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Fracture Behavior of Nano Particle Reinforced Sisal Fiber Composites using Analytical and Experimental Methods

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Abstract: *Sisal fiber reinforced composites are being replaced with manmade composites as these materials are difficult to manufacture and non biodegradable. On the other hand, the natural fiber reinforced composites such as sisal fiber reinforced composites shows less strength compared to manmade composites. The objective of the present work is to explore the mechanical properties of sisal fiber composites and hybrid sisal composites using analytical and experimental methods. The sisal composites and hybrid sisal composites are prepared by using hand layup techniques. The hybrid composites are prepared by reinforcing nano carbon powder and sisal fibers in a polymer matrix with the weight fraction of 9% of carbon powder and 50% of sisal fiber. The elastic modulus of polymer matrix with carbon powder reinforcement and polymer matrix, carbon powder and sisal fiber reinforced composites are identified by conducting suitable experiments. Later by using the finite element method, the fracture behavior of sisal fiber composites and hybrid composites are estimated. The energy released (E_R) and energy required to create the surface (E_S) are estimated to identify the critical crack length of the respective material. The present work is used for the design of sisal fiber composites with respect to young's modulus and fracture response.*

Index Terms: *Sisal fiber composites, Young's modulus, Fracture behavior, crack length.*

I. INTRODUCTION

Researchers in early 80's have made considerable efforts to replace the metals with polymers which are having high strength to weight ratio and low density also. From space applications to household products, polymers have been used intensively[1]. The polymers are having advantages along with the disadvantages like disposal problem. Use of the polymers is also causing environmental pollution; it can be reduced by replacing the polymers with the biodegradable polymers. Researchers are interested in the development of the natural reinforced fibers to replace the synthetic fiber reinforced composites. For example, glass fiber causes threat to the environment and health problems to people working on it.

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Abdul Khalil, Alwani [2] has shown the wide range of natural fiber application and also mentioned that fibers like bamboo fiber has prominent potential in composite making due to its high strength to weight ration and environmentally friendly nature. The combination of Sisal fiber with the epoxy as matrix has been used by various researchers.

C. McCarthy et al found that the stress concentration at the tip of the transverse crack results in delamination at the boundaries of the ply and results in redistribution of the stress to nearby plies, causing earlier failure through fibre fracture and affects the composite on the 'laminate level'.[3]

Qian Li et al reported that using the experimental applied stress as reference, the double-interface model provide a more accurate quantitative theoretical prediction of the interfacial failure behavior of PFRCs during multi-stage fracture of the two interfaces.[4]

Z. Khan et al reported that the Bamboo fiber reinforced epoxy composite of fiber length of 25mm are having more fracture toughness (KIC) value than the composites having smaller fiber lengths. Matrix cracking, fiber pull out, fiber breakage and fiber matrix debonding are the main causes of failures [5]. According to Shane Johnson et al, two new macro and one micromechanical models are developed to characterize the nonlinear orthotropic behavior of the composite in the transverse, axial and shear directions.[6].Several researchers developed hybrid composites by chemically modifying fibers chemically or by making use of the coupling agents to improve the fiber-matrix interface in composites .Mustafa Abu Ghalia et al, determined the influence of fracture toughness and compressive response of natural and synthetic fiber-reinforced composites.[7]M K Guptaa& R K Srivastava studied that the Mechanical, thermal, water absorption properties and dynamic mechanical analysis of sisal fiber composites and also found that the glass transition temperature value obtained from loss modulus curve is lower than that tan delta curve.[8]Quim Tarresa et al, reported that the henequen fibers have a high cellulose content that results in the strong interfaces in addition of coupling agent to the composite formulation.[9] According to the report by Arain Muhammad Fahad et al, the interfacial behavior was studied making use of the single fiber pull-out tests and tensile test was carried out to analyze the properties of the PVA composite [10]. Natural fibers are available in abundance, eco-friendly, biodegradability, reliability along with advantages like low cost, low density, non-toxicity, high flexibility and high specific strength and modulus.

