture, biochemistry, chemistry, technology, environmental sciences, forestry, etc) which make it very difficult to have an expert view on the complicated interaction [1]. These fiber composites have found their place in the market due to biodegradability, less emissions to the atmosphere, abundant availability , being renewable and the production at low cost. From the environment perspective these fiber are more carbon positive i.e. they absorb more carbon di-oxide then they produce.

The fiber with rough surfaces has good surface adhesion. The property derived from the fiber composites has different use as per requirement. The mechanical properties of composite are a function of distribution of fibers in matrix and the efficiency of stress transfer between them [2]. Different methods have evolved with time for manufacturing the natural fiber composites some of them namely are press moulding , pultrusion ,extrusion , hand layup method, injection moulding, compression moulding, resin transfer moulding , sheet moulding etc[3].

Structure of fiber determines the characteristics, functionalities and processing efficiencies. Most plant fibers, including sisal, are composed of mainly cellulose and lignin, but a number of other minor constituents, such as pectin, wax, inorganic salts, nitrogenous substance and pigments, etc., are also found in them [4]. The sisal leaf consists of roughly 4% fiber, 0.75% cuticle, 8% dry matter and 87.25% water. The total cellulose and lignin contents of sisal fibers are about 67 and 12% respectively [5]. Cellulose occurs in plant cell walls providing a linear and structurally strong framework while Lignin reported to be the second most abundant material in plants is responsible for strength, rigidity [6]. Sisal fibers have found applications in composite industry, housing, railways and aerospace applications on account of its low cost and density, high specific strength and stiffness, and good range of aspect ratio [7]. The table 1 shows the different mechanical and chemical properties of sisal fiber.

Table 1: properties of sisal fiber [8]

Fiber bundle dia. in (μm)	Density in g/cm³	Moisture content at 65% RH in %	Tensile strength in N/mm²	Young's modulus in N/mm²	Elongation in %	Flexural Modulus in N/m	Chemical constituents in %	
							cellulose	lignin
50–200	1.45	11	412–640	9400–15200	2.5–5.0	12.5–17.6	66–78	8–14

Bio-char is created by heating organic material under conditions of limited or no oxygen (Pyrolysis). Pyrolysis, basically changes a low density and energy biomass product to high density and energy product such as bio-char, bio-oil and syngas .Slow pyrolysis gives a higher bio-char yield whereas fast one yields more of bio-oil. The chemical and physical characteristic gets changed as per the slow or fast pyrolysis resulting in change of elemental composition and its porosity. Most of the work till date has been done seeing bio-char as a soil enhancer and recently it is being investigated for use in other application [9].A table showing constitution of a bio-char is as follows:

Table 2: Properties of bio-char [9].

Sample	Component, Wt.%							Total pore volume (cc/g) $[10^{-2}]$
	C (%)	**H (%)**	**N (%)**	**O (%)**	**Ash (%)**	**Fixed carbon (%)**	**Volatile Matter (%)**	
MB	66.49 (0.38)	2.90 (0.07)	1.59 (0.34)	22.88 (0.51)	8.4 (00.03)	58.04 (0.25)	30.81 (0.29)	1.23 (0.18)
SB	59.16 (0.25)	2.37 (0.08)	1.10 (0.09)	18.95 (0.07)	19.4 (0.03)	48.32 (0.54)	27.75 (0.28)	2.12 (0.16)
SWB	81.01 (2.45)	2.40 (0.13)	0.50 (0.15)	11.15 (0.62)	1.3 (0.70)	75.24 (0.76)	18.72 (0.43)	7.76 (0.61)

It has a good surface area and adsorbent capability with an appreciable carbon sequestration value. These properties may be measured through characterization scheme, or by carbon emission offset protocol.

II. EXPERIMENTAL WORK

2.1 Hand lay-up method: This technique is the easiest way of fabricating composite being one of the cheapest. The quality of the product depends mainly on the skill of the worker. The disadvantage with this technique is the long curing time and low production rate. A mold of dimension 150x130x5 mm^3 is used for composite preparation. Different composition for which fabrication of the composite was done is shown in table.

