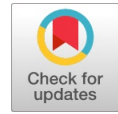# Fatigue Characterization Of Sisal Fiber Reinforced Composites Using Experimental And Finite Element Method

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*Abstract***:** *The objective of this study is to investigate the fatigue behavior of sisal fiber reinforced with carbon nanotubes. The hand lay-up technique is used to prepare the composite material samples. The fatigue response of pure polymer matrix, composite material which is prepared by reinforcing a sisal fiber reinforced with a polymer matrix was studied. The effectiveness of nano reinforcement of fatigue response is identified from experiments. Later, the fatigue response of sisal and nano particle reinforced sisal fiber composites (hybrid composite) is identified with irregularities by using finite element based software ANSYS. The elastic properties of sisal fiber reinforced composite and carbon nanotube reinforced composite is estimated by using the principles of Micromechanics and Macro-mechanics. The failure mechanism of polymer, conventional sisal fiber composites and nano filled sisal fiber reinforced composites are identified. The effect of the shape of the irregularities on the fatigue response is also identified from ANSYS software. From the present work, it is observed that, the reinforcement of nano reinforcement has considerable influence on the fatigue response of the resulting composite.*

*Index Terms***:** *Sisal fiber, Carbon nanotube, Fatigue behavior, Finite Element method, Micromechanics and Macro-mechanics*

I. INTRODUCTION

In the present decade, plant based fibers have replaced many man-made composites due to their biodegradability to save the nature [1]. Due to the favorable physical and mechanical properties of plant based fibers, these are becoming an alternative to the many synthetic fibers [2]. The fatigue behavior of the composite structures depends on many factors such as type of reinforcement, the matrix phase, fiber volume fraction, the interface between the constituents, geometrical particulars of the specimen, and the type of the load on the material [3].

On the other side, many authors studied the behavior of natural fiber reinforced composites in the view of fatigue behavior. According to Yidong Zhang et al. the process of fatigue testing results shows that failure modes of the structural component are mainly due to delamination which occurs in the thickness transition area [4]. Meltem AltinKaratas et al. reported the machinability properties and failure mechanics for carbon fiber reinforced polymer and glass fiber reinforced polymer [5].

The paper reported by Paul Van Der Sypt et al. reposes an experimental protocol on both micro and macroscopic level to monitor the mechanical response of a pin-loaded Carbon reinforced fiber polymer laminate under different cyclic loadings conditions [6]. Zengewn Wu et al studied that the fiber pull-out and fiber splitting were the majority failure mode of fibers in both the longitudinal and transverse directions and also damage in specimen is mainly due to the tensile force induced in reverse bending load [7]. Failure is observed around an open hole where stress is concentrated in mid of plies quasi-isotropic GFRP laminate under fatigue loading when dynamic strain reaches or exceeds static strain by Pintu Kumar Vishwakarma et al [8].

In the report by Waqas Anwar et al. investigated the material making use of different fracture mechanics based techniques found fatigue and damage tolerance [9]. Archana et al. found that the spider silk epoxy composite exhibits more toughness and lesser failure at high stress levels when compared with S-glass epoxy composite [10]. KhudariBek et al indicated that the overall elastic modulus of Nano-composite material increases with the volume fraction of nano-particles and inter-phase thickness [11]. According to J F Durodola et al. greater resolution was observed with the artificial neural network method than with other available methods that include the effect of mean stress on the frequency domain approach and predict the fatigue damage [12]. Aparna Gangele et al. mentioned in the report that the FEM model shows that the single layer graphene helps to enhance the mechanical properties of silicon nanosheets, which is helpful for the silicon-based semiconductor industry [13].The work of HaolingJia et al. discusses nearly all factors like composition, specimen geometry, surface condition, temperature, cyclic frequency, etc. that could affect the fatigue and fracture behavior of bulk metallic glasses (BMG)and their composites. Furthermore,the smechanisms of fatigue-crack initiation, propagation, and fracture of BMG composites in different loading conditions and environments were analyzed [14].

Stress intensity factors in the mixed- mode condition is studied by using the virtual crack closure method in the report by Masanori Kikuchi et al. The crack growth amount and crack growth path are based on Stress intensity factors, and the growing crack configurations are also obtained [15].

