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FRACTURE TOUGHNESS OF SISAL/BANANA HYBRID COMPOSITE REINFORCED POLYESTER COMPOSITES

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ABSTRACT

In the present research paper, the behavior of mechanical and fracture of sisal/banana fabrics reinforced polyester composites was investigated. Composites laminates are prepared by Hand Layup and Vacuum Bagging Method (VBM). The fibers strength was studied by the chemical treatment of NaOH solution. For mechanical properties, each laminate consists of five plies fabrics and resin which are mixed with thickness of 3 mm according to the different layering designation. For fracture properties, each laminate has 16 plies of resin and fabrics mixed with 10 mm thickness according to the different layering designation. The specimen preparation and test was done by according ASTM standards. Tensile test, flexural test (three-point bending) and fracture toughness tests on these laminates were carried out. It was absorbed that maximum tensile and maximum bending strength found in L_D laminates, and maximum fracture toughness found in L_G laminates. By scanning electron microscope (SEM), we studied the fracture surfaces which are formed due to the different failure mechanism.

KEYWORDS: Banana and Sisal Fabrics, Polyester Matrix Composites, NaOH Solution & Scanning Electron Microscope

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Original Article

1. INTRODUCTION

The materials of composite are made two or more constituents with difference in physical and chemical properties. Natural fiber composites are environmentally good due to lower impact on the environment compared with the glass fibers. Perm kumar Naik *et al.* [1] worked on mechanical properties of fibers areca, which has reinforced with resin phenol formaldehyde (PF) and concluded that 300 ml PF of composite plates gives the maximum tensile strength, 500ml PF gives better moisture absorption resistance and 400ml PF gives maximum bending stress. Laxmana Naik *et al* [2] investigated the tensile property of glass/sisal fiber which has reinforced by polymer based hybrid composites prepared by VBM and the observed tensile strength of hybrid composite of glass & glass/sisal fiber gives maximum strength compared to composites reinforced with sisal only. Mohan *et al* [3] worked on the mechanical properties of the areca fibers using PF as a resin comparing with the other known natural fibers coir. Mechanical properties of hybrid epoxy/jute composite was studied by Gassan and Blledzki [4] and observed that, improved the dynamic modulus using incorporating jute fibers with epoxy. Avci *et al* [5] worked on the glass fiber reinforced with concrete polyester using the Linear Elastic Fracture Mechanics (LEFM). Load and displacement curves of SENB specimen increased in both fiber and resin results in improved the composites of load carrying capacity along with improved fracture toughness. Author also observed initial notch depth method that, increment of 10% in fracture toughness was achieved with 1 wt.% of glass fiber reinforcement at 13 wt.% of polyester content. Fracture behavior from short bamboo fiber which has reinforced with polyester was studied by Won *et al* [6] reinforced the matrix with fibers varying from 10–50, 30–50 and 30–60 vol.% with increments of 10 vol.% for bamboo fibers at 4, 7 and 10 mm length, respectively. Author has concluded from his result observation that, maximum fracture toughness is achieved at 10 mm/50 vol.%.

In the present work, we studied the mechanical and fracture behavior of sisal/banana fabrics reinforced polyester and characterized through LEFM method. Sisal-banana fibre fabrics are chosen because of its relatively excellent mechanical and physical properties in terms of strength, density, strain and stiffness at break point [6]. Fracture test for composite studied using ASTM standard is yet to be developed, and at present an available standard for polymer i.e. ASRM D5045 is the only choice for fiber reinforced polymer composite and was often adopted by some other researcher [5, 6]. Therefore, a special interest is required to study the fracture behavior of composite using LEFT technique for mode I, single edge notch beam (SENB)/three point bend loading. Along this, fracture toughness of the brittle thermosetting matrix composites is normally characterized by using critical stress intensity factor i.e. KI_C [7]. For this result, we also discussed the fracture toughness of brittle thermosetting matrix materials and it was characterized by critical stress intensity factor i.e. KI_C [7].

