MODELING AND EVALUATION OF TENSILE PROPERTIES FOR BANANA/GLASS FIBRE HYBRID COMPOSITES

[1]SANTHANAM.V, [2]CHANDRASEKARAN.M

[1]Research Scholar, Sathyabama University,
[2]Director, Vels University
E-mail: cadsanthanam@gmail.com, chandrasekar2007@gmail.com

Abstract- This study aims at comparing the experimental values of tensile properties with those obtained through various theories of micromechanical modeling for hybrid fibre reinforced polymer composites. Models used in this study are Rule of Hybrid Mixtures, Hirsch, Halpin-Tsai equation, Nielson (Modified Halpin-Tsai equation), Modified Bowyer and Bader's method. Banana/Glass fibresare reinforced with epoxy composites with different volume fraction and fabricated using hand layup method. Experimental values of tensile properties were determined as per ASTM standard. Of various theories of reinforcement, Modified Bowyer-Badermodel predicted tensile properties are closer to the experimental values. Further, the effects of fibre length and fibre volume fraction on the tensile properties were compared with Modified Bowyer-Bader model.

Keywords- Banana Fibre, Glass Fibre, Hybrid Composites, Mathematical Modeling, Polymer Composite.

I. INTRODUCTION

Fibre reinforced polymers can be tailor made to suit the requirements of specific application. The advantages such as high strength to weight ratio, low density, superior tensile properties, and corrosion resistant make them as a suitable alternative for conventional materials. Synthetic fibres such as Glass fibre, Carbon fibre, and Kevlar fibre are being used extensively in automotive industry, aircraft industry, structural, and packaging industries. But due to environmental problems and strict emission norms, natural fibres have gained considerable research interest as a suitable replacement for synthetic fibres. Natural fibres possess several advantages such as high strength, low weight, low cost, non-toxic, recyclable, and bio degradable. Several researchers have shown interest on the development of natural fibre reinforced composites. Several natural fibres such as Hemp, Palmyra, Kenaf, Jute, Banana, Coir, and Sisal are being investigated for their potential use in industrial applications. But the mechanical properties of natural fibres are inferior to that of synthetic fibres. Also they are hydrophilic in nature and their moisture properties are poor. Recent studies by researchers have shown that the drawbacks of natural fibres can be eliminated by hybridizing with synthetic fibres. A brief discussion on the hybrid composites is given as follows.

Pandita D et al. studied the mechanical properties of Jute-Glass fibre hybrid composites. Study shows an improvement in the tensile strength, flexural strength, Impact strength, and water absorption properties by hybridizing Jute fibres with Glass fibres. Atiqah A et al. investigated the tensile, flexural, and Impact properties of kenaf-Glass fibre hybrid reinforced composites. The results indicated an enhancement in the flexural properties by surface modification of the kenaffibre. John K et al. developed Sisal-Glass hybrid composite by hand layup method. The resistance of hybrid composite for various chemicals was evaluated. It was found that the hybrid composite exhibited better chemical resistance for various chemicals. Angrizani Clarissa C et al. investigated the mechanical properties of Curaua-Glass fibre hybrid composites. They have shown that the suitable stacking arrangement and mechanical loading, results in the mechanical properties of hybrids closer to that of glass fibre composites. Sathishkumar T.P et al. reported the development of hybrid composite system consisting of natural fibre and synthetic fibre, for various applications. Venkateshwaranet al. reviewed various works carried out using Banana fibre. Santhanamet al. studied the mechanical properties of Banana-Glass fibre reinforced hybrid composite. It was reported that the hybridisation of banana fibre composite with glass fibre resulted in an increase of more than 150% in the value of tensile strength.