From the previous works, it is observed that, most of the work is focused on Fatigue and Fracture of monolithic composite materials and the influence of nano reinforcement on sisal fiber composite is not performed yet. The objective of the present work is to estimate the fatigue behavior of sisal and hybrid (sisal and carbon nanotube reinforced composite) using experimental and analytical methods. The influence of irregularities on the composite objectives will be evaluated from finite element simulations to select a best shaped hole in the view of life of the member under fatigue loading and safety factor.

II. EXPERIMENTATION

Sisal fibers used in this work are procured from Vruksha composites, Andhra Pradesh, India. The epoxy resin, Araldite LY 5052, used in this study was obtained from Bindu agency, Andhra Pradesh, India. The untreated sisal fibers were treated by using NaOH solution. Using the Hand lay-up technique, composite is prepared using treated sisal fibers. The Unidirectional composite is prepared with sisal fibers. The weight fraction of sisal fibers is maintained at 50%. For CNT composite, 10% of CNT is used in sisal composite.

Static and Fatigue testing were performed by conducting suitable testing on pure polymer matrix, sisal fiber reinforced composite and CNT mixed composite material. The specimens are prepared according to the ASTM D3039. The tensile strengths of the sisal fiber epoxy matrix composites were tested for polymer, sisal fiber composite and CNT reinforced composite. The static strength of the three materials is measured using a tensile testing machine. The results obtained from the static test are used to obtain the fatigue response of three materials. For each result, four specimens are prepared. The ultimate strength of a polymer matrix, sisal fiber reinforced composite and Sisal and CNT reinforced composite are 70, 385 and 687MPa respectively. The fatigue test is conducted at 2/10th to 6/10th of the ultimate load of the respective composite and the S-N curve is obtained under tension-tension load condition. Tension-tension fatigue testing is conducted at a stress ratio of 0.1 (R=0.1).

Fig.1.a. Sisal Fiber Reinforced Composite At 50% Volume Fraction

Fig.1.b Sisal Fiber and carbon nanotube reinforced
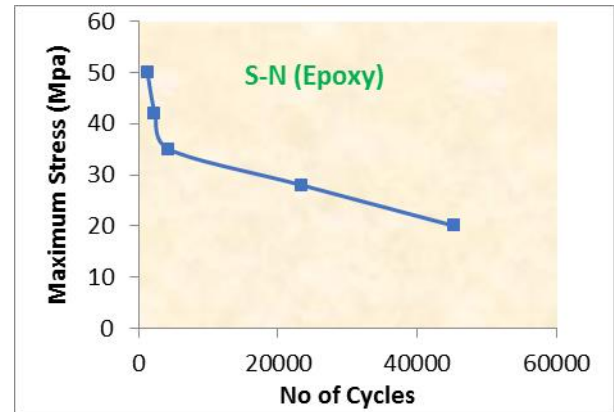Composite at 50% of fiber and 10% of CNT

