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Experimental Influence of Bagasse/Sisal Fiber Stacking Sequence on the Mechanical Characteristics of Hybrid-Epoxy Composites

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Abstract: The current study deals with the mechanical and morphological properties of sisal/bagasse fibers reinforced epoxy composites. The composites were developed by the hand layup process in four different proportions of sisal/bagasse fibers. The produced composites were characterized for its mechanical characteristics, namely, tensile, flexural, impact, Shore D hardness compression tests, water absorption and biodegradation tests as per ASTM. Morphologies were studied using Scanning Electron Microscopy. It was inferred that composites with three layers of sisal fibers and a core layer of sisal fibers produced good properties.

Keywords: Hand layup; bagasse; sisal; morphological studies; tensile strength; water absorption

I. INTRODUCTION

A. Sisal-Bagasse Composites

There is numerous literature which is available regarding the characterization of several natural fibers, but there are no works related to the characterization of sisal-bagasse fibers. The composite was fabricated by varying the sisal, and bagasse fiber layers by hand lay-up processes. The developed composite was characterized by tensile, flexural, impact, compression, Shore D hardness, water absorption, and biodegradation tests. The morphological characterization of the samples was carried out by Scanning Electron Microscope (SEM).

B. Sugarcane

Sugarcane, is one of the several species of tall perennial true grasses of the genus Saccharum, tribe Andropogoneae, native to the warm temperate to tropical regions of South and Southeast Asia, Polynesia and Melanesia, and used for sugar production with a total production of 500 million tons. It has stout, jointed, fibrous stalks that are rich in the sugar sucrose, which accumulates in the stalk internodes. The plant is two to 6 m (6 to 20 feet) tall. Sugarcane belongs to the grass family Poaceae, an economically important seed plant family that includes maize, wheat, rice, and sorghum, and many forage crops. Bagasse is the fibrous matter that remains after sugarcane crushed to extract their juice. It is dry pulpy residue left after the extraction of juice from sugar cane. Bagasse is used as a biofuel and in the manufacturer of pulp and building materials. The bagasse fibers were washed and dried in the sunlight. It was kept in a cabinet oven with air circulation for 48 h at 60°C Saw and Datta (2009) to get fibers. The fibers were chopped and used.

C. Sisal

The botanical name of sisal fiber is agave sisal, and it is found in southern Mexico but widely cultivated and naturalized in many other countries. It yields a stiff fiber used in making various products. From each sisal fiber leaf, nearly 1000 fibers can be manufactured. Sisal fibers are extracted from the leaves of the sisal plant. They were extracted by hand extraction machines. The sisal fiber was weaved in the form of biwoven mat and used. The constituents of sisal and bagasse fibers are shown in Table 1. The details given in Table 1 are calculated, but the values are within the range as described in the literature (Idicula et al. 2005; Tita et al. 2018).

Constituents Of Bagasse And Sisal Fibers

Sl. No.	Constituents	Bagasse fibre percentage (%)	Sisal fibre percentage (%)
1	Cellulose	47	63
2	Hemicellulose	21.5	12
3	Lignin	23	5
4	Waxes	0.9	2

II. LITERATURE SURVEY

Tara Sen and H. N. Jagannatha Reddy, Application of Sisal, Bamboo, Coir and Jute Natural Composites in Structural Upgradation. International Journal of Innovation, Management and Technology, 2011, 2(3): 186-191.

Sabu Thomas, K. T. Varughese and Maya Jacob John, Green Composites from Natural fibers and Natural Rubber: Effect of fiber Ratio on Mechanical and Swelling Characteristics. Journal of Natural fibers, 2008, 5(1): 47-6

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Riedel, Ulrich and Jorg Nickel, 2005, Applications of Natural fiber Composites for Constructive Parts in Aerospace, Automobiles, and other Areas. Biopolymers Online, 2005.

Sabah M, Reem, Mohamed Ansari and Mohannad Saleh H, A Study On Mechanical, Thermal and Morphological Properties of NaturalFibre/Epoxy Comosite. Journal of Purity, Utility Reaction and Environment, 2012, 1(5): 237-266.