Among various categorizations of composites, short fibre composites are inexpensive and most commonly used. Several theories of reinforcement are used to model and predict the tensile properties of composite materials. The advantage of using theoretical model is that, costly time consuming experiments can be avoided. Rule of Mixtures (RoM) is successfully used to predict and model the tensile properties of unidirectional, continuous fibre composites. Rule of mixtures is known as parallel model, in which the load is applied parallel to the fibre orientation. Matrix and fibre both undergo uniform strain and a decent interfacial bond between the matrix and fibre is assumed in RoM. Several theories have been proposed for predicting and modeling the properties of short, random oriented fibre composites. The Properties of short fibre, random oriented fibre composites are largely influenced by the fibre length, fibre orientation, interaction between the fibre and matrix, fibre dispersion, and fibre geometry. To achieve better

interfacial strength the fibre length must be greater than critical length (lc) of the fibre as shown in Fig. 1. Some of the micro mechanical models include orientation factor and reinforcement efficiency factor to predict the tensile properties.

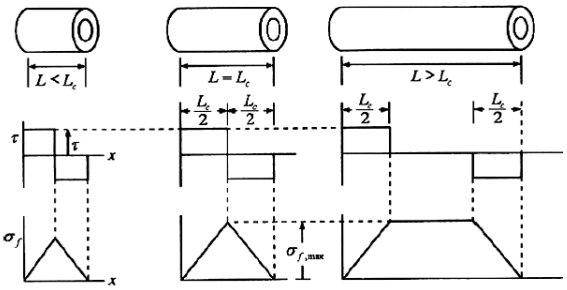


Figure 1.Effect of fibre length on stress distribution along fibre according to Kelly Tyson model.

Various theories of reinforcement include RoM, Inverse RoM, Hirsch model, Halpin Tsai model, Modified Halpin Tsai model (Nielson), Cox model, modified Bowyer and Bader model. Migneaultet al. produced wood plastic composites with white birch pulp and High Density Polyethylene(HDPE). It was reported that the Cox model and Halpin–Tsai models showed good fit to the experimental values of tensile properties. Kalaprasadet al. developed sisal fibre reinforced low density polyethylene composites. The experimental values of tensile strength was compared with various theoretical models, and found that Hirsch and modified Bowyer and Bader models predicted better than other models. Prediction of tensile properties for hybrid composites i.e., with more than one reinforcement is also studied by several researchers. Mirbagheriet al. have developed hybrid composite consisting of kenaffibre and wood flour reinforced polypropylene composite. Rule of Hybrid Mixtures (RoHM) was used to compare the computed tensile strength with experimental values. It was reported that RoHMshows good agreement with the experimental values. Mansor, MuhdRidzuanet al. compared the experimental results withRoMand RoHM in predicting the tensile properties of kenaf/Glass fibre hybrid composites. It was found that both the models produced negative hybrid effect on the stiffness values due to hybridization. Fu et al. suggested that the properties of hybrid system can be evaluated as follows. First, the properties of single fibre systems are computed separately then both are combined together to get the properties of hybrid system. In this case, it is assumed that both the fibres act separately do not interact between them. The drawback of RoM and RoHM is that both models neglect the effect of fibre length, fibre interaction with matrix, fibre orientation factor and fibre aspect ratio. However both models can be used for rough estimation of strength during the preliminary stages of design. Of all the models analyzed, Hirsch model, Modified Bowyer and Bader, and Halpin Tsai models were able to reasonably predict the values.

In this work, hybrid composite was developed by using Banana fibre and Glass fibre reinforced with Epoxy matrix. Composites were prepared by random orientation with different volume fractions. Banana and glass fibres were mixed at 50% each and the overall fibre volume fraction was kept at 0.05, 0.10, 0.15 and 0.20. Also the fibre length was varied as 5mm, 10mm, 15mm, and 20mm for each volume fraction.

II. MODELS OF REINFORCEMENT

Models used for the comparison are Rule of Hybrid Mixtures, Hirsch model, Halpin Tsai model, Neilson model, and Modified Bowyer and Bader model. A brief description of these models of interest is given below.