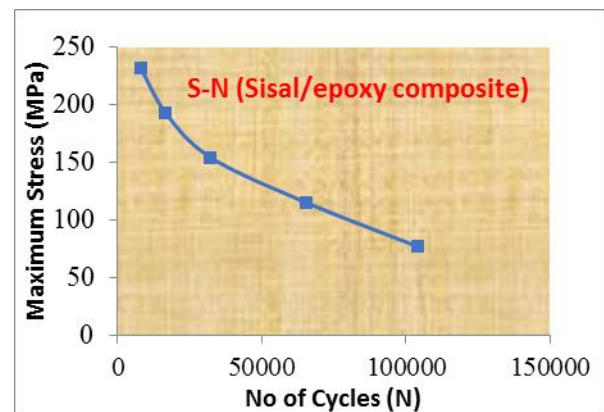**Fig.2. S-N curve of polymer matrix**

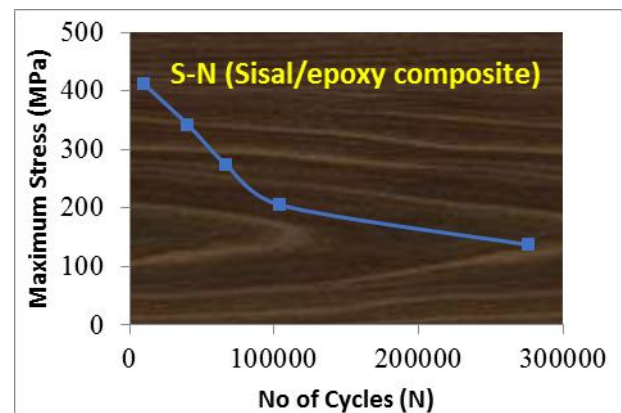**Fig.3. S-N Curve Of Sisal Fiber Composite**

Fig.4. S-N Curve Of Sisal And CNT Mixed Composite

From Fig.2-4, it is observed that the life of the material is increasing with decreasing the stress applied to the specimen of pure polymer matrix, sisal fiber composite and CNT mixed sisal fiber composite under fatigue loading. The testing is conducted at 70% of ultimate strength to 10% 0f ultimate strength of the respective composite. The failure mechanism of the polymer matrix, sisal fiber reinforced composite and sisal and CNT reinforced composite is observed.The polymer matrix failure is observed at the surface of the specimen and for Sisal fiber composite and the CNT and sisal fiber composite the interfacial defect is observed.

The reason for these defects is provided below. Due to surface tension effect, pure polymer specimen failure started at the surface. Due to the reinforcement effect, the surface failure is changed to interfacial failure in sisal and sisal hybrid composite (Fig.5-6).
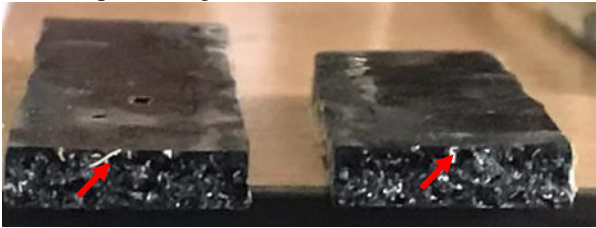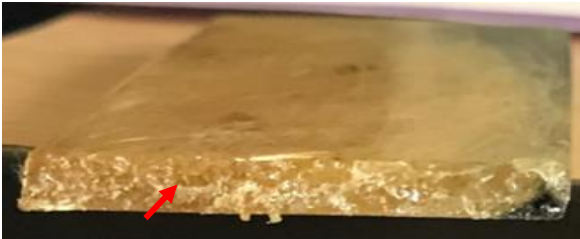

Fig.5. Hybrid composite Specimen after failure

Fig.6. Sisal composite Specimen after failure

Due to the surface tension effect, i.e the atom on the surface and near to the surface have a different behavior compared to the interior atoms. This concept is explained trough the following Image Fig.7. Consider two atoms A and B The atom A is located at the center of the material and atom B is on the surface of the material. The atom A is having different behavior compared to Atom B. The material under loading, the atom will attain an equilibrium position easily where as the Atom B has different behavior and the energy will be spent on that particular atom to bring the equilibrium position. As results more deformations will be concentrated on that atom. This is the reason for the polymer material failure from the surface of the material. For the reinforced composite, these effects will be suppressed due to the reinforcement.
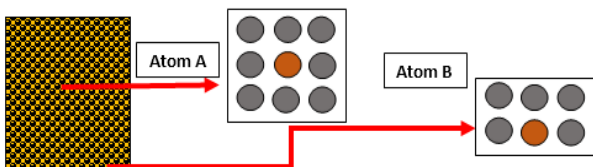

Fig.7. Surface Tension Effect In Polymer Matrix

III.   FINITE ELEMENT METHOD:

One of the objectives of the present work is to identify the fatigue behavior of sisal fiber composites with irregularities such as holes in the geometrical center of the composite material. In this study, different shaped irregularities such as square, triangle, rectangular and circle is analyzed to estimate the S-N curve along with the factor of safety. The S-N curve obtained from the experimental work is used to simulate the fatigue behavior of the same composite material with different shape irregularities. A rectangular block with 300 mm × 125 mm × 3 mm is modelled in Ansys workbench software and with 20 mm diameter a hole is provided at the center of the generated models. The elastic properties required for the analysis are Young's modulus and Poisson's ratio along with the SN curve. The SN curve is obtained from the above section 2.