Low impact strength, high brittleness and higher moisture absorption properties are the drawbacks of the natural fibers. Now a days, Agro based natural materials are popularly utilized in aerospace, automotive, building and appliance industries promoting the green movement as well. According to researchers, 40-67% body weight of the automobile can be reduced by replacing the conventional materials like steel with the engineered materials like composites. A report by Silva et al. [11] illustrated that the sisal and jute fibers can be replaced by the glass and carbon fibers in many applications. By Scheider, understanding the size effects of fiber, the failure mechanisms can be modified effectively and the properties of the composite can be improved significantly [12].Thus, the objective of the present work is to identify the mechanical properties of sisal fiber reinforced composites and fracture behavior of the composites to understand the enhancement of the considered properties with nano reinforcement.

II. FABRICATION OF COMPOSITE

A. Materials

Submit your manuscript electronically for review. Sisal fibers were used as reinforcement and epoxy as a matrix in this study. Sisal fibers and epoxy matrix were purchased from local resource Bindu agency, Vijayawada, Andhra Pradesh, India. Epoxy resin and hardener are mixed, for 100ml of epoxy 1ml of hardener is mixed. The chopped sisal fiber and the above mixture are taken in 1:2 (fiber: matrix) by weight with and without carbon nano powder to prepare the specimens. The technique used for the preparation of the samples is usual hand lay-up technique with the combination of compression moulding technique. After the curing period of 48hours, the samples of the composite are taken out of the mould and cut as per the ASTM standards and to protect from corrosion they are preserved in airtight containers.

B. Tensile test

Young's modulus and Tensile strength are the important indications to determine the strength of the material and it is one of the most specified properties of any material. Tensile tests are carried on sisal-epoxy composite samples made based on ASTM D 3039 standard (Fig.1). The samples are tested using a tensile machine with a crosshead speed of 2mm/min. The prepared specimen at 50% sisal fiber and 9% carbon powder is shown in Fig.2. Clamps are used to set the gauge length and deformation is measured using the extensometer. These samples are prepared for the failure to be occurred within the gauge length, eliminating the fiber pullouts or debonding at the anchorage. All the samples with different weight fractions are tested.

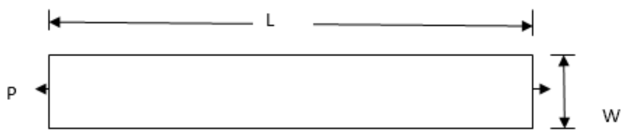

Fig.1: Dimensions Of Tensile Test Specimen (ASTM D 3039)
Where, L=Length (250mm), W=Width (25mm); T=Thickness (3mm); P= Load.

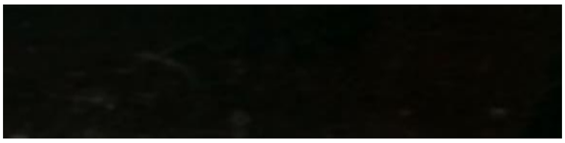

Fig. 2: Prepared Specimen According To ASTM D 3039 Standard.

C. Tensile test results

The tensile test is conducted on carbon powder reinforced epoxy composite and sisal fiber, carbon powder reinforced composites using tensile testing machine. The specimens are prepared according to the ASTM standard. At each weight fraction, four specimens are prepared and average value is taken from the testing results of 4 specimens. The Table.1 shows the Young's modulus of carbon powder reinforced composites.

Table1. Tensile Properties Of The Carbon Powder Reinforced Composites.

S.No	Weight Fraction (%)	E (MPa)
1	3	3590
2	6	3850
3	9	4290

Later, the sisal fiber and carbon powder mixed epoxy composites are prepared and the tensile testing is performed on the prepared specimens. The sisal fiber is maintained at 10% and 50% weight fraction and the nano carbon powder is maintained at 9% weight fraction.

Table.2. Young's Modulus In Longitudinal And Transverse Direction Of Hybrid Composite.

S.No	Wfiber(%)	Wcarbon powder	E1(MPa)	E2 (MPa)
1	10	9	6552	5602
5	50	9	12087	9270

III. FINITE ELEMENT METHOD

Using the concept of Micromechanics and homogenization concepts, the properties of carbon powder reinforced composites and sisal fiber and carbon powder reinforced epoxy composites are identified. One of the objectives of the present work is to identify the fracture behavior of conventional and hybrid composites. Here a hybrid composite means the sisal and carbon power reinforced in epoxy composite.