Table 3: composition for fabrication of composite

Sr. No.	Sisal (gms)	Bio-char % weight fraction	Epoxy (gms)
1	2	5%	93
2	2	10%	88
3	2	15%	83

2.2 Materials

Epoxy resin, (grade LY556) and hardener, (grade HY-951) was used in this study. The reinforced matrix material was prepared with a mixture of epoxy and hardener at a ratio of 10:1.sisal is used as fiber and softwood bio-char as filler. Wax is used as a relieving agent.

2.3 Alkali treatment

Before the chemical treatments, sisal fibers were prepared by chopping and then washed with distill water at 80°C for 1 hr followed by drying in oven at 100°C for 5 hrs [10]. The alkali treatment of dried sisal fibers was carried out by soaking them into 5 wt. % solution of NaOH for 2 hrs at room temperature. After this process the fibers were thoroughly washed with distilled water and dried in hot air at 50°C for 10 hrs [11].This treatment causes increase in amorphous cellulose reducing crystalline cellulose.

2.4 Preparation of composite

The mold is first cleaned and then a mold releasing agent is applied for easy removal of composite from the mold. The epoxy resin mixture and hardener are mixed in the ratio of 10:1 (by weight). The weight % of fiber used is 2 grams. The sisal fibers are placed in the mold and required amount of epoxy resin mixture with bio-char is poured. The mixture was prepared using a magnetic stirrer in which the epoxy is stirred for reducing viscosity and then bio-char is added in the required amount. Sample is then cured in atmosphere for 12 to 15 hours of time [12].

2.5 Material Testing

Tensile

The tensile strength of a material is the maximum amount of force that it can take before failure. The commonly used specimen for tensile test is the dog-bone type. ASTM D3039 is used for tensile testing of specimen. The tensile test was performed in the universal testing machine (UTM) instron 3382(bi-axial testing machine, load capacity 100 kN) with a rate of 50 mm/min.

Flexural

Flexural strength is defined as a materials ability to resist deformation under load. The short beam shear (SBS) tests are performed on the composites samples to evaluate the value of inter-laminar shear strength (ILSS). It is a 3-point bend test, which generally promotes failure by inter-laminar shear. This test is conducted as per ASTM D790-03 standard using UTM .The dimensions of the rectangular shaped flexural specimens were 80mm×20 mm×3.2 mm with span length 48 mm. These specimens were also tested on universal testing machine (UTM) instron 3382 (bi-axial testing machine, load capacity 100 kN) with 3.29 mm/min crosshead speed. The flexural properties may be calculated by

Flexural strength= $3FL/2bd^2$

Flexural modulus= $mL^3/4bd^3$

Where; F is ultimate failure load in N, L is span of the supporting centre in mm, b and d are the width and thickness of specimen for flexural test correspondingly in mm, m is slope of tangent to the initial straight portion of the load-deflection curve[13].

Impact

Izod impact test specimens were prepared as per standard ASTM D 256 of had dimension 65 mm×13 mm×3.2 mm. Impact test of specimens were performed on the Tinius Olsen Impact 104 machine and the results were reported.

III. RESULTS AND DISCUSSION

3.1 Water absoption test

Reduction in weight of the fiber can be attributed to the fact that surface and heat treatments will decrease the intrinsic moisturizing contents which while further help in improving the surface adhesion characteristics. The % weight reduction of the sisal fiber was:

% weight reduction = (33.26-27.46)/27.46 x100= 21.12 %

3.2 Tensile Test

The table depicts the trend of variation in the tensile properties with the considered variation. It clearly indicates that longitudinal Sisal fibers have an edge over orthogonal sisal fiber in capacity of taking tensile stress. Reasons pertaining for these values can be detailed in the fact that longitudinal fibers are in better position to hold the material matter, increasing their stress transfer between fiber and matrix whereas in case of orthogonal fibers, the holding capacity of the fiber reduces due to formation of rubber kind of substance which holds the material matter very unevenly. These fibers also tear apart with the application of extra force as the adhesion force of fiber and matrix only comes to work.