The elastic properties of the sisal composite and sisal hybrid composite (Sisal+ CNT reinforced composite) are calculated using Micromechanics approach. In the Micromechanics approach, the fibers are assumed to be distributes uniformly and the material is assumed to be divided into known shaped unit-cells and selecting one unit cell of the array and applying periodic boundary conditions, the elastic response of the unit cell will be evaluated after considering the symmetry in geometry, loading and boundary conditions. The properties in longitudinal and transverse direction is evaluated by applying load parallel and transverse direction of the fiber. The micromechanical model at 50% volume fraction of sisal and 10% CNT in the matrix is shown in Fig.8. The fatigue model with circular hole is presented in Fig.9.

Table.1 Mechanical Properties Of Sisal Fiber Composite And Hybrid Sisal Fiber Composite.

Material	E_1 (MPa)	E_2 (MPa)	E_3 (MPa)
50% and 10% CNT	12710	127085	127085
50% sisal fiber	12086	5678	5678

Table.2. Poisson's Ratio Of Sisal Fiber Composite And Hybrid Sisal Fiber Composite

Material	µxy	µyz	µxz
50% and 10% CNT	0.02	0.05	0.02
50% sisal fiber	0.3	0.26	0.3

Table.3. Shear Modulus Of Sisal Fiber Composite And Hybrid Sisal Fiber Composite.

Material	GXY (MPa)	GYZ (MPa)	GXZ (MPa)
50% and 10% CNT	7000	3765	7000
50% sisal fiber	3421	2365	3421

Using the elastic properties from Table.1-3 and SN curve from experimental results, the fatigue response of sisal and hybrid sisal composites with irregulaties are evaluated from Ansys workbench.
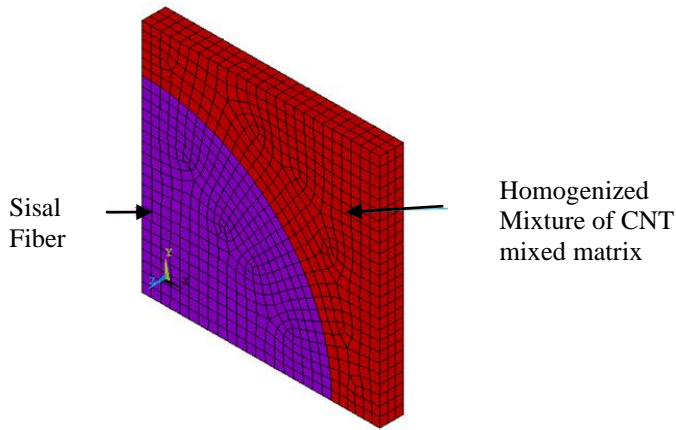
Sisal Fiber

Homogenized Mixture of CNT mixed matrix

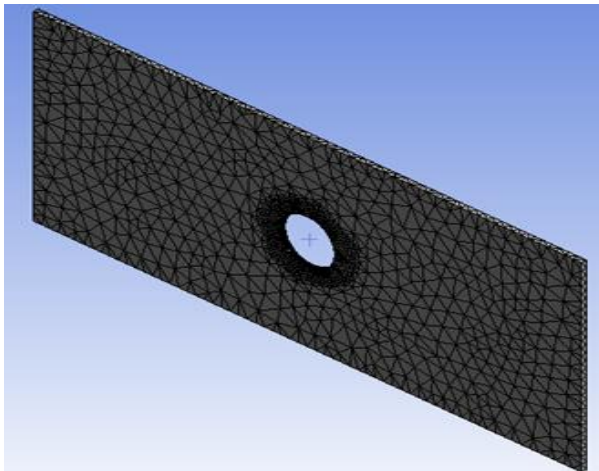**Fig.8. FE Model At 50% Sisal With CNT Mixed Matrix.**

Fig.9. Fatigue Model With Circular Irregularity.