A. Rule of Hybrid Mixtures (RoHM):

According to this model, tensile properties of hybrid composite were evaluated as follows. Initially the properties for the systems containing the individual fibres were estimated. Then they are combined together to form hybrid system. This model assumes that both fibres constitute separate composites; there is no interaction between the fibres in hybrid system. In this case the strain of total system is equal to the individual systems.

$$\varepsilon_c = \varepsilon_{c1} = \varepsilon_{c2} \quad (1)$$

Whereε_c, ε_{c1} and ε_{c2} are the strains of hybrid system, first system and second system respectively. The force equilibrium requires that,

$$E_c\varepsilon_c = E_{c1}\varepsilon_{c1}V_{c1} + E_{c2}\varepsilon_{c2}V_{c2} \quad (2)$$

Where E,E_{c1} and E_{c2} denotes tensile modulus for the hybrid system first system and second system respectively. V_{c1} and V_{c2} are the volume fraction of first and second system in the hybrid composite. The modulus of hybrid system is evaluated by assuming iso-strain condition in the hybrid composite.(i.e. $\varepsilon_c = \varepsilon_{c1} = \varepsilon_{c2}$).

$$\text{Hence, } E_c = E_{c1}V_{c1} + E_{c2}V_{c2} \quad (3)$$

Also, $V_{c1} = V_{f1}/V_t$, $V_{c2} = V_{f2}/V_t$ and $V_t = V_{f1}+V_{f2}$ where V_t = the total reinforcement volume fraction and V_{f1}, V_{f2} = volume fraction of the individual firstand second system.

B. Hirsch Model

It is a combination of parallel land series model as shown in Fig. 2.

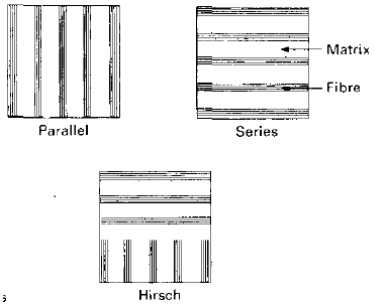


Figure 2. Illustration of Hirsch Model

The properties are given by,

$$Tc = x(TmVm + TfVf) + (1 - x)\frac{TfTm}{TmVf+TfVm} \quad (4)$$

Where Tc, Tm, Tf are the tensile properties of the composite, matrix (epoxy), and the fibres (Banana & Glass) respectively. Vm and Vf are the volume fractions of the matrix and fibre respectively. xis a parameter which gives the stress transfer between fibre and matrix.

C. Halpin-Tsai model

According to this model, the tensile strength and modulus are given by,

$$Ec = Em\left[\frac{1+A\eta Vf}{1-\eta Vf}\right] \quad (5)$$

$$Tc = Tm\left[\frac{1+A\eta Vf}{1-\eta Vf}\right] \quad (6)$$

Where,

Ec and Tc are the tensile strength and tensile modulus of the composite.

$$\eta = \frac{Tf/Tm-1}{Tf/Tm+A} \quad (7)$$

For tensile strength.

T_f and T_m are replaced by E_c and E_m for computing tensile modulus.

The value of parameter A is found from Einstein coefficient K as given below,

$$A = K-1 \text{ and } K = 1+2l/d$$

Where l and d are the length and diameter of the fibre respectively.

D. Neilson Model

Neilson modified the Halpin-Tsai model byintroducingparticle packing factor ψ in the equation.According to this model the equations to predict tensile strength and tensile modulus are given by,

$$Ec = Em\left[\frac{1+A\eta Vf}{1-\eta\psi Vf}\right] \quad (8)$$

$$Tc = Tm\left[\frac{1+A\eta Vf}{1-\eta\psi Vf}\right] \quad (9)$$

Where,

$$\psi = 1 + [(1 - \emptyset max)/\emptyset^2 max]Vf$$

And$\emptyset max$ is the maximum packing fraction, its value is 0.82 for randomly oriented fibres.

