MECHANICAL CHARACTERIZATION AND PROPERTY PREDICTION OF SISAL/POLYESTER COMPOSITE

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Abstract
The large amount of work was recorded on mathematical modeling of unidirectional composite to predict the longitudinal elastic modulus of composite without considering the interphase. Hence, it is a need of considering interphase in a measurement of elastic modulus of unidirectional composite due to its effects on the elastic modulus of composite. In present study, the mathematical model is proposed to measure the elastic modulus of composite with considering an interphase as a third phase in between fiber and matrix. The experimental study was also carried out for the sisal fiber reinforced polyester composite (SFRPC) and measure the experimental elastic modulus of composite. For the measurement of experimental elastic modulus of composite, the tensile testing was carried out of the sisal fiber reinforced polyester composite (SFRPC). The flexural testing was also carried out with tensile testing and provides the characterization data for sisal fiber polyester composite (SFRPC). The unidirectional composite was fabricated with hand layup technique. The comparison of analytical results through proposed model and experimental results was carried out and observes that the results of elastic modulus of composite through proposed mathematical model are in good agreement with experimental results. Moreover, the analytical result of elastic modulus of composite through proposed model was compared with other researcher's model results and observes that the proposed model has less error to the experimental results compared to other researcher models. Hence, it may be suggested that the proposed mathematical modeling can be used to predict the elastic modulus of composite.

I. Introduction

The present study surveyed the mechanical characterization of sisal fiber reinforced polyester composite and proposed model to predict elastic modulus of unidirectional composite with considering the interphase. It is possible to find the volume of interphase by experimental means as well as by some mathematical treatments, as it is a region created between the two main phases of a composite by using DSC or the identification of the interphase region using SEM or some other sophisticated instrumental techniques.

All these techniques require technical skill and involve a lot of cost. Hence, an attempt is made to propose an evaluation model for interphase volume fraction without using any sophisticated instruments and to carry out the study for the elastic behaviour of fiber reinforced composites in longitudinal and transverse directions, which can be utilized for the design of composites where high accuracy is required such as in aircraft structures and missiles. [10]

II. Literature Review

A. H. Abdullah et al. (2011) presented the effects of fiber volume fraction on the existence of a transition region in unidirectional kenaf/epoxy composites. The composites were made from hand Lay-up techniques, with three formulations of fiber volume fraction employed: 0% (neat), 15% and 45%. The results showed that tensile properties such as tensile strength and modulus of elasticity increased as the fiber volume increased. The stress-strain curves showed that the kenaf/epoxy composites exhibited bi-linear responses with reductions in the modulus of elasticity. Surface morphology aided by a scanning electron microscope (SEM) revealed that the reduction in the modulus of elasticity was due to matrix cracking. [1]

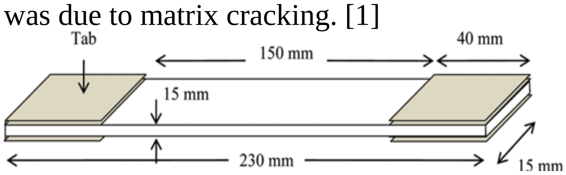

Figure 1 Tensile test specimen as per ASTM D3039

R.B. Yusoff et al. (2016) studied on tensile and flexural properties of hybrid composite using Kenaf, Bamboo and Coir Fibers. To prepare the composite they used hot pressing method. The mold was heated by setting the temperature of upper and lowers heating plates at 210^0C and 185^0C respectively. [2]

Gohil et al. (2010) carried the testing of composite as per ASTM standard D3039/D3039 M08. They have experiment on cotton-polyester composite and conclude that fiber volume fraction increases as well as longitudinal elastic modulus also increases. Fiber /Matrix interphase / interface play an important role in natural fiber composite properties. The experimental investigation indicates that, as the fiber volume fraction increases the strength as well as longitudinal elastic modulus increases linearly. Proposed model is very useful for the prediction of longitudinal elastic modulus and it can be applied to high strength fiber, natural fiber and even the textile fiber composite also. [3]