M. Joshy, L. Mathew and R. Joseph, Studies on short Isora Fibre-Reinforced Polyester Composites. Composite Interfaces, 2006, 13(4-6): 377-390.

D. Chandramohan and J. Bharanichandar, Studies on Natural fiber Particle Reinforced Composite Material for Conservation of Natural Resources. Advances in Applied Science Research, 2014, 5(2): 305-315.

III. PROPOSED SYSTEM

A. Methodology

The literature review has given an insight of the composites research works and the gaps found in it enabled to identify problem areas and find solutions through the experimental methodology fulfilling the objective

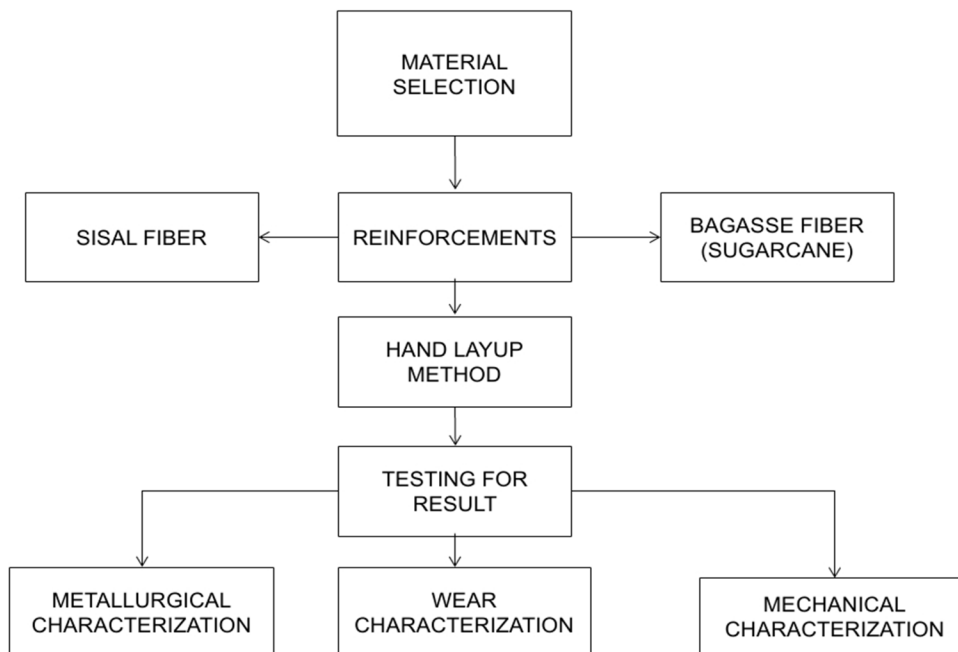


Figure 3.1 Flow chart of the work

B. Resin And Hardener

The binding of the fibers was carried out using an epoxy resin which has a grade name of LY556.

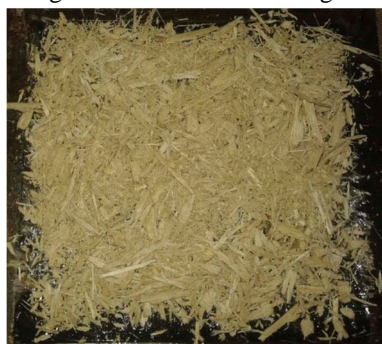
It comes from the family of epoxide, and the common name given to it is Bisphenol A Diglycidyl Ether. The hardener used in the present investigation was HY951, which is used for providing better bonding between the matrix and the fibers. The ratio between the epoxy resin and the hardener was 10:1.5

C. Development Of Composites

The composite materials were fabricated using the Hand lay-up process. Initially, the raw material was dried in sunlight for the removal of moisture. The resin and hardener were mixed in the ratio of 10:1. For uniform distribution of the mixture of resin and hardener rollers were used. First, a layer of resin was applied over the smooth surface, then, the fiber layer was placed over it. In Figure 1(b) the layer of bagasse fiber was placed followed by the application of resin and rolling using a roller. Then, a layer of sisal was placed over it in the form of mat, further resin was applied and rolled using a roller. Finally, a layer of bagasse fibers was placed, then, a layer of resin was applied followed by leveling using a roller. The process of manufacturing is shown in Figure 1(a–d). Once the stacking gets completed, it was kept under the load of 25 kg and allowed it for curing at room temperature at



(a) Application of Resin.