E. Modified Bowyer and Bader's Model

According to this model tensile strength and modulus are given by,

$$Tc = TfK_1K_2Vf + TmVm \quad (10)$$

$$Ec = EfK_1K_2Vf + EmVm \quad (11)$$

Where K_1 is the fibre orientation factor (varies from 0-1) and K_2 is the fibre length factor,

$K_2 = (l - lc)/2l$for l >lc(12.a)

or

$K_2 = lc/2l$for l <lc. (12.b)

Where l is the length of the fibre and lcis the critical length of the fibre.

III. EXPERIMENTAL PROCEDURE

A. Materials

Epoxy LY556 and hardener HY951 were used as matrix material. The properties are shown in table 1. Processed Banana fibre was obtained from M/s ROPE International Pvt. Ltd. Chennai. E-Glass fibre used in this study was purchased from M/s SakthifibreGlassLtd., Chennai. The properties of Banana Fibre and Glass fibre are given in Table 1.

B. Fabrication of composites

The fabrication of composite was carried out by hand layup method. A wooden mold of 300 x 300 mm was used. Rubber beadings of 3mm thickness were used as stoppers at the sides. Fibres of different lengths (5mm, 10mm, 15mm and 20mm) and volume fractions (0.05, 0.10, 0.15 and 0.20) were used in this study. Both Banana fibre and Glassfibre were mixed at equal ratio in overall fibre volume fraction. Initially a calculated amount of resin as per the volume fraction was poured over the mold. Then mixed fibres are gently applied over the resin. After uniformly arranging the fibres, again resin was poured over the mixture. After the hand layup process, the specimen is cured at room temperature and pressure is applied on top of the mold. After 24 hrs, the samples were taken and the tensile specimens were cut as per ASTM standard.

Table I. Physical and Mechanical properties of Banana, Glass fibre and epoxy resin

Material	Density (gm/cm^3)	Tensile Strength (N/mm^2)	Tensile Modulus (N/mm^2)	Elongation at break (%)
Banana Fibre	1.35	400-600	16,000 – 20,000	7-12
E-Glass Fibre	2.55	2400	65,000	3
Epoxy resin	1.13	10	300	5-12

C. Testing procedure

Tensile test were conducted at M/s Metmech Labs, Chennai. The tests were conducted as per ASTM D638 with test speed of 2.5mm/min. the load strain curve was generated as the output. The tensile strength and tensile modulus were computed from the output results. The test results were taken as the average of 5 samples.

D. Morphological study

The fractured specimens were analyzed using scanning electron micrograph (SEM)to evaluate the fibre matrix interaction, fibre fracture, fibre pull out and matrix crack. The fractured portions were cut from the test samples and ion sputtering was performed before the SEM analysis.

IV. RESULTS AND DISCUSSION

Composites were fabricated with the fibre lengths of 5, 10, 15 and 20mmrespectively. However,it was observed that the composites with 15mm fibre length gave maximum mechanical properties. Hence, the hybrid composite with fibre length of 15mm was preferred in this study.

Theoretical strength of the composites was calculated using different models discussed earlier. Fig.3 and Fig. 4shows the comparison between experimental and theoretical values of the tensile properties.

From Fig. 3, it is clearly seen that the tensile strength of the hybrid composite increases with increase in fibre volume fraction. It can also be observed that the trend is similar in all the cases. Also, the predicted valuesare closer to the experimental valuesat the lower fibre volume fraction. Much deviation was observed at higher fibre volume fraction.

It can be attributed towards the poor fibre matrix interaction and agglomeration of fibre at higher volume fraction. It was found that the rule of hybrid mixture predict higher bound in the tensile properties of the hybrid system. It is because that the hybrid system neglects the effect of fibre orientation and fibre interaction with matrix.

Hirsch model is the combination of parallel and series model. This model value has largest deviation from the experimental values. In this model, x is a parameter which plays an important role in predicting the tensile properties of hybrid system. x is a parameter which indicates the stress transfer between the fibre and matrix. The closest values are obtained when the value of x is assumed as 0.13.