A.R. Malingo et al. (2009) studied on effect of interphase material properties in unidirectional fibre reinforced composites. A three-dimensional (3D) micromechanical study has been performed in order to investigate local damage in unidirectional (UD) composite materials with epoxy resin under transverse tensile loading. Finite element analyses indicate that unit cells with soft interphases show superior characteristics in terms of ultimate strength and strain under transverse loading. [4]

L Zhang et al. (2015) investigated on ceramic matrix composites, in this investigation, a new model material consisting of the chemical vapour infiltration unidirectional C/SiC composites with PyC fibre coating were prepared and evaluated to predict the interfacial mechanic properties of woven composites. Detailed microscopic analyses confirm that both the fibre and surrounding matrix have no plastic deformation throughout the process. [5]

Md. Abdulla Al Masud and A.K.M. Masud (2010) studied on effect of interphase characteristic and property on axial modulus of carbon nanotube based composites. Their main research will be derived in a four different part as given. They focused on topic of interfacial bonding strength between the nanotubes and their surrounding matrix because poor interphase can degrade the overall quality of Nano composites. The effective mechanical properties of carbon nanotube based composites, presented in several numerical examples; demonstrate that interphase thickness and stiffness has significant impact on the stiffness of composite. With only about 0 to 0.8 nm of the interphase thickness variation in a matrix, the stiffness of the composite in the CNT axial direction can increase as many as 1.1 and 4.3 times for the cases of long and short CNT fibres, respectively. [6]

Gohil and Shaikh (2009) studied the interface/interphase primarily; the pull out test was carried out for different specimens to study the effect of fiber surface roughness and embedded length of the fiber. The pull out test was carried out for different specimens and the pattern of load vs. displacement pattern was observed. One or more peaks in the ascending part of the curve were found which showed that the debonding process was stepwise for steel polyester composite. The CAD/FEA tool was used to simulate fiber pull-out mechanism and results obtained had a deviation from 5 to 8% with the experimental displacements. [7]

Gohil et al. (2010) discovered interfacial interactions and interphases play a key role in all fiber reinforced composites. However, a clear distinction must be made between interface and interphase. Interphase becomes interface if its thickness decreases to zero. They proposed the Soft and Hard interphase equation as given below.[8]

$$E_c = E_f v_f + E_i v_i + E_m v_m$$

The notations f, i and m represents fiber, intermediate phase and matrix. They assume that the interphase region takes care of imperfect bonding, geometry of inclusion, void, micro cracks, etc. In this paper cotton polyester composite were prepared and cut by a lessor cutting machine perpendicular to the fiber direction. The transverse section of the specimen was carried out and coated in a coating unit with gold. SEM (Model: Hitachi S-3400N) images were taken to identify the existence of interphase.

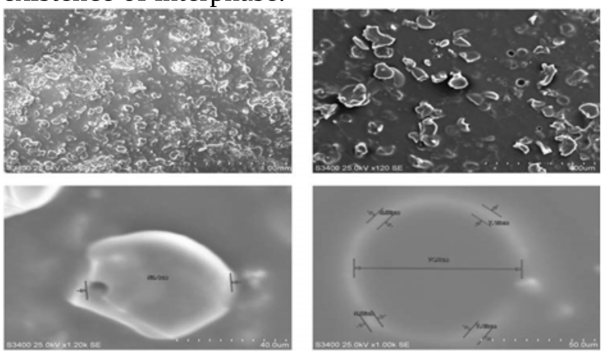

Figure 2 SEM Images of cotton polyester composite.[7]

