International Journal of Scientific & Engineering Research Volume 12, Issue 2, February-2021
ISSN 2229-5518

Mechanical property assessment of Sisal and Roselle epoxy hybrid Composites

Varunkumar T, Thatikol Harish, Darshan M L, Dr. Ravishankar K S

Abstract— Over the past few decades natural fiber reinforced epoxy composites have become a viable option to create a sustainable environment owing to their superior properties like high strength to weight ratio, good mechanical and insulating properties, excellent resistant to corrosion and creep, biodegradability that enables them for use in construction of building, automotive and aerospace industries, internal and external fixation on human body, packing material. Natural fibers like *Roselle* and *Sisal* offer certain benefits like reduction in CO_2, weight and cost, less dependence on foreign oil sources. Fabrication of this hybrid composite is done by using the mentioned natural fibers, reinforced with epoxy resin and Hardener along with filler, *fly ash* (~5% to strengthen the hybrid composite) by hand lay-up. Different weight fractions of reinforcement were considered (25%, 45%, and 65%) to assess the best composition. Tests like tensile and bending/flexural were carried out to assess their mechanical and physical properties. The reinforcing fibers were treated chemically with 8% NaOH to decrease the fiber density and increase the surface roughness. In addition to all these, Sisal-Roselle production systems are energy efficient and are associated with low equipment wear. As these fibers can be cultivated in huge volume, the farmers get benefited out of it if demand increases, certainly these crops will occupy commercial position

Index Terms— Epoxy resin, Fly ash, Hardener, Hybrid composite, Sisal fibres, Roselle fibres and Mechanical properties

1. Introduction

Aerospace and automobile sectors are continually aiming for low weight, high strength material to enhance the capability and trustworthiness of their organizations. Natural fiber composites have established in a solid manner and became an outstanding alternative to this need, particularly fibers reinforced with polymeric composite. Natural fiber composites are the replacement for the synthetic fiber reinforced composites. The fibers made an impact on a wide variety of engineering applications due to their easy availability, cost, non-abrasive, eco-friendly and biodegradable in nature [1]. Due to these reasons, natural fiber-reinforced composite is gaining much attention from scientists [4]. In the automotive industries, the natural fiber composite is slowly gaining demand due to high strength to weight ratio. Most popular car companies like Mercedes-Benz, Audi and Volkswagen use natural fiber composites for the car interior sections [6]. The fiber reinforced epoxy composite has better mechanical properties when compared with fiber reinforced with polyester composite. The low cost of production and excellent re-usability properties of both Sisal and Roselle fibers are now the most dependable natural fibers as per the many researchers. The fly ash is an extraction or outcome of a Thermal power plant extensively used in cement industries in order to strengthen the different cement grades. Natural fiber reinforced composites are emerging very rapidly as the potential to the metal or ceramic based materials in many Aerospace and construction industries [1]. The current work deals with the mechanical characteristics of Sisal and Roselle natural fiber-reinforced composite with fly ash as filler, as there are very few literature works found in this topic. The natural composites were developed using hand lay-up technique. Tensile and Flexural tests were conducted according to ASTM standards. After the mechanical tests, the fractured surface is examined by using Scanning electron microscopy. Moreover, the overall mechanical characteristics of Sisal and Roselle natural fiber-reinforced composite with fly ash as filler found to have better mechanical properties when compared to without fillers. However, natural fibers have some disadvantages like low impact strength, high brittleness and high moisture absorption properties [5].

2. Materials, methods and testing

The main focus of our study is the tests that are being conducted. Hence it is important to have the right kind of fibers and materials for the test. Therefore the material selection is an important process in designing of laminated composites for the study. Bi-directional Sisal and Roselle fibers in woven mat form of 280 GSM were bought from Go-green Products Chennai-87. F type Fly-ash is procured from KPCL Raichur Thermal Power plant. Later the fly-ash is sieved to less than 500 microbes, by using sieving standard mess BSS 36. Matrices act as a bonding for the composite material and provide a sufficient strength to fibers when they undergo different types of load within the fiber, thereby enabling the inter-laminar strength and even they have an excellent property of corrosion resistance. The ideal matrix for the polymer matrix composite (PMC) is epoxy resin. Lapox resin L12 and Hardener K6 were bought from Solind services private ltd, Bangalore-29. Initially the fresh woven mat fibers of 1 sq.mt each are treated with 8% NaOH solution and soaked thoroughly for 1-2 hours, later the wet sample is dried under the sunlight for 24 hrs. Mild steel rods are welded and form a mold size of dimension 250*130*5 mm3 for the study. Roselle fibers have less moisture content compared to Sisal fibers. Both physical and chemical properties of Sisal and Roselle fibers are mentioned below.