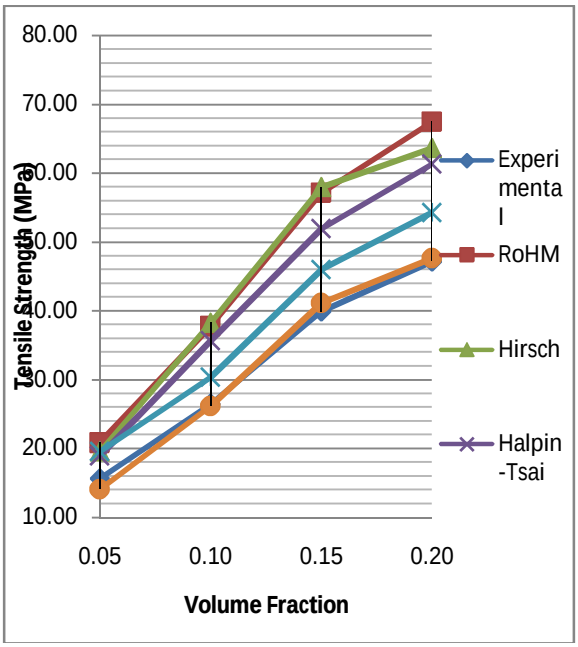


Figure 3.Plot of Experimental and theoretical tensile strength.

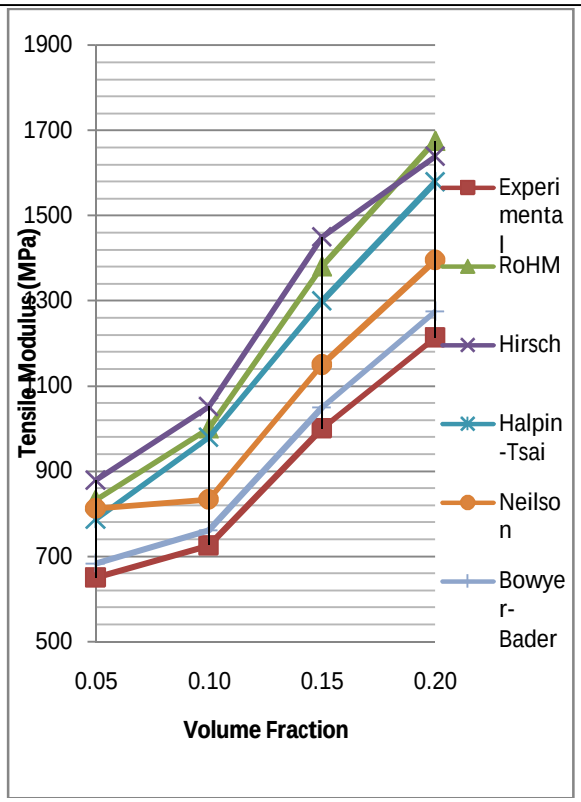


Figure 4.Plot of Experimental and theoretical tensile strength.

The values predicted by Halpin Tsai model also had positive hybrid effect on the values. The value of l/d ratio, otherwise known as aspect ratio, plays an important role in overall behavior of composite.

The parameter A is the measure of fibre geometry, is derived from Einstein Coefficient K, and K is determined by considering the aspect ratio of the fibre. Predicted values of tensile properties according to this technique are higher than the experimental values. Neilson model predicts the values closer to that of experimental values than Halpin Tsai model. This is largely due to the introduction of packing factor ψ in the equation.

Of all the theoretical models, Modified Bowyer and Bader model was able to predict the values closer to the experimental values. The orientation factor K1 was assumed as 0.2 and fibre length factor K2 was calculated from (12). The introduction of length factor K2 enables this model to correct itself for different values of fibre length.

This is in good agreement with the literature. Venkateshwaranet al. reported that, the tensile properties predicted by Bowyer and Bader model are closer to that of experimental values.

Fig. 5 and Fig. 6 shows the variation tensile strength at different fibre length (5mm, 10mm, 15mm and 20mm). The comparison between experimental values to that of the Modified Bowyer and Bader model is presented for 0.10 and 0.20 fibre volume fraction.