(b) Layering of Bagasse



(c) Sisal over Bagasse



(d) Application of Bagasse over sisal

Figure 4.1 (a) Application of Resin. (b) Layering of Bagasse. (c) Sisal over Bagasse. (d) Application of Bagasse over sisal.

S.No	Sample Designation	Composition of developed composites
1	A1	bagasse -bagasse- bagasse
2	A2	sisal – sisal – sisal
3	A3	bagasse – sisal – bagasse
4	A4	sisal – bagasse – sisal

Room temperature under constant pressure. The resin which was in excess was squeezed out during the compression process. Once the developed composites get dried, the testing samples were cut according to ASTM. The sample code for the developed composites is shown in Table 2.

- 1) The characterization of the developed composites was carried out by tensile, flexural, compression, impact and Shore D hardness according to ASTM. For confirmation of the results, all tests done for five times, and the average values are noted down.
- 2) The tensile strength of the developed composites was carried out according to ASTM D638-14. The test was carried out at room temperature and strain rate of 5 mm/min in the universal testing machine. The dog bone shape samples for tensile tests were cut using a saw cutter.
- 3) The dog bone shaped samples were fixed between the grippers, and the load was applied until the failure occurs. The flexural strength was carried according to ASTM D790-10 using a three-point setup in the universal testing machine. The crosshead speed of the test was kept at 2 mm/ min during the testing.

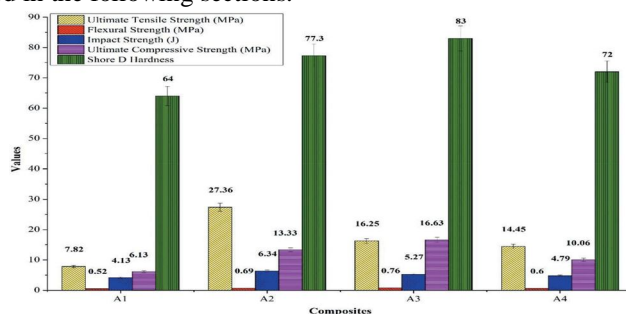
- 4) During the testing process, the samples were subjected to load in the middle, and the values are noted until there is a fracture. The impact tests for the developed composites were done according to ASTM D256-10 using an Izod impact machine.
- 5) The hammer angle was kept at 150° initially, and the notched specimen was kept in the sample holder.
- 6) The energy absorbed during the fracture was noted. The compression properties of the developed composites were carried out according to ASTM D 695-15 in the universal testing machine.
- 7) Shore D hardness evaluated the hardness of the developed composites as per ASTM D2240-05.
- 8) The hardened steel rod with 1.25 mm in diameter was used as an indenter, and it has a conical angle of 30°. The load applied during the testing was 4.550 kg.
- 9) The developed composites were characterized by water absorption characteristics according to ASTM D570-96
- 10) The sample size selected for the tests is 50 × 50 × 10 mm³. It was immersed in normal water. The samples were initially weighted and immersed in water at room temperature.
- 11) At regular intervals of time the specimen was taken out of the water, weighed and it was placed inside the water again.
- 12) The procedure was carried out until it reaches the point of saturation. The percentage of water content is determined using the following equation (1)

$$\text{Weight } \delta P \% = \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial Weight}} \times 100 \quad (1)$$

- 13) Biodegradation can be defined as the chemical suspension of materials by bacteria or any other biological means. The sample size selected for the tests is 50 × 50 × 10 mm³.
- 14) During the test, the samples were kept for 20 days, and the changes in the weight of the specimen were noted. Morphological characteristics were studied using Scanning Electron Microscopy by cutting the ample using the diamond cutter for the size of 1 cm*1 cm.

IV. RESULT AND DISCUSSION

In the current investigation, the manufacturing of the fiber reinforced samples was carried out by hand lay-up techniques were carried out. The main aim of the current investigation is to find the tensile, flexural, impact, compression tests, Shore D hardness, water absorption and biodegradation tests of the manufactured composites, and their values are listed in Figure 2, Figures 6 and 7. The finding of the results is discussed in the following sections.