TABLE 1
PHYSICAL PROPERTIES OF FIBRES

Physical properties	Sisal fibres	Roselle fibres
Density (g/cc)	1.45	1.40
Tensile strength (MPa)	340-350	180-200

TABLE 2
CHEMICAL PROPERTIES OF FIBRES

Chemical properties	Sisal fibres (%)	Roselle fibres (%)
Cellulose	72.5	61.21
Hemicellulose	18.1	19.11
Legnin	5.9	8.11
Pectin	2.3	1.45
Moisture	10	4.8
Wax	0.5	-

For every laminate 600g of epoxy resin is used and hardener is taken in the ratio 1:10 (i.e for every 10g of resin 1g of hardener is added), along with these fly-ash of 5% is added. These are thoroughly mixed and used in preparing the laminates. Before the preparation of the sample in laminate form, it is equally important to decide the stacking sequence of Sisal and Roselle fibers. We know that the Roselle fibers have less moisture absorption than Sisal fibers, due to this property the Roselle fibers have a hydrophobic surface and are used as an outer layering for composite laminate. The working table needs to be cleaned with acetone ensuring no residuals on it. Initially the woven mat fibers are cut as per the mold dimension 250*130*5 mm3 and these fibers are compressed under high pressure (200psi) for a few minutes. We need to calculate the weight of each layer of fiber and further the layers required for the reinforcement are decided on the total weight calculated. A thin film sheet (ohp sheets) is placed on the working table to get a good surface finishing and later a mold is placed on it, here we add lubricant (wax) on the thin film sheet as well as on the mold surface to avoid sticking of epoxy mixture. The matrix epoxy mixture is poured on the mold surface and is uniformly spread with the help of brush. Before placing the mat fibers we need to make sure that the fibers with less moisture absorber are placed as an outside layer at both the ends. The first layer of mat fiber is dipped in the beaker containing matrix epoxy mixture so that the mat is completely wet and later it is placed on the mold and finally a mild pressure is applied on the mat-epoxy layer to remove the air present and also to remove the excess epoxy resin. Before adding the second mat fiber, add matrix epoxy mixture on the first layer and place the second layer on it. The process is repeated for epoxy and woven mat fibres, till we get the required stacking. Immediately after this process a thin film sheet with lubricant applied on it is placed on the stacked layers. After completing the composite laminates, keep a rectangular plate with load applied on it. Here we use a rectangular plate to minimize the moment of fibers and to reduce the presence of air bubbles in the stacked layers. For an epoxy base system, the normal casting time at room temperature of 250C is 48 hrs. After casting at room temperature the mold is opened and the laminate is taken out for further process.

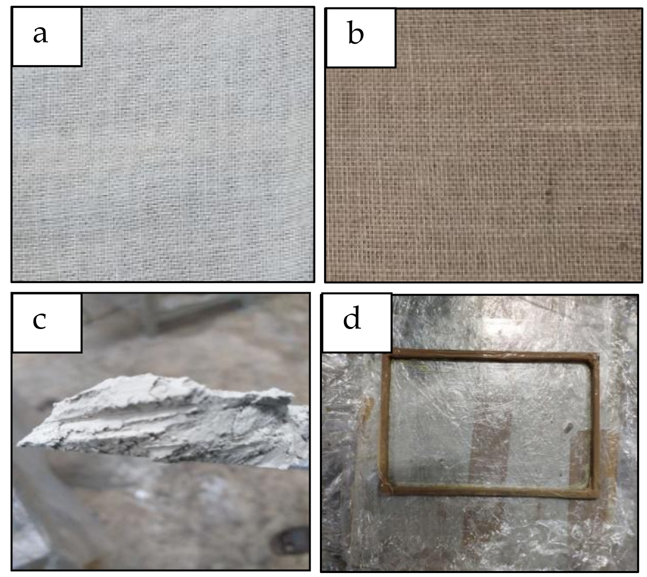


Fig 1, a) Sisal woven fibres b) Roselle woven fibres c) F type Fly-ash d) Mold

TABLE 3
WEIGHT OF FIBRES AND FLY-ASH FOR DIFFERENT REINFORCEMENT

Reinforcment wt% (S-R-F)	Total weight		
	Sisal fibres (g)	Roselle fibres (g)	Fly-ash (g)
10-10-5	23.94	19.9	17.71
20-20-5	47.17	39	18
30-30-5	79.55	65.83	20