Table 4: Results of tensile behavior of specimen

Orientation	Thickness (mm)	Width (mm)	% Bio-char weight fraction	Max Tensile load (N)	Max Tensile Stress (MPa)	Elongation at break (%)
Longitudinal	3.77	11.66	5	631.17	14.4	1.8
	4.92	13.34	10	682.92	10.4	1.75
	4.83	13.29	15	559.11	8.7	1.7
Orthogonal	3.77	11.66	5	257.43	5.9	2.5
	4.92	13.34	10	249.40	3.8	2
	4.83	13.29	15	70.51	1.1	0.9

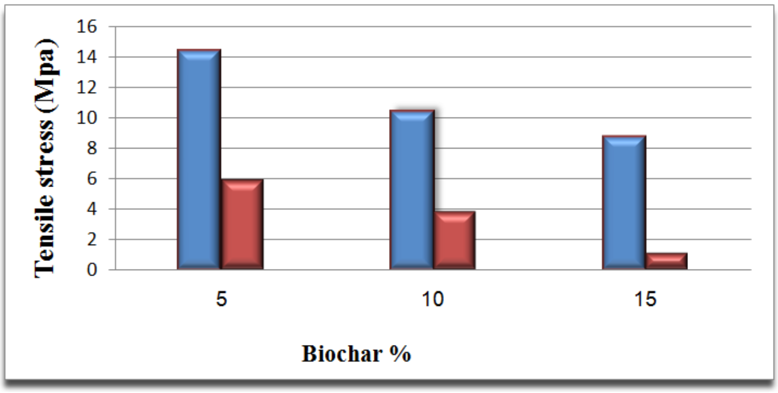

Fig 1: max tensile stress of longitudinal(blue) and orthogonal(red) fibers

3.3 Flexural strength

The flexural strength of the fibers remains constant for the first two without much variation while for the third specimen it goes down. The bio-char here being a porous structure seems to control the variation in the compressive stress on the upper part and the tensile stress in the lower part. On the other hand more addition of bio-char causes decrease in strength due to increase in porosity.

Table 5: Table showing flexural properties

Sample	Flexural modulus (MPa)	Max flexural strength (MPa)
5% Bio-char	4615.33	21.2385
10% Bio-char	2589.78	21
15% Bio-char	2070.19	14.466

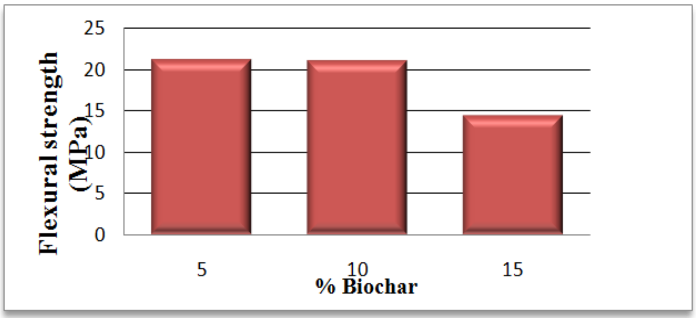

Fig 2: variation in flexural strength for longitudinal fiber

3.4 Impact strength

The fibers were randomly oriented and the edge here is again taken by the longitudinal fibers. The variation in the impact energy is found low. Some of the variations that occur may be attributed to the randomly oriented fibers which may be dense at some places and the porous structure of Bio-char.

Table 6: Result of impact test

Orientation	% of Bio-char	Total energy (Joule)	Energy / unit area (KJ/ m^2)
Longitudinal	5	0.2485	2.7392
	10	0.2994	5.7639
	15	0.6987	6.68496
Orthogonal	5	0.0784	0.8703
	10	0.0652	1.0581
	15	0.1247	1.5667

3.5 Material selection chart

Strength Vs density .The design guide-lines in this chart assist in selection of materials for minimum weight, strength-limited design. Below the chart shows the position of the materials, the longitudinal fiber with 5% Bio-char (red star) lies in the engineering polymer zone whereas the position of the orthogonal fiber with 5% bio-char (black star) lies just at the outer boundary of engineering polymer and elastomer.