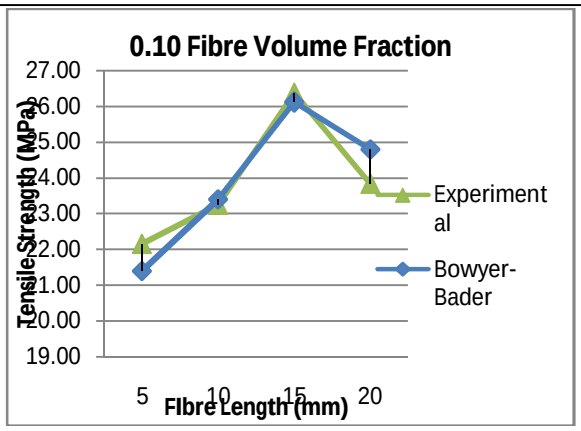


Figure 5.Variation of tensile strength at different fibre length for 0.10Vf

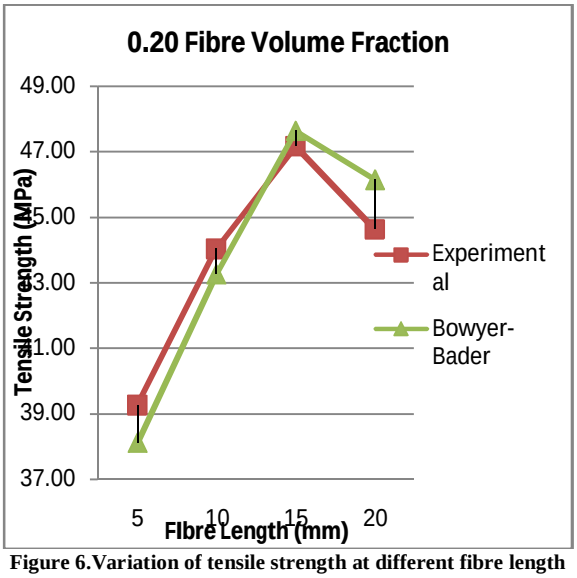


Figure 6.Variation of tensile strength at different fibre length for 0.20Vf

The maximum value of tensile strength was observed at 15mm fibre length for both fibre volume fractions. The value of tensile strength for a fibre length of 15mm is 26.3MPa at 0.10 fibre volume fraction. And its value is 47.15MPa at 0.20 fibre volume fraction. Further increase in fibre length decreased the tensile strength of the composite. Also it is to be noted that the experimental value and predicted value are closer at critical fibre length.

SEM images were taken to analyze the samples. Fig. 7 and Fig. 8show the samples with 15mm fibre length. It was observed from the samples that the failure of the fibre has taken place normal to the fibre axis.This is due to proper orientation of the fibres in the matrix. The applied load was effectively transferred to the fibres.Fig. 9 and Fig. 10 show the SEM images of samples with 20 mm fibre length. It has been observed that, the fracture was taken place along the lateral surfaces of the fibre. As the fibre length increases, the chance of curling of the fibre also increases. Due to fibre bending, some of the sections of the composite become weaker. The weaker part leads to the reduction in overall composite strength.