TABLE 4
SAMPLE PREPARATION AND ITS COMPOSITION

Stacking sequence	Sisal (wt%)	Roselle (wt%)	Fly-ash (wt%)	Total reinforcement (wt%)
RSSR	10	10	5	25
RRSSSR	20	20	5	45
RRRSSSSSRR	30	30	5	65

*R- Roselle, S- Sisal

Sample wt% amount and their stacking sequence are noted in table 4. When the composite laminates are prepared, it is essential to carry out the mechanical behaviour of these laminates to understand the laminate performance. The tensile and flexural tests are conducted as per ASTM D 3039, ASTM D 7264 standards respectively. Tensile and flexural tests are conducted at a crosshead speed of 2 mm/min in SHIMAZDU UTM of 100kN capacity and the tested samples fractography study is carried by scanning electron microscopy (SEM) located at MME department NITK. Tensile test helps to determine its elongation and the maximum strength or load that a material can withstand. When the material can no longer withstand the stress applied to it, material will fail or cause excessive deformity. The specimen was in rectangular cross-section (Flat type straight sided). The main purpose of the Flexural test is to determine the flexural strength, fracture strength, fracture toughness/shear strength. The flexural stress is maximum at the centre and minimum at the edges of the sample. The test was carried out at room temperature of 250C and the corresponding readings were recorded.

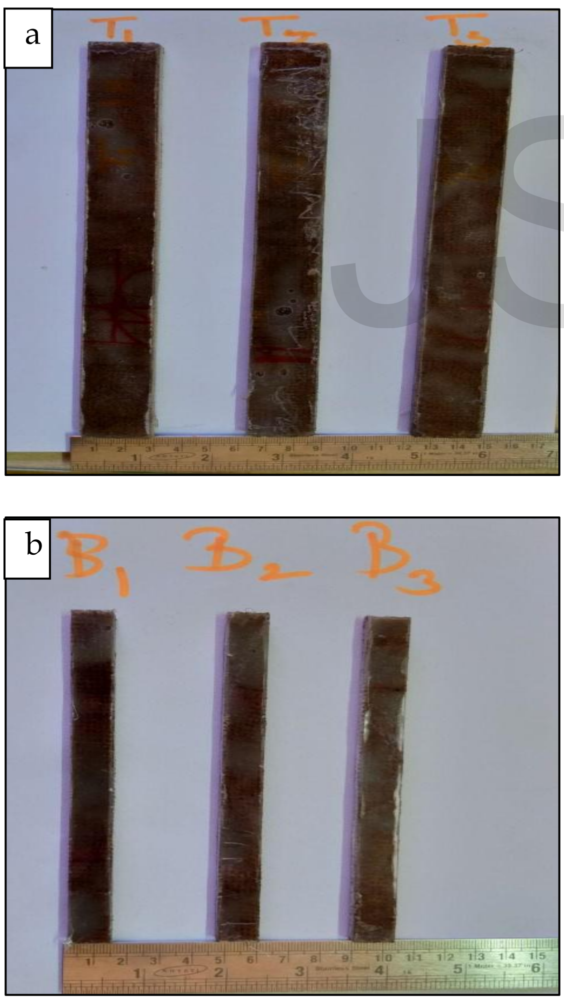


Fig 2, a) Tensile samples b) Flexural samples cut as per ASTM standard before test.