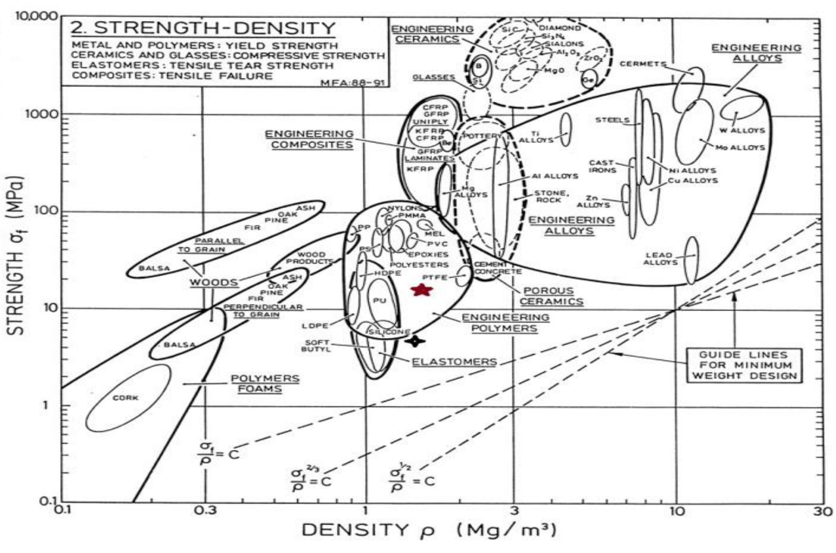

Fig. 3: Position of materials in strength vs. density [14].

Fracture toughness vs strength: The design guide-lines in this chart are used in selecting materials for damage tolerant design. Below both the material occupy position in the polymer foam zone the red star (longitudinal fiber with 5% Bio-char) at the inner periphery and black (orthogonal fiber with 5% bio-char) below it.

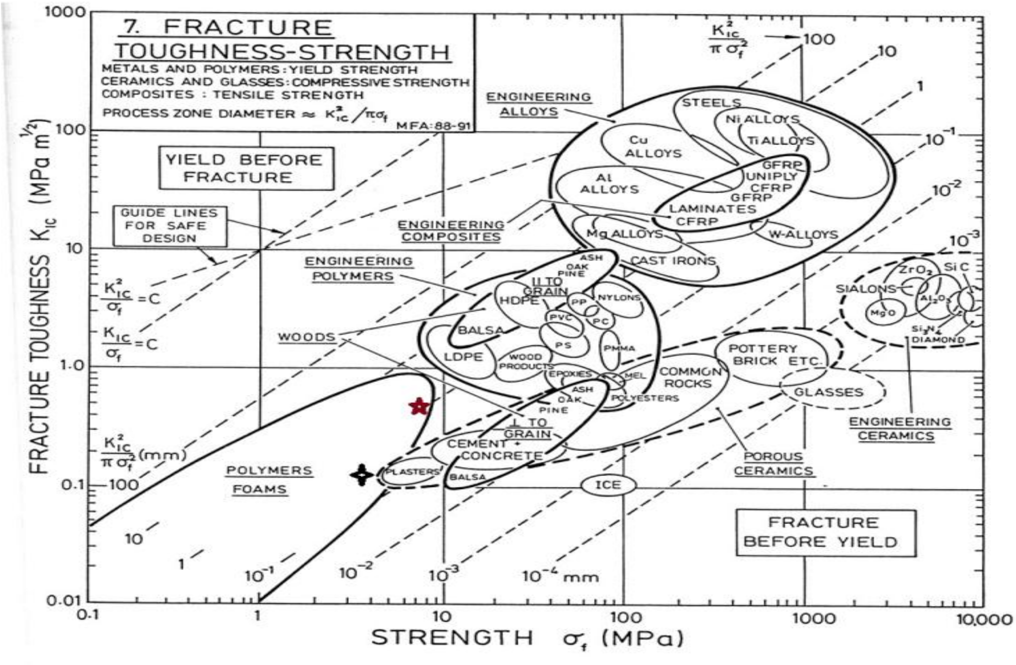

Fig. 4: Position of materials in fracture vs. toughness[14].

IV. CONCLUSIONS

A hybrid composite was fabricated by changing the constituent of Bio-char and varying the fibre orientation of the Sisal fiber in epoxy matrix. After fabrication material was tested based upon different mechanical tests viz. tensile, flexural and impact for its characterization and for plotting in material selection chart. The conclusions that can be drawn through the results of conducted study are as followed:

- Surface and heat treatments lead to the reduction in weight of Sisal fibers decreasing the moisturizing content as well as improving the surface adhesion characteristic.
- Change in orientation clearly shows the superiority of longitudinal fiber over orthogonal one. The longitudinal fiber is found far better in mechanical characteristic compared to the orthogonal fibers
- Tensile properties of the composite having longitudinal fibers with 5% bio-char was seen maximum compared other composite specimen.
- Flexural strength was found maximum of composite containing 10% bio-char and longitudinal composite while flexural modulus was maximum for longitudinal fiber with 5% bio-char.
- Impact properties of sisal composite were found maximum for the composite containing 15% bio-char with longitudinal fibers.
- The materials lie in the engineering polymer and polymer foam zone showing its area for uses.