A. Tensile Properties Of The Developed Composites

- 1) The mechanical properties of the composites depend upon several factors like mechanical interlocking, types of bonds and van der Waals force.
- 2) The strength of any developed composites depends upon the initiation of crack followed by propagation of crack on the matrix surface, and it depends upon the shape and orientation of the matrix surface.
- 3) The ultimate tensile strength of the various manufactured composite samples was found out using a tensile test. The ultimate tensile strength was noted for all the specimens, and it is shown in Figure 2, and their stress-strain graphs are shown in Figure 3.
- 4) From Figure 3 it can be seen that when the load increases the displacement also increases simultaneously.
- 5) The stacking sequence A2 has a maximum load-bearing capacity when compared to other manufactured composites.
- 6) The ultimate tensile strength of sisal – sisal – sisal composites are superior when compared to the remaining manufactured composite specimens
- 7) The increase the ultimate tensile strength of sisal–sisal–sisal is duet the presence of the lignin content of the core layer which makes the fiber stiffer and tougher. The horizontal orientation of the sisal fiber increased strength.

- 8) The increase in the ultimate tensile strength may also be due to the proper adhesion between the matrix and the epoxy matrix.
- 9) The developed composite A2 has a maximum strength of 27.36 MPa followed by 16.25, 14.45 and 7.82 MPa for A3, A4, and A1 developed composites.
- 10) The debonding of the sisal fiber takes place very slowly when compared to remaining manufactured composites which increased ultimate tensile strength.
- 11) The increase in the load-bearing capacity of the bagasse fiber is similar to the results suggested by Santulli et al. (2013).
- 12) The reduction for the reduction of ultimate tensile strength in the case of other manufactured composites is due to the improper adhesion between the resin and the matrix. Thus, the developed sisal – sisal – sisal can be used where load-bearing capacity is applicable.

B. Flexural Properties Of The Developed Composites

The flexural strength is a property which measures the stiffness of the developed composites. The flexural strength of the manufactured composites is depicted in Figure 2, and their stress-strain graph is shown in Figure 4. The failure begins to develop when the crack was initiated at the tension side. The flexural strength of the bagasse-sisal-bagasse is more when compared to the remaining composites. The sample A3 has a maximum strength of 0.76 MPa and sample A2, A4, and A1 have a load of 0.69, 0.60, and 0.52 MPa. The reason for the increase in flexural strength in A3 sample is

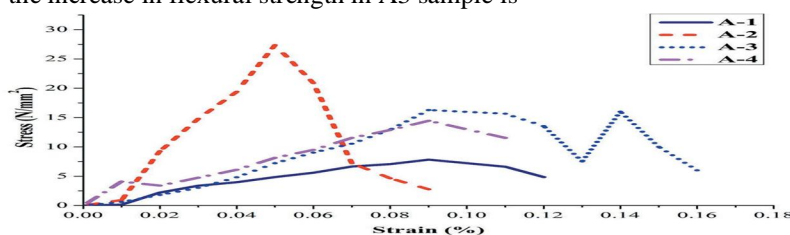


Figure 5.2 Tensile Stress-strain graph of the developed composites.

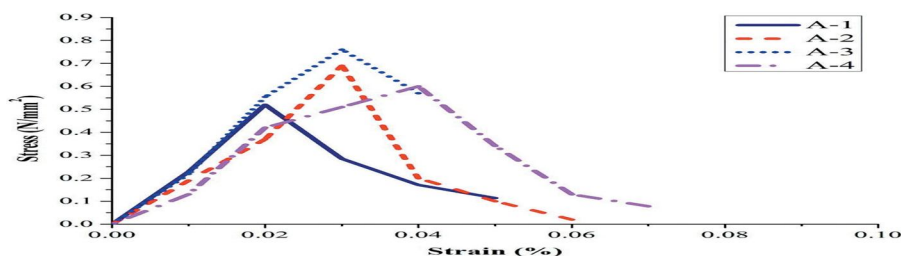


Figure 5.3 Flexural Stress-strain graph of the developed composites.