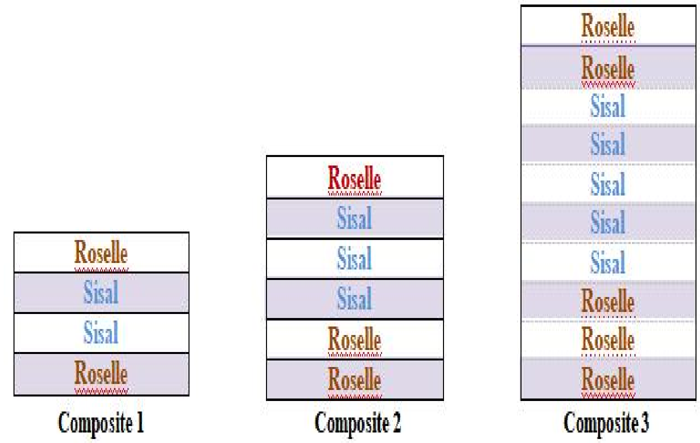


Fig 3, Stacking sequence pattern for 3 different composites

3. RESULTS AND DISCUSSION

Tensile tests were conducted for 25wt%, 45wt% and 65wt% fiber reinforced epoxy hybrid composite as per ASTM D 3039 for which the failure mode was lateral gauge middle portion. In this test, 3 samples of each reinforced laminate were tested and an average is determined and noted. The results are clearly shown in table 5, where it can be observed that tensile strength and strain at breakpoint is almost the same in all three cases. The fracture or failure observed is brittle in nature since matrix epoxy material is highly brittle in nature. The result highlighted maximum tensile strength of 32 MPa and minimum tensile strength of 28.86 MPa for 25wt% and 45wt% of fiber composition respectively. The individual strength of all fibers embedded in matrix, contributes their individual strength together giving rise to better composite strength. The maximum tensile modulus of 5.56 GPa and minimum tensile modulus of 2.89 GPa for 25wt% and 45wt% fiber composition. Tensile modulus is dependent on the fiber property and the composite material can be affected as a result of water absorption, whereas the tensile strength of the composite is more sensitive to fiber-matrix interface. 65wt% fiber composition has a high strain rate of 3.00%, which absorbs high energy. The fracture strain increased from 1.92% to 3.00%, an increase of 57%, due to increase in fiber reinforcement.

TABLE 5
TENSILE RPOPERTIES

Mechanical properties of composite	Total reinforcement		
	10-10-5 (25)	20-20-5 (45)	30-30-5 (65)
Maximum tensile strength (Mpa)	32	28.86	29.20
Tensile strain at break (%)	2.04	1.92	3.00
Tensile modulus (GPa)	5.56	2.89	2.91

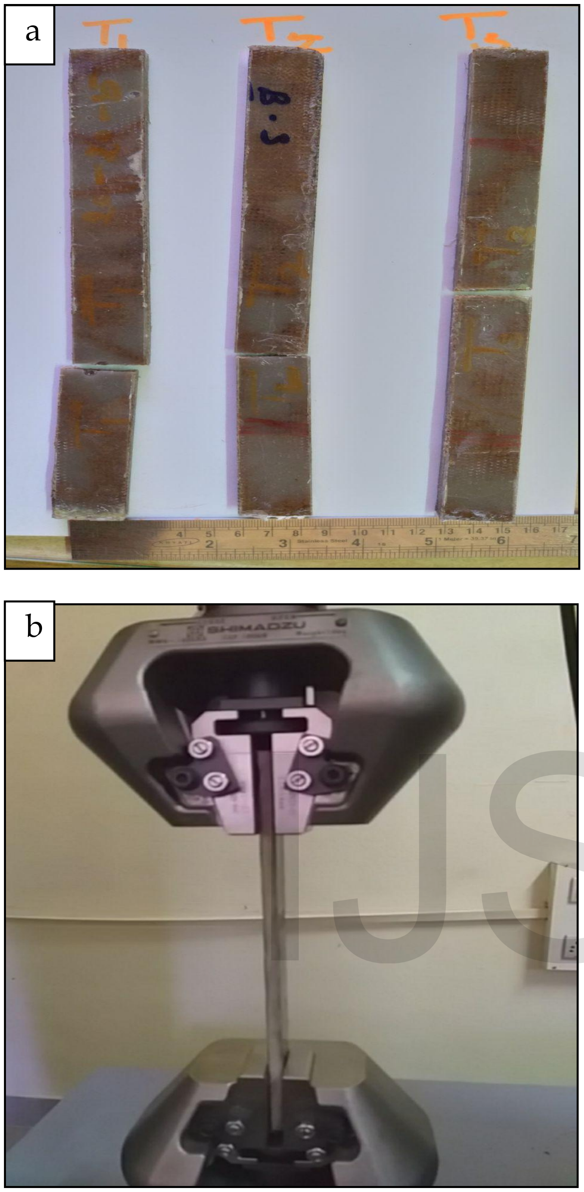


Fig 4, a) After test tensile samples b) Tensile testing machine.

Below figures are highlighting variations of stress vs strain plot. Larger variation is mainly due to selection of edge samples. At the edge of laminated plates, the distribution of material won't be as proper as at the centre. Here almost all three samples have failed at near middle or inside the gauge length. From the graphs below we can justify the catastrophic failure (brittle failure) in figure 4a, in figure 4b we observe premature failure due to presence of voids and cracks, but the failure is resisted by the fibers due to their ductile property and then sharp failure at the end. Whereas in figure 4c, initially we observe premature failure then the fibers resist the breakage due to the highest wt% (65 wt%) of fibers and its ductile property increases the strain rate and finally sudden catastrophic brittle failure is observed. The further analysis on the failed sample has been done in a scanning electron microscope (SEM).