With the support of finite element method, and Micromechanics approach, a representative volume element is generated using Finite element based software ANSYS. Applying periodic boundary conditions and Unit pressure in longitudinal and transverse directions to estimate the E_1, μ_{12} and E_2, μ_{21} properties respectively.

Table3. Longitudinal And Transverse Properties Of The Hybrid Composite From FE Models.

S.No	Weight fraction (%)	E_1(MPa)	μ_{12}	E_2 (MPa)	μ_{21}

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Carbon Powder composite	9%	4356	0.34	4356	0.33
Hybrid Composite	10 fiber and 9% carbon powder	6553.94	0.32	5809.90	0.28
	50% fiber and 9% carbon powder	12084.74	0.31	9677.73	0.25

IV. FRACTURE BEHAVIOR OF CONVENTIONAL AND HYBRID COMPOSITES

The Fracture behavior of polymer matrix, carbon powder reinforced composite at 9% weight fraction and hybrid composite at 50% weight fraction and 9% weight fraction of carbon powder are estimated by using Finite element software ANSYS. The Finite element models are generated with V- shaped crack and the crack length is varied from 5 mm to 30 mm. The Finite element model is shown in Fig.3.a-b. The loading and boundary conditions are applied as shown in Fig.3.b.

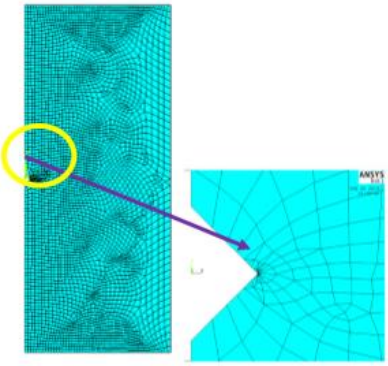

Fig.3.a.Finite Element Model For Fracture Analysis.

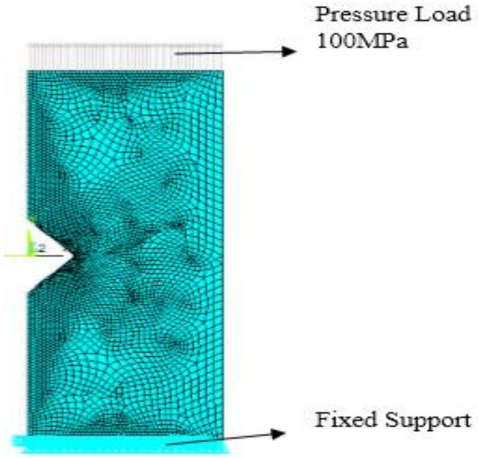

Fig.3.b.Loading And Boundary Condition On FE Modal.

Fig. 4-6, show the variation of energy release rate (E_R) and surface energy required for crack growth (E_S) with respect to crack length (a) for polymer matrix, carbon powder reinforced polymer matrix, hybrid composites. From the Fig.4 it is understood that, the surface energy required for crack and energy release during crack growth are presented with respect to crack length. up to 15mm crack length in polymer matrix E_R is less than Es and after 15mm crack length more energy is released which is more than the surface energy required for crack growth.

That means the material can sustain upto 15 mm cracks, after that the material will fail due to release of high energy at crack tip. Due to the reinforcement of carbon powder, the stiffness of the material is increased and the material is safe upto 18mm crack length (Fig.5). A better performance is observed for hybrid composites (Fig.6) due to the reinforcement of fiber and nano particle. With the reinforcement of sisal fiber and nano particles, the longitudinal and transverse modulus is increased as a result, the material offered more resistance to crack growth. As a result, the material is safe upto the crack length of 20mm.

The energy supplied or created in the material will be utilized for crack growth and plastic deformation. Fig.7-8 shows the plastic zone size of polymer matrix and hybrid composite at crack length of 5 mm and 30mm. Compared to polymer matrix, (Fig.7) the plastic zone size is more in Hybrid composites (Fig.8).