Due to the presence of stiffer bagasse fiber which as a skin material, and it has enhanced load-bearing capacity. The higher surface roughness of the sisal fiber ensures that there is a perfect adhesion between the resin and matrix which resulted in increases in flexural strength. The proper adhesion between the matrix and the epoxy matrix has enlarged the stiffness of the matrix. The improper adhesion between the matrix and epoxy resulted in a reduction of stiffness in the remaining developed composites. The stress-strain graph of the laminated composites Figure 3 shows the good distribution of stress since the impurities and brittleness causing elements are removed leading to the enhanced flexural strength. Similar kind of increase in flexural strength characteristics was noted by Ramnath et al. (2013) when there is a proper adhesion between matrix and fiber.

C. Compression Properties Of The Developed Composites

- 1) The ultimate compressive strength of the developed composites are shown in Figure 2, and their stress-strain values are shown in Figure 5.
- 2) When compared with all developed composites bagasse sisal-bagasse composites had superior compressive strength when compared to other developed composites.
- 3) The improvement in ultimate compressive strength is due to the excellent adhesion between the fiber and matrix.
- 4) The same kind of increase in ultimate compressive strength was also noted by Sathish et al. (2017).

D. Water Absorption Test Of Developed Composites

- 1) In the case of lignocellulosic fibers, the presence of hydrophilic hemicelluloses is responsible for water absorption.
- 2) The other factors which are responsible for water absorption are cellulose chains of non crystalline domains and the presence of lignin content.
- 3) The water absorption tests of the different stacking sequences of the composites are studied in detail, and the same is shown in Figure 6.
- 4) The better adhesion between the matrix and fiber resulted in a reduction in water absorption which also matches the results suggested by Bharath et al. (2018). Figure 6 shows the thickness swelling % vs. a number of days of the developed composites.

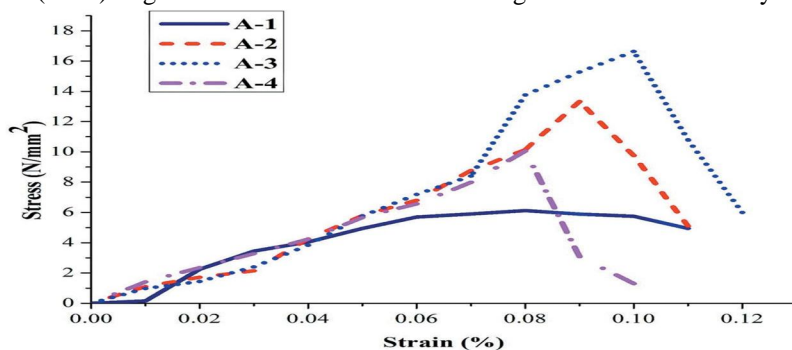


Figure 5.4 Compressive Stress-Strain composites for developed composites.

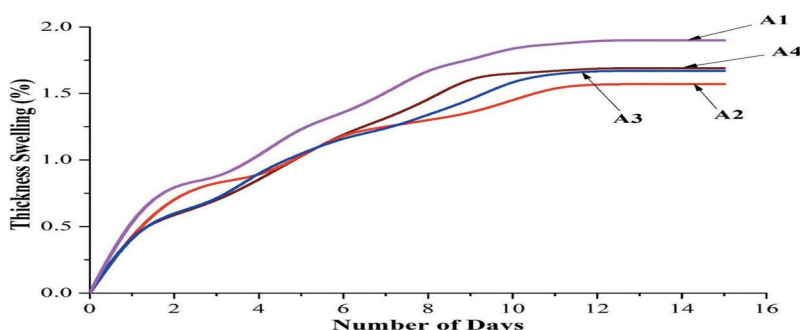


Figure 5.5 Water absorption characteristics of developed composites in stated proportions.