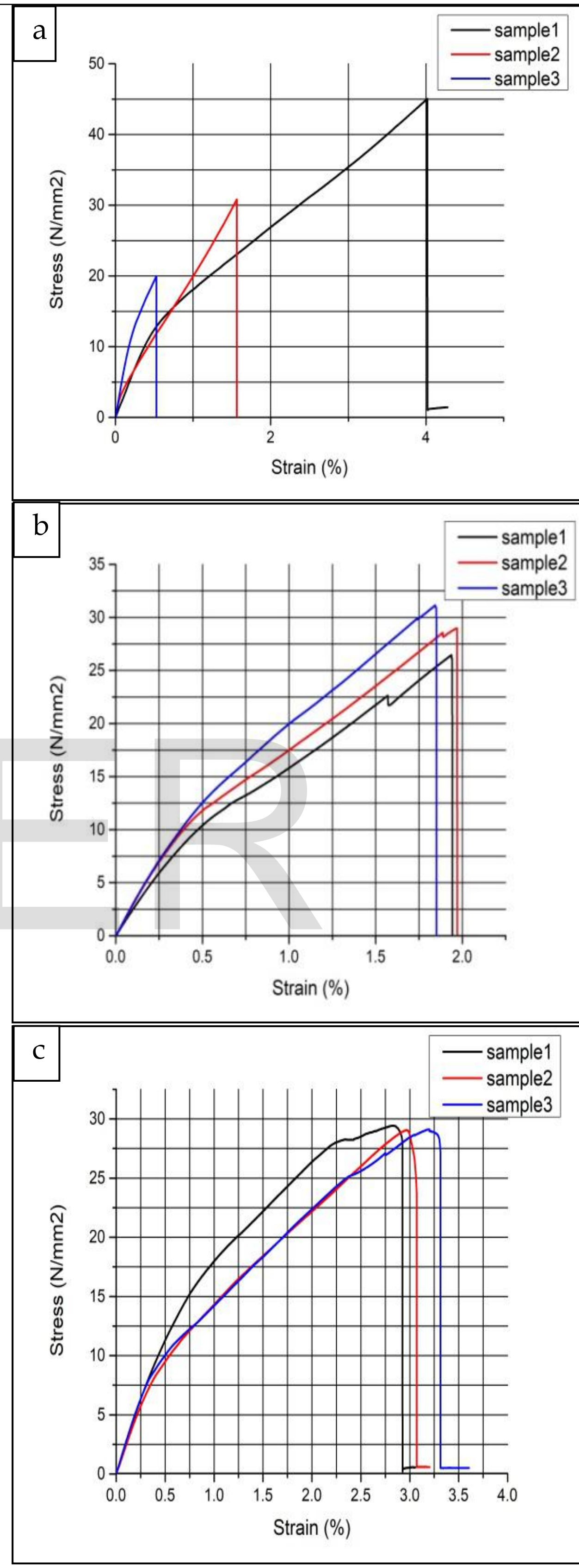


Fig 5, Tensile results graph after testing for different reinforcement a)10-10-5 wt% b) 20-20-5 wt% c) 30-30-5wt%

Flexural tests were conducted for 25wt%, 45wt% and 65wt% fiber reinforced epoxy hybrid composites as per ASTM D 7264. To obtain valid flexural strength, it is necessary that failure occurs on either of its outer surfaces. The outer layer undergoes tension whereas the inner one undergoes tension. The maximum flexural strength is 114 MPa and minimum flexural strength is 75.31 MPa for 25wt% and 45wt% fiber composition respectively. The variation in strength is mainly due to presence of some voids and due to non-uniform distribution of resin in the laminate. The maximum flexural modulus of 50.7 GPa and the minimum flexural modulus 25.51 MPa for 25wt% and 45wt% fiber composition. The variation is due to simultaneous application of tension on the bottom fibers and compression on top of the fiber laminates. The strain rate is maximum of 0.40% for 65wt% fiber composite, the load bearing capacity increases with the increase in fiber weight percentage. The fiber laminate specimen fails suddenly in a linear mode at the bottom surface of the specimen. The Test results are tabulated as follows.