Author's developed the equation for Volume fraction of interphase using average concept and also developed the equation of thickness of interphase as follows:

$$v_i = 0.215 * v_f^2$$

$$t_i = r_f (1 - \sqrt{(1 - 0.215 v_f})$$

They considered the two types of interphase as Soft interphase, which having very low elastic modulus as compared with fiber elastic modulus and hard/stiff interphase having average value of elastic modulus of fiber and matrix and this values are very high as compared with the matrix elastic modulus as shown in equation 4 and 5. [8]

$$E_i = \frac{E_{f+} E_m}{20}$$

$$E_i = \frac{E_{f+} E_m}{2}$$

G. Leburn et al. (2013) performed the tensile test as per ASTM D3039. The dimension for composite 12.7mm*170mm .composite tested on an Instron Machine. To found tensile test of resin material they follows the ASTM D638 standard. [9]

Shinji ochi (2007) studied on mechanical properties of kenaf fibers and kenaf composite. In which they prepared the prepregs and used the PLA as matrix and prepared composite and tensile test and three point flexural test were conducted with an Instron testing machine (Model 4428). Tensile test were performed at a strain rate of 0.02 per mm and a gauge length of 50 mm, Flexural test were performed at a crosshead speed of 1mm/min and a span length of 32 mm. [10]

Yashwant S. Munde and Ravindra B. Ingle (2014) focused on study of mechanical properties of bio composite using available theoretical mathematical modelling and experimental verification of mechanical properties. Compression moulding method was used to make the coir-PP composite. They encode the theoretical model in MATLAB R2009. They conclude that as the volume fraction increase the tensile strength and tensile modulus of composite increases and for these experiment author investigate the volume fraction increases up to 30%. According to comparison of experimental and theoretical model values the Hirsch's model are closer to experimental values from the tensile module vs volume fraction of fiber and Tensile strength vs volume fraction of fiber. Author agreed that the tensile properties of randomly oriented composites showed good agreement with all the models at low volume fraction of fiber. [11]

III. Mathematical Modeling

From the literature it was surveyed that interphasial bond was generated between the fiber and matrix materials in composite and discovered interfacial interactions and interphases play a key role in all fiber reinforced composites. So, it plays a major role in prediction of elastic modulus of composite. Hence, a mathematical model is proposed to measure the elastic modulus of composite with considering interphase. Gohil et al. (2010) discovered the equation to measure the elastic modulus of composite and tensile strength as shown in equation 6 and 7. Here, in present study the elastic modulus of interphase is proposed as shown in equation 8. The volume of interphase is considered as per Gohil et al. (2010) shown in equation 9. The value of elastic modulus of fiber, elastic modulus of matrix, volume fraction of fiber and volume fraction of matrix is taken from the experimental testing.

$$E_c = E_f v_f + E_i v_i + E_m v_m$$

$$\sigma_c = \sigma_f v_f + \sigma_i v_i + \sigma_m v_m$$

$$E_i \quad \frac{E_f + E_m}{3}$$

$$v_i = 0.215 * v_f^{\ 2}$$

An experimental study was carried out after proposing a mathematical modeling of composite. Then, an experimental longitudinal elastic modulus of composites is compared with analytical longitudinal elastic modulus of composites and measured the % error. The proposed model is also compared with other researchers' model and derives the importance of the interphase are discussed below.

IV. Materials and Methods

A fabrication of sisal/polyester composite was carried out by hand-layup technique as shown in figure 3. Fiber were arranged in a single direction to make unidirectional composite. For this, initially fibers were starched and the weight was putted on the fibers to make it as straight as possible to achieve unidirectional properties. An unsaturated polyester based resin was used to make composite plate. The composite plates was fabricated with volume fraction of fiber as 10% of volume fraction of composites. The plate was prepared of size 30 mm * 30 mm * 4 mm. After fabrication of composite, the testing was carried out with testing machine. The characterization was evaluated by doing the tensile testing and flexural testing. The setup of tensile testing and flexural testing is shown in figure 4 and figure 5. The tensile testing was carried out as per ASTM D3039 and flexural testing was carried out as per ASTM D790. Five specimens was selected for the tensile and flexural testing of composites and average of five samples was evaluated as final result of testing. The samples are shown in as shown in figure 6 and figure 7