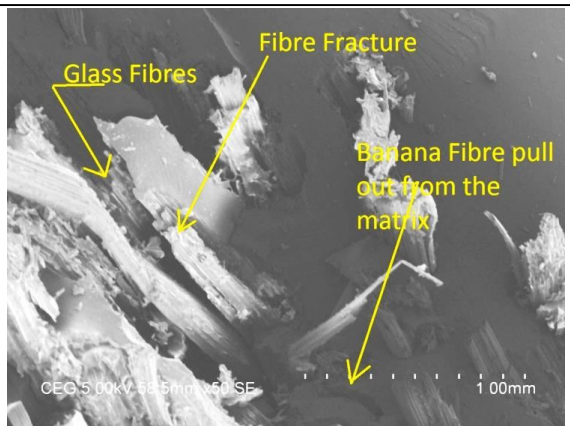


Figure 7. SEM image of sample with 15mm fibre length and 0.20 volume fraction

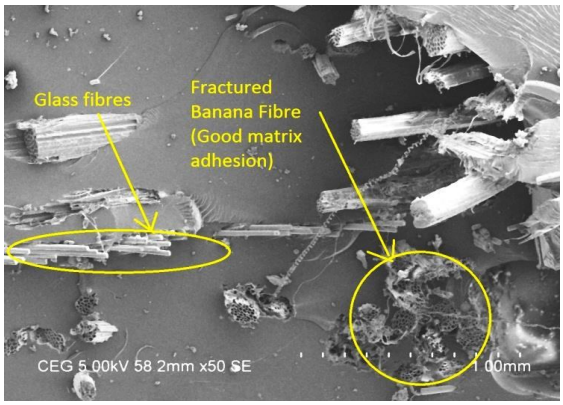


Figure 8. SEM image of sample with 15mm fibre length and 0.10 volume fraction

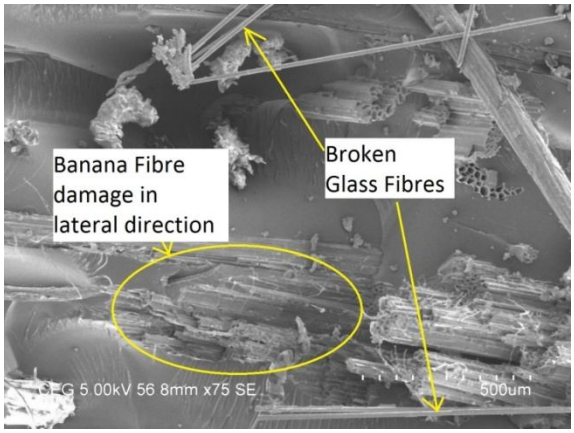


Figure 9. SEM image of sample with 20mm fibre length and 0.20 volume fraction

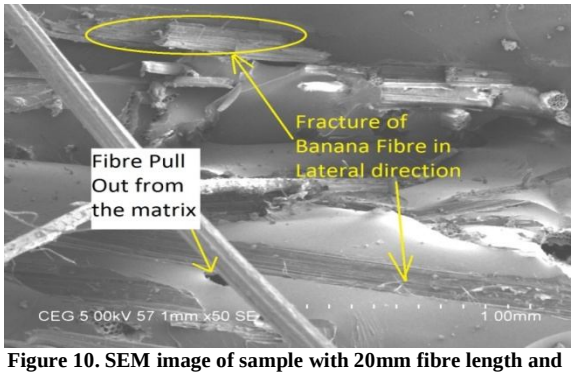


Figure 10. SEM image of sample with 20mm fibre length and 0.10 volume fraction

If the fibre length is smaller, then the interfacial shear strength is very less and the fracture takes place due to matrix crack and fibre pullout from the matrix. At critical fibre length, the strength of the fibre equals interfacial shear strength; hence the failure occurs due to fibre fracture. This results in maximum strength of the composite. If the length of the fibre exceeds the critical length, then extreme care has to be taken for proper alignment of the fibres. Weaving of the fibres is one of the methods to enforce proper arrangement of the fibre. Hence most of the mathematical models are successful in predicting the tensile properties for woven fibre composites. SEM images clearly show the role of fibre length in overall composite strength.

CONCLUSION

Hybrid composite was developed by using short Banana-Glass fibre reinforced in Epoxy matrix. Comparison between experimental values of tensile properties and that of theoretical models was carried out. Of the various theoretical models,Modified Bowyer-Bader model was able to predict the values closer to that of experimental ones. It is because of introduction of fibre orientation parameter and fibre length parameter in the equation. Both RoHM and Hirsch model have shown larger deviation from the experimental values on the higher side.Hence, this study shows that the Fibre parameters such as fibre orientation and fibre length had crucial role in predicting the tensile strength of the composite.

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