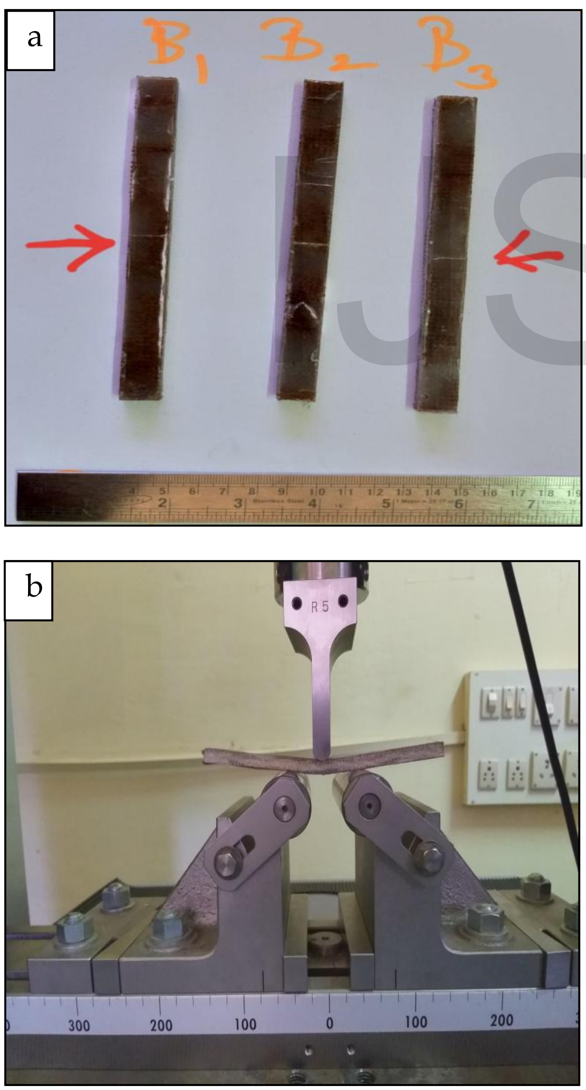
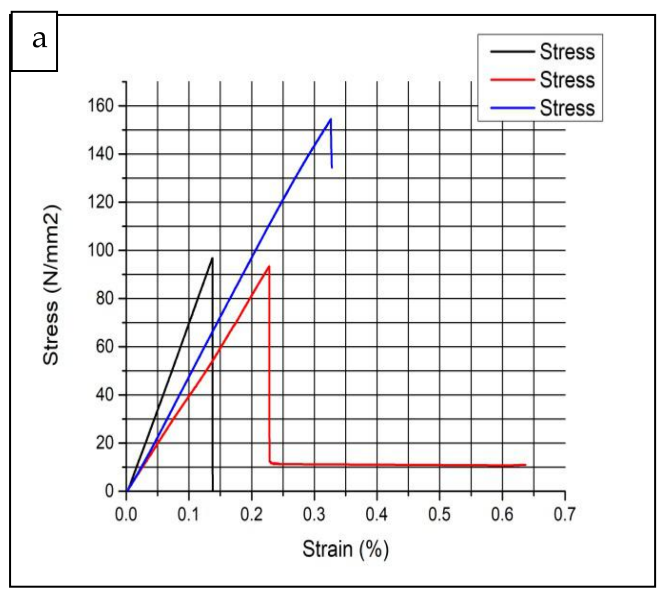


Fig 6, a)Flexural samples (After test samples) b) Flexural testing machine

TABLE 6
FLEXURAL PROPERTIES

Mechanical properties of composite	Total reinforcement		
	10-10-5 (25)	20-20-5 (45)	30-30-5 (65)
Maximum flexural strength (Mpa)	114	75.31	110
Flexural strain at break (%)	0.23	0.27	0.40
Flexural modulus (GPa)	50.7	25.51	35.56

Below figures are highlighting variations of stress vs strain plot. Poor flexural strength is mainly due to presence of voids in the samples. Hence fibers failed as they were unable to transfer loads to subsequent fibers. Here, all the three samples have failed at near middle or inside the gauge length. We observed a bump on stress versus strain curve of figure 6c. This happened because when the laminate is subjected to a three-point loading, specimens entered the elastic phase first with linear curve in the graph then plastic phase with non-linear curve. After the plastic phase, specimens enduring maximum load will fail on some lamina. In figure 6c ductile failure of the specimen is due to increase in wt% of fibers. Fibers have more ductility than the matrix, which carries more load and this leads to smooth failure. Whereas in figure 4a and figure 4b, we observed a catastrophic brittle failure mainly due to less fiber weight% in the laminates. The further analysis on the failed samples has been done in a scanning electron microscope (SEM) to understand the actual reasons for variation of flexural strength.