- 5) There was an increase in the percentage of moisture absorption as the number of day increases, and it reaches the saturation value when it reaches 15 days.
- 6) From Figure 6, it can be seen that the water absorption capacity of A4 composites is more when compared to the other developed composites.
- 7) The developed composites which have all three layers of sisal fibers have less water absorption capacity sisal fibbers has lower water absorbing capacity. The composite A1 has more water absorption capacity because the water absorption is more in the case of bagasse fibers Tita et al. (2018) also concluded that the bagasse fibers

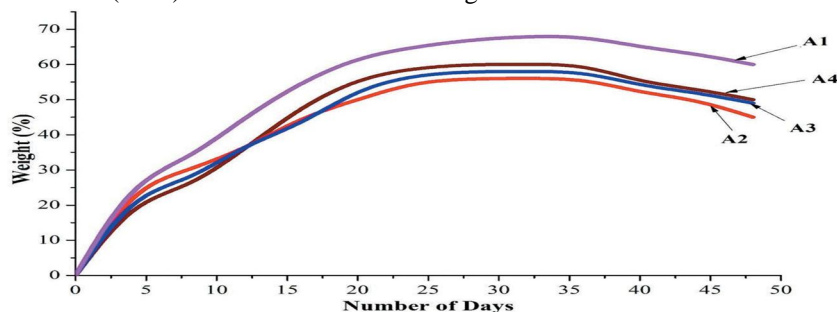


Figure 5.6 Biodegradability tests for developed composites in stated proportions.

- 8) have more water absorbing capacity when compared with sisal fibers which also matches with our experimental results.

E. Biodegradability Test For Developed Composites

- 1) From Figure 7, it can be seen that there was an increase in weight at the initial stages of the specimen and it continued up to 37 days, and then it started to lose its weight.
- 2) The developed composite A2 is less biodegradable because it has less water absorbing capacity.
- 3) The developed composites A1 has more water absorbing capacity due to the presence of hydroxyl and other polar groups.
- 4) The abovesaid phenomenon leads to poor interfacial bonding between the fibers and matrix which results in higher biodegradation values which also matches with the results suggested by Bharath et al. (2018).

F. Morphological Studies

- 1) The morphological studies of developed composites were studied using SEM for studying the surface characteristics. The samples for the SEM test was cut, dried, and a coating layer of 15–25 nm thickness of gold sputtering was given.
- 2) Figure 8(a) shows the SEM image of the A1 sample.
- 3) When compared to all other processed samples it has low strength characteristics.
- 4) The presence of fiber tear and pull out can be visibly seen which resulted in a decrease of strength characteristics.
- 5) The stress transfer between the matrix and fiber is less which also resulted in a decrease in strength characteristics.
- 6) The SEM image of the A2 sample is shown in Figure 8(b).
- 7) It is evident from the image that there was a proper bonding of sisal fiber with the matrix which improved the strength of the developed composites.
- 8) From Figure 8(b), it can be seen that the initiation of the cracks starts from the matrix surface and then it goes to the fibers.
- 9) The presence of fiber pull out and debonding of fibers is not visibly seen which in turn increased the tensile strength of the composites.
- 10) This phenomenon mentioned above leads to an increase in tensile strength characteristics.
- 11) Figure 8(c) shows the SEM image of A3 samples.
- 12) There was a proper bonding with the outer core layer with an inner sisal layer which resulted in improvement in Shore D hardness and impact strength properties.
- 13) The presence of cracks or blow holes cannot be visibly seen which increased impact and Shore D hardness characteristics.