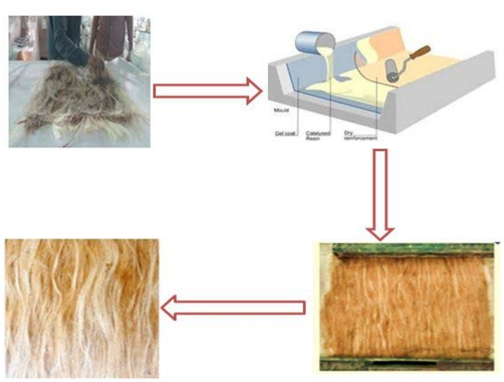

Figure 3 Hand-lay up technique for fabrication of composite.

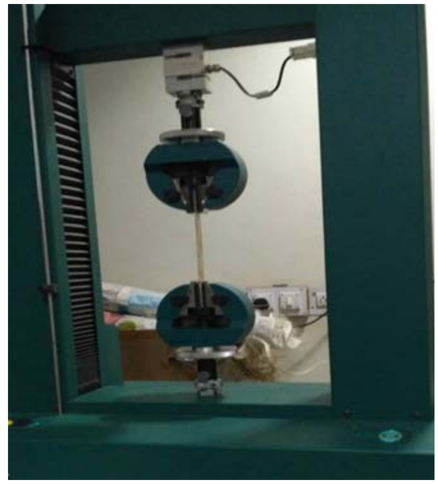

Figure 3 UTM setup for tensile testing.

Figure 5 UTM setup for flexural testing.

Figure 6 Tensile test specimens of sisal reinforced polyester composite.

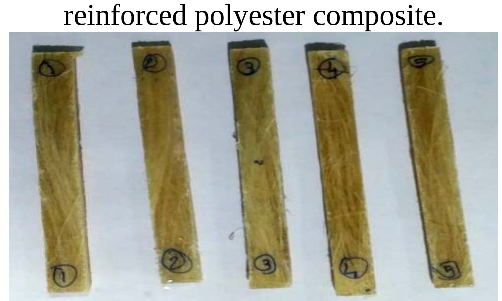

Figure 7 Flexural test specimens of sisal reinforced polyester composite.

V. Results and Discussion

The results of tensile testing of sisal fiber reinforced polyester composite (SFRP) is shown table 1. The results of flexural testing of sisal fiber reinforced polyester composite (SFRP) is shown table 2.

Table 1 Tensile test result of sisal fiber composite as per ASTM D3039

Composite	Volume Fraction (%)	Tensile strength (MPa)	Modulus of Elasticity (GPa)
SFRPC	10	30.1	1.192

Table 2 Flexural test result of sisal fiber composite as per ASTM D3039

Composite	Flexural strength (MPa)	Modulus (GPa)
SFRPC	76.9	7.640

Table 1 and 2 shows the results of tensile and flexural testing of sisal/polyester composite. For the prediction of elastic modulus of composite, the elastic modulus of fiber and elastic modulus of matrix is required. So, the tensile testing of fiber and polyester resin is also carried on universal testing machine. The results are shown in table 3. The fiber testing was carried out as per ASTM D3822 and polyester resin was carried out as per ASTM D638.

Table 3 Tensile testing of sisal fiber and polyester resin.

Testing Sample	Tensile strength (MPa)	Modulus of Elasticity (GPa)
Sisal Fiber	257	9.312
Polyester Resin	25.8	0.30

Here, it is observed that the tensile strength of sisal fiber as 257 MPa, polyester resin as 25.8 MPa and SFRP as 30.1 MPa. The tensile strength is obtained for SFRP is quite less as compared to the sisal fiber. It may be happened due to the fiber volume fraction is considered as only 10% volume fraction of composite.