The life number of cycles, softy factor are computed from Ansys workbench for polymer, sisal fiber composite and sisal with CNT reinforced composite by applying tension-tension load by maintaining R=0.1. Fig.10. shows the variation of safety factor of polymer, sisal and hybrid sisal composite with different irregularities. It is observed that a safety factor of polymer is very less and the hybrid composite (sisal and CNT composite) has more safety factor. Compared to the shape effect of the irregularities on safety factor, the elliptical shaped hole has more factor of safety than all shaped holes and square hole have less safety factor. The safety factor of hybrid composite is more due to the increasing the strength of resulting composite due to CNT reinforcement. The life of the polymer, sisal and hybrid composite is presented in Fig.11. Due to the CNT reinforcement, the number cycles under fatigue load is more in hybrid composite.
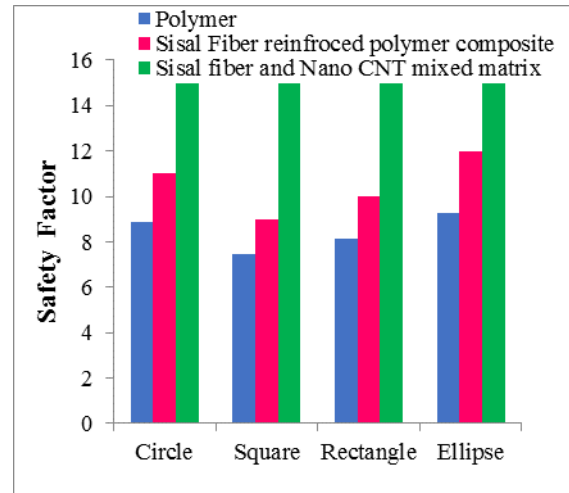

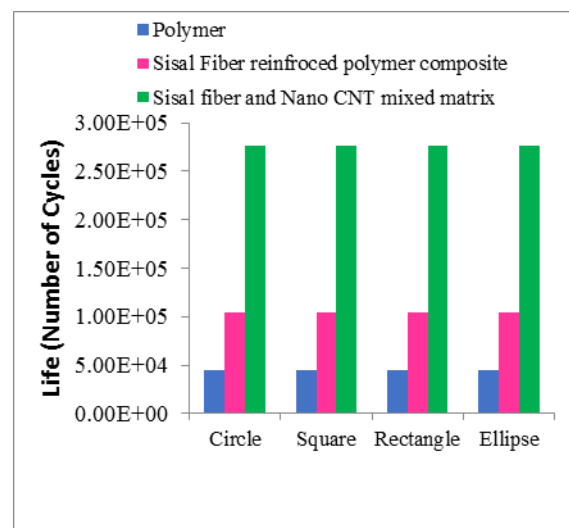**Fig.10. Safety Factor Of Composite With Different Irregularities**

Fig.11. Life Of Composite With Different Irregularities

IV. CONCLUSIONS:

The SI unit for magnetic field strength H is A/m. However, if you wish to use units of T, either refer to magnetic flux density B or magnetic field strength symbolized as $\mu_0 H$. Use the center dot to separate compound units, e.g., "A·m^2." The fatigue behavior of natural fiber such as sisal fiber reinforced composite is evaluated with experimental techniques. The life and safety factor of sisal and hybrid composite is also identified with the support of finite element method. The following conclusions are obtained from the present work.

- The ultimate strength verses the number of cycles under fatigue loading is predicted from experimental results for polymer, sisal fiber reinforced composite and sisal fiber and CNT reinforced composite

- The life of the member made with sisal fiber will be increased by reinforcing the hosting matrix with carbon nanotubes.

- The safety factor of a sisal fiber is increased with carbon nanotubes reinforcement.

- While making a hole for sisal fiber composite, it is better to select an elliptical shape compared to round, square and rectangle. Because the elliptical shaped hole in composite material showed better performance in terms of life and safety factor compared to other shaped consider in the analysis.
- The usage of sisal fiber composite reduces global warming as these are natural fibers are easy to decompose, and these sisal fiber composite performance will be enhanced by using carbon nanotubes.

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