V. SCOPE OF FUTURE WORK

The material can be further enhanced by variations, yielding different properties. The use of bio-char as fillers seems promising and its effect in the field of vibration as well as tribology can also be studied.

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REFERENCES

[1]. F.G. France, Historic Usage and Preservation of Cultural Heritage. In Jorg Mussig (Ed.), *Industrial application of natural fibers,1* (United Kingdom: John Wiley & Sons publisher,2010) 3-9.

[2]. S.D. Bavan and G.C. Mohan, Finite element analysis of a natural fiber (maize) composite beam, *Journal of engineering, vol. 2013*,article ID

450381,dx.doi.org/10.1155/2013/450381, 2012

[3]. Josmin P. Jose , S.K Malhotra, Advances in Polymer Composites: Macro- and Microcomposites–State of the Art, New Challenges, and Opportunities. In sabu Thomas(Ed.),*Part one:Introduction to polymer composite*,*1*(Wiley-VCH Verlag, 2012) 3-16.

[4]. D.E. Akin, Chemistry of plant fibers. In Jorg Mussig (Ed.), *Industrial application of natural fibers,1* (United Kingdom: John Wiley & Sons publisher,2010) 14-21.

[5]. J. Kuruvilla, D.T.F. Romildo, J. Beena, T. Sabu and H.D.C. Laura. A Review on sisal fiber reinforced polymer composite, *Revista Brasileira de Engenharia Agrícola e Ambiental,* 3(3), 1999,367-379

[6]. M. Eder, and I. Burgert , Natural Fibres – Function in Nature. In Jorg Mussig (Ed.), *Industrial application of natural fibers, 1* (United Kingdom: John Wiley & Sons publisher,2010) 23-39.

[7]. M.Kumaresan, S. Sathish , and N. Karthi, 2015.Effect of Fiber Orientation on Mechanical Properties of Sisal Fiber Reinforced Epoxy Composites. *Journal of Applied Science and Engineering, 18(3)*, 2015, 289-294 (2015), DOI: 10.6180/jase.2015.18.3.09

[8]. R. D. Anandjiwala and M. John, Sisal-Cultivation, Processing and Products. In Jorg Mussig (Ed.), *Industrial application of natural fibers, 1* (United Kingdom: John Wiley & Sons publisher,2010) 181-195

[9]. E. Behazin, and E. Ogunsona, Mechanical, chemical and physical properties of wood and perennial grass bio-char for possible composite application. *Bioresources 11(1)*, 2016, 1334-1348.

[10]. Sood, M., Dharmpal, D. and Gupta, V.K. 2015.Effect of Fiber Chemical Treatment on Mechanical Properties of Sisal Fiber/Recycled HDPE Composite. *Proc 2 Materials Today:elsevier* (2015), 3149 – 3155.

[11]. R. Shrivastava, A. Christy, A. Telang, and R.S. Rana, Effect of chemical treatment and curing parameters on mechanical properties of natural fiber reinforced polymer matrix composites-a review. *Int. journal of engineering research and applications, 5(6),2015*, 55-59

[12]. K.L Pickering, M.G. Efendy, and, T.M. Le, A review of recent developments in natural fibre composites and their mechanical performance. *Composites: Part A, sciencedirect: elsevier 83(*2016), 98–112 dx.doi.org/10.1016/j.compositesa.2015.08.038

[13]. H.O. Maurya, M.K. Gupta, R.K. Srivastava, and H. Singh, Study on the mechanical properties of epoxy composite using short sisal fiber. *Proc. 2 Materials Today:Elsevier* ,2015,1347 – 1355

[14]. M. F. Ashby, *Materials selection in mechanical design* (Butterworth-Heinemann, Boston: Elsevier, 2005).