Then, the comparison is carried out of experimental results of elastic modulus through the tensile testing of composite with the analytical results from the developed model as shown in Table 4. The % error of proposed model result with experimental result is also measured as per the following equation 10.

$$\%Error = \frac{\left|(E_{c\_Experimental}) - (E_{c\_Analytical})\right|}{E_{c\_Experimental}} * 100$$

Table 4 Comparison for results of elastic modulus of composite.

Composite	Proposed model: Analytical Elastic Modulus (GPa)	Experimental Elastic Modulus (GPa)	Proposed model Error (%)
SFRPC	1.2089	1.192	1.69

From table 4, it is observed that % error is 1.69 which is less than 10%. Hence, it can be said that the results of elastic modulus of composite from proposed mathematical model is in good agreement with experimental results for sisal fiber reinforced polyester composite.

A comparison of analytical elastic modulus through the proposed model with other researcher's model is also carried out as shown in Table 5. The equations of other researcher's models: Hirsch's model (HM), puck model (PM), and Whitney & Riley model (WRM) are used to predict elastic modulus of composite using the equation 11-13. [3, 12-13]

$$Ec = Em\left(3.92V_f + 0.89\right)$$

$$Ec = x*Ec = x*\left(Em*Vm + Ef*Vf\right) + \left(1-x\right)*(Em*Ef/\left(Em*Vf + Ef*Vm\right)$$

$$Ec = E_m*V_m + E_f*V_f$$

Here, x is considered as 0.4 for unidirectional composite in equation 12.

The % error is also found for the other researcher's model with experimental results using equation 14.

$$\%Error = \frac{\left|(E_{c\_Experimental}) - (E_{c\_Other's\,model})\right|}{E_{c\_Experimental}} * 100$$

Table 5 Comparison of proposed model with other researcher's model.

Composite	Proposed model Error (%)	HM Error (%)	PM Error (%)	WRM Error (%)
SFRPC	1.69	42.95	67.73	3.36

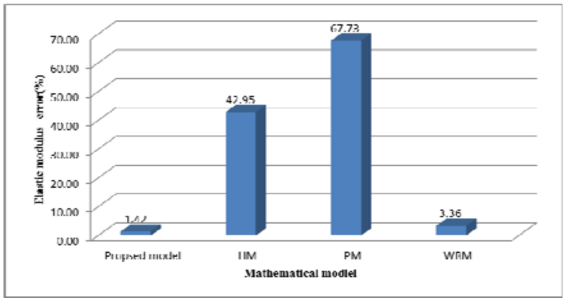

Figure 8 Comparison of proposed model with other researcher’s model.

From table 5 and figure 8, it is observed that the % error for proposed model is less compared to the other researcher’s mathematical models to the experimental results. Hence, it may be suggested that the proposed mathematical modeling can be used to predict the elastic modulus of composite

VI. Conclusion

This paper reported the mechanical characterization of sisal fiber reinforced composite (SFRPC) with tensile strength of SFRP as 30.1MPa and flexural strength as 76.9MPa.

Through the comparison of analytical results through proposed model with experimental results, it is observed that % error is 1.69 which is less than 10%. Hence, it can be said that the results of elastic modulus of composite from proposed mathematical model is in good agreement with experimental results for sisal fiber reinforced polyester composite.

Through the comparison of analytical results through proposed model with other researcher’s model results, it is observed that the % error for proposed model is less compared to the other researcher’s mathematical models to the experimental results. Hence, it may be suggested that the proposed mathematical modeling can be used to predict the elastic modulus of composite.

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Nomenclature

E_c – Composite elastic modulus

E_f – Fiber elastic modulus

E_i – Interphase elastic modulus

E_m – Matrix elastic modulus

v_f – fiber volume fraction

v_m – matrix volume fraction

v_i – interphase volume fraction

t_i – thickness of interphase

σ_c – Composite elastic modulus

σ_f – Fiber tensile strength

σ_i – Interphase tensile strength

σ_m – Matrix tensile strength