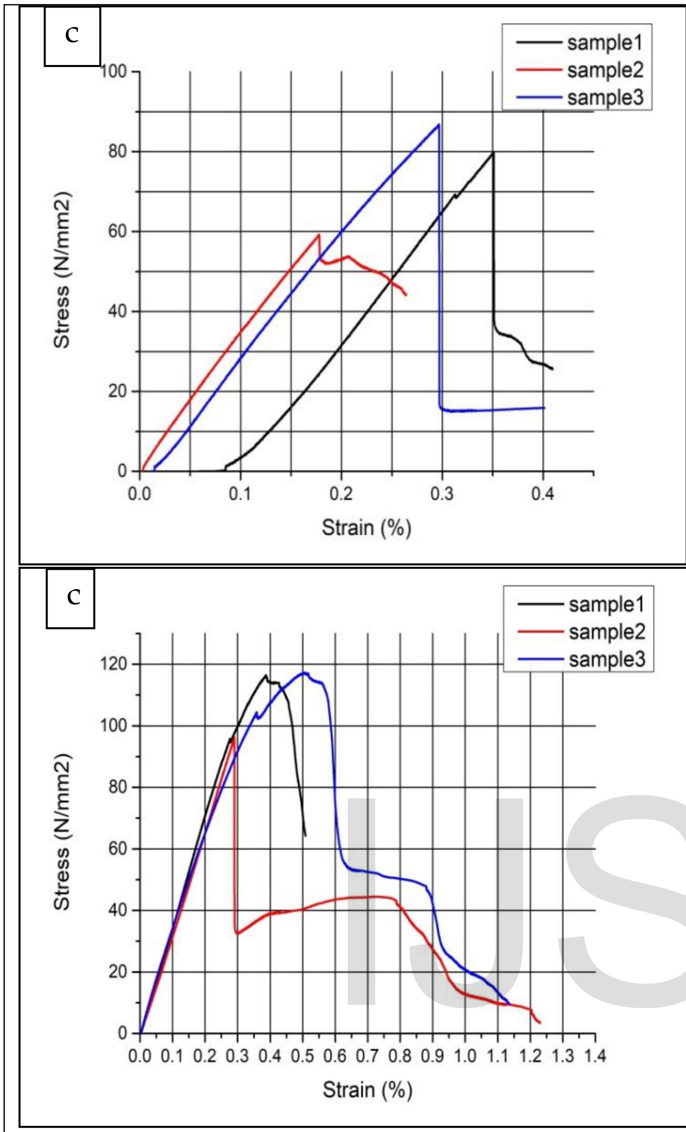


Fig 7, Flexural results graph after testing for different reinforcement a)10-10-5 wt% b) 20-20-5 wt% c) 30-30-5wt%

4. SEM ANALYSIS

The SEM image of tensile tested samples in figure 7a and figure 7b indicates that the fiber rupture is due to primary brittle catastrophic failure followed by fiber pull-out and debonding of the fiber and matrix traces. The SEM image of flexural tested samples shown in figure 7c and figure 7d, shows that there was fiber breakage and presence of voids because of the uneven distribution of epoxy resin. Fiber surface irregularities and fiber pull-out are observed. The reason for the fiber breakage occurs as a result of poor interfacial bonding between fiber and matrix.