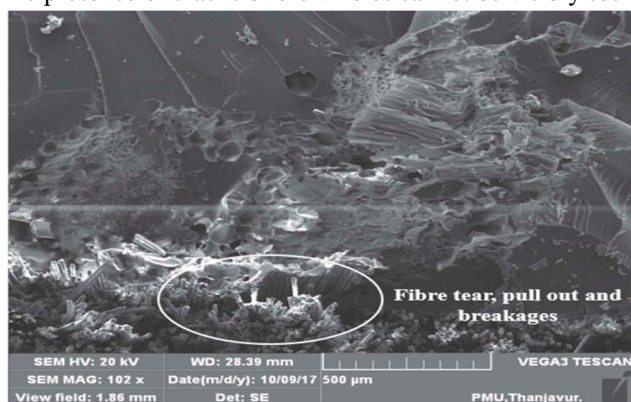


Figure 8(a) SEM image of A1 composite

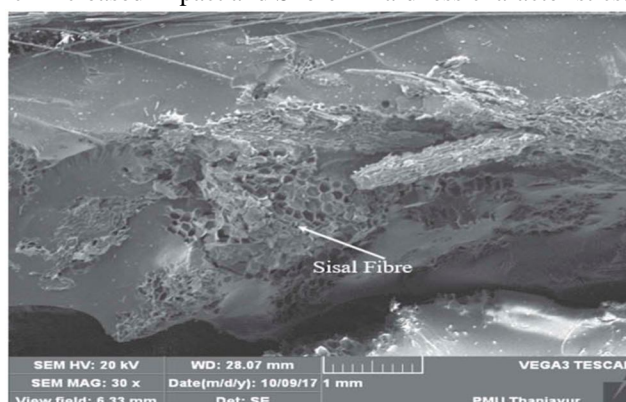


Figure 8(b) SEM image of A2 composite

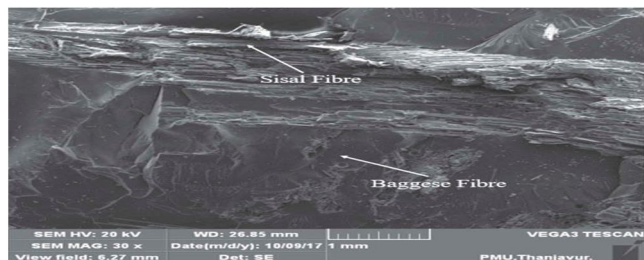


Figure 8(c) SEM image of A3 composite

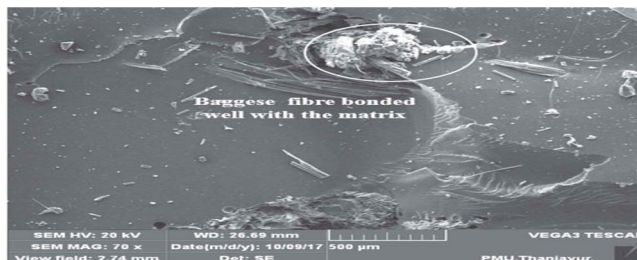


Figure 8(d) SEM image of A4 composite

Figure 5.6 (a) SEM image of A1 composite. (b) SEM image of A2 composite. (c) SEM image of A3 composite. (d) SEM image of A4 composite.

- 14) Figure 8(d) shows the SEM image of A4 sample.
- 15) There was an enhanced bonding between the sisal and bagasse fibers with the matrix which resulted in the good structural capacity of the developed composite.
- 16) It is evident that some part of the fibers got split which also increases the loadbearing characteristics.
- 17) The results obtained was also matching with the results suggested by Chaudhary, Bajpai, and Maheshwari (2018).ultimate compressive strength due to the presence of sisal layer at the middle. The fractography studies revealed the absence of cracks and pores which increased flexural and shored hardness characteristics.
- 18) Three layers of sisal fibers have less water absorption and least biodegradation characteristics which are due to the absence of voids in the interface between matrix and fibers

V. CONCLUSION

The hybrid composites sisal/bagasse fibers were produced by the hand lay-up process. The produced composites were characterized by tensile, flexural, impact, Shore D hardness, and compression tests. SEM was used for studying the fractured surfaces. The results obtained from the experiments are listed below

- A. Three layers of sisal fibers resulted in enhanced ultimate tensile strength and impact strength due to the presence of three layers sisal fibers at the center and also due to better adhesion between matrix and sisal fiber.
- B. The core layer of sisal and an outer skin layer of bagasse composites increased flexural strength, Shore D hardness and ultimate compressive strength due to the presence of sisal layer at the middle. The fractography studies revealed the absence of cracks and pores which increased flexural and shored hardness characteristics.
- C. Three layers of sisal fibers have less water absorption and least biodegradation characteristics which are due to the absence of voids in the interface between matrix and fibers.

From the above things, it can be seen that three layers of sisal fibers and an intermittent layer of sisal fibers with bagasse fibers as the outer layer were the best one in the case of all characterization. The hybridization of sisal fiber could be a possible one for the enhancement of several properties. This work can be further extended by studying the thermal and tribological properties

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