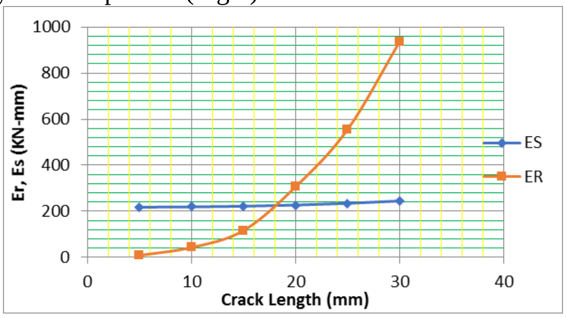

Fig.4. Variation Of Energy Released And Energy Required With Crack Length For Polymer Matrix.

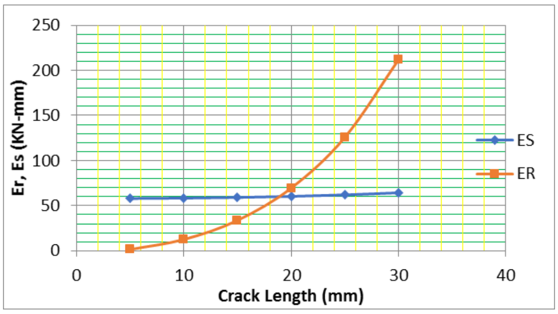

Fig.5. Variation Of E_R And Es With Crack Length For CNP Reinforced Polymer Matrix

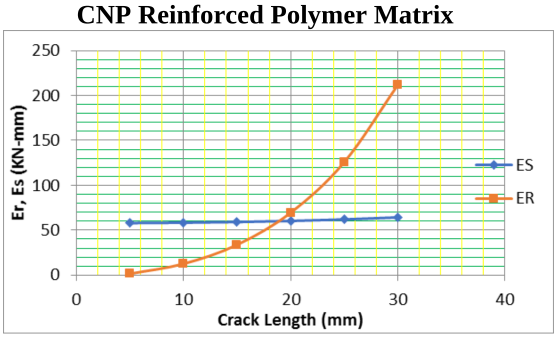

Fig.6. Variation Of E_R And Es With Crack Length For Hybrid Composite.

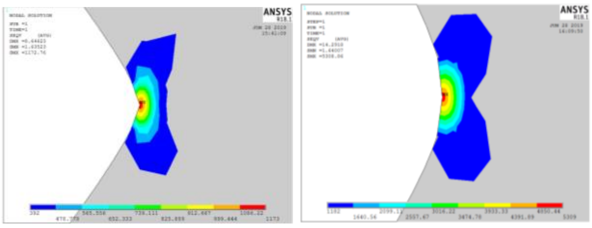

Fig.7. Plastic Zone Size Of Polymer At A=5 Mm And 30mm

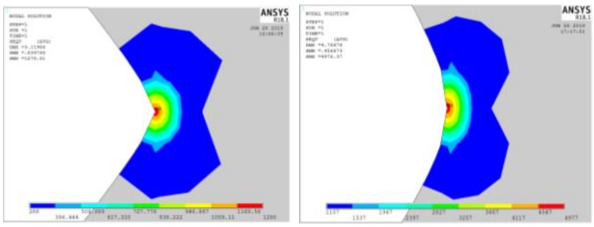

Fig.8. Plastic Zone Size Of Hybrid Composite At A=5 Mm And 30mm.

V. CONCLUSIONS

The sisal fibers reinforced with carbon powder reinforced composite elastic properties are identified by conducting suitable experiments. The fracture response of a polymer matrix, carbon powder reinforced polymer matrix, sisal fiber and carbon powder reinforced hybrid composites are identified from finite element based software ANSYS. The following conclusions are identified from the present work:

- The modulus of sisal fiber composites can be enhanced by the nano powder reinforcement.
- The critical crack length of polymer matrix is 15 mm and for carbon powder reinforced composite the critical crack size is in between 15 mm and 20mm. For hybrid composite the material will be safe upto 20mm crack length due to increase in the stiffness of the respective materials.
- The size of plastic size contour of a polymer matrix, hybrid composite at minimum crack length and maximum crack length is also presented. Due to the reinforcement, the size of plastic zone is high for hybrid composite than pure polymer matrix.

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