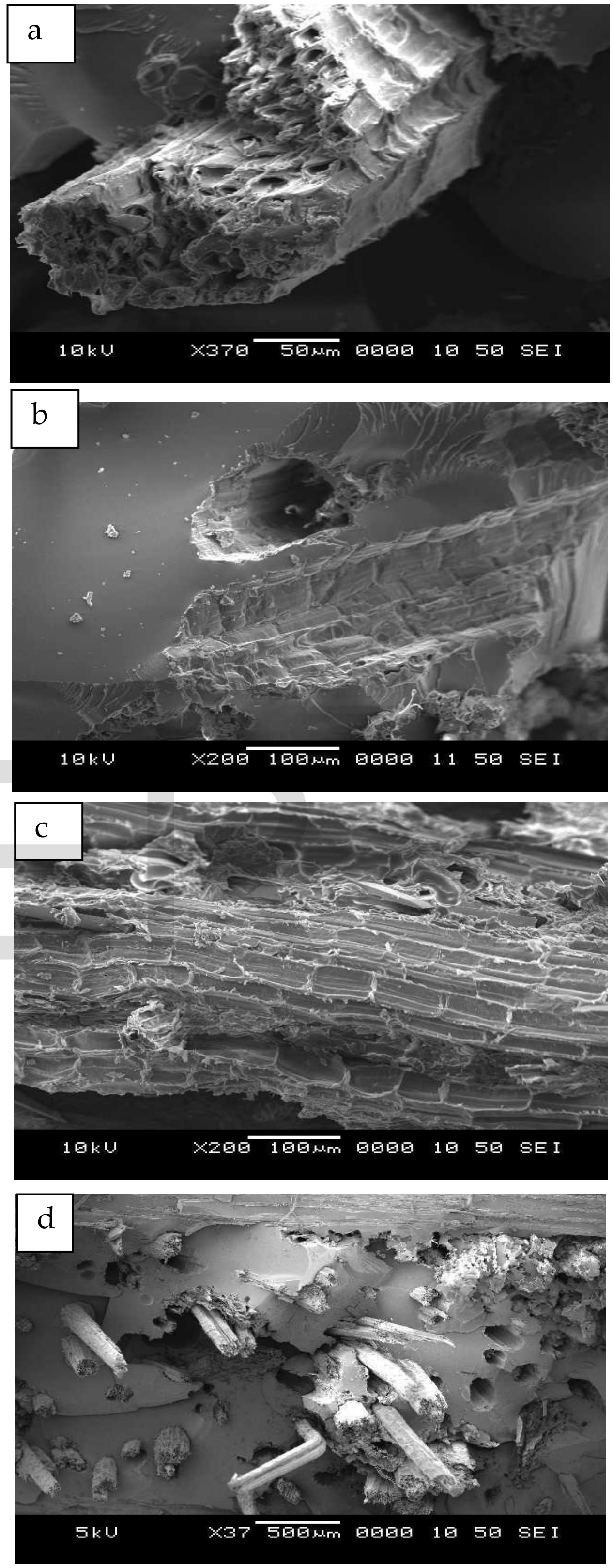


Fig 8, Fractography SEM image of
a) and b) for Tensile sample
c) and d) for Flexural sample

5. CONCLUSION

In this study we have fabricated the laminates of Sisal and Roselle hybrid natural composites using hand lay-up technique. The following conclusions are made out of these mechanical tests:

- The tensile strength of all three cases is almost the same. This is due to lesser influence of stacking sequence and NaOH treatment.

- In tensile tested specimens the fracture or failure observed is brittle in nature since matrix epoxy material is highly brittle whereas the fibers are ductile.

- The improvement of interfacial bonding properties and energy absorption capacity were the fundamental reasons for the increase in the ultimate strength and fracture strain of hybrid composites at high strain rates.

- Flexural strength of the 25wt % composite is high due to increase of transferred strength from matrix to the fibers, because of higher adhesion at interface zone (fiber-matrix) region, and due to the property of cellulose fibers as flax fiber to support bending loads.

- Flexural strength is also hardly influenced by increasing fiber fraction. But in case 2 (45wt %) the result dropped a little. This is mainly due to presence of voids, or poor interfacial bonding between top and bottom fibers.

- As we go on increasing the wt % of the composite, there would be a decrease in strength of the composite which can be due to manufacturing defect or due to variation in the thickness of the composite

- Overall these natural composites have bettered in their properties compared to existing untreated natural composites as per literature survey.

6. ACKNOWLEDGE

It gives me immense pleasure to express my deep sense of gratitude to my supervisor Dr. Ravishankar K S,Associate Professor, Department of Metallurgical and Materials Engineering, National Institute of Technology Karnataka, Surathkal for his invaluable guidance, motivation, constant inspiration and above all for his ever co- operating attitude that enabled me in bringing up this thesis in the present form. I am thankful to Mr. Darshan M L, PhD research scholar of the Metallurgical and Material Engineering department for his support and help during my experimental work.

7. REFERENCES

[1] Dipen Kumar Rajak , Durgesh D. Pagar , Pradeep L. Menezes and Emanoil Linul. "FiberReinforced Polymer Composites: Manufacturing, Properties, and Applications" Polymers , Volume 11, No 1667, 2020.

[2] J. Naveen, M. Chandrasekar, in Mechanical and Physical Testing of Biocomposites, Fiber-Reinforced Composites and Hybrid Composites, 2019

[3] Namvar, F., Jawaid, M., Md Tahir, P., Mohamad, R., Azizi, S., Khodavandi, A., Rahman, H. S., and Nayeri, M. D. (2014). "**Potential use of plant fibers and their composites for biomedical applications,**" *BioRes*. 9(3), 5688-5706.

[4] The Effect of Copper and Aluminium Foil on Mechanical Properties of Natural Fiber Reinforced Plastics M. Indra Reddy , Ch. Srinivas , M. Anil Kumar , V. Manikanth

[5] Gurunathan, T., Mohanty, S., & Nayak, S. K. (2015). A review of the recent developments in biocomposites based on natural fibers and their application perspectives. *Composites Part A: Applied Science and Manufacturing*, *77*, 1-25.

[6] D. Puglia, J. Biagiotti, and J.M. Kenny, **0478**, (2008).

[7] Aliakbar Gholampour, Togay Ozbakkaloglu."A review of natural fiber composites: properties, modification and processing techniques, characterization, applications." J Mater Sci , Volume 55, pp 823-892,2020.