2. MATERIALS

The employed thermosetting polyester (Isophthalic) resins was used in the fabrication of banana-Sisal fabrics reinforced hybrid composite and also it has high versatility, excellent adhesive characteristic, lesser amount of shrinkage and low cost. Methyl Ethyl Ketone Peroxide (MEKP) is applied as a catalyst & cobalt naphthenate is used as accelerators, is supplied by Chemicote Engineers, Bangalore, India. Alkali (NAOH) treated plain-woven sisal and banana fabric was used to fabricate composites. Sisal fabric (SF) was supplied by Go Green Products, Tamil Nadu, India. Banana fabric (BF) of plain woven was supplied by J. C Overseas INC Jaipur, Rajasthan, India. Mechanical properties of sisal-banana fibers as shown in Table 1 and fabric of Sisal and banana are shown in figure 1.

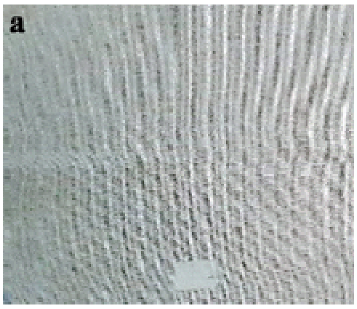

Figure 1(a): Sisal Fabric.

Figure 1 (b) Banana Fabric.

Table 1: Mechanical Properties of Sisal/Banana Fibers

Properties	Density (Kg/m^3)	Flexural Modulus	Tensile Strength	Young's Modulus	Elongation at Break
Sisal fibers	1450	13.5	500–855	9–28	2.4
Banana fibers	1350	4	529–914	7.7–32	2.6

3. EXPERIMENTAL DETAILS

3.1. Fabrication of Tensile & Fracture Tests Specimens

Figures 2–4 show the dimensions of tensile, bending and fracture test specimen used in the present work. The mentioned dimensions of the each specimen for testing are defined as per ASTM D638 [8], D790 [9] and ASTM D5045–99 [10], respectively. Composite laminates were fabricated with 300 x 300 x 3mm^3 for mechanical properties, 300 x 300 x 10mm^3 for fracture properties. The composite laminate consists of alternate layers of fabrics of sisal-banana as per the stacking sequence. Weight of the fibers and matrix are calculated by using Equation 3. Number of layers was decided to achieve the laminate thickness of 3 mm and 10mm. Each weight of banana fabric (W_b) is 13 ± 2 g, and weight of sisal fabric (Ws) is 16 ± 1 g for a dimension of banana and sisal fabric 300mm x 300mm. For the preparation of matrix system, the resin, accelerator and the catalyst are mixed in the ratio of 10:1. Hand lay-up and vacuum bagging technique is adopted to fabricate both types of the specimens. In this vacuum bagging process 80 bars pressure is applied to fabricate laminate, which is duly sealed with mastic sealant. The layers of fabric materials are kept one on another on the flat mold and later applied the resin after each layer followed by tissue using hand layup method. Later, place the release fabric & breathable fabric on the laminated layers have restrictions on the amount of resin that can be pulled out of the basket. Then the resultant composite materials cured using vacuum at room temperature for 24 hrs. After that, removed the laminates from the mold and kept it using autoclaved at 80°C / 5 hrs before specimen is cutting as per required dimension. Laminate designation as per stacking sequence for mechanical and fracture properties are shown in Tables 2 and 3. For Single Edge Notch Beam (SENB) specimen, thickness of razor blade about 0.1 ± 0.005mm is inserted at the center for initiate 2 mm pre-crack. Later, the composite is cooled at room temperature for 24 hrs. Crack to width ratio (a/W) of 0.45 was obtained.

$$wf = \frac{wf}{wf + wm} \quad \text{and} \quad Wm = \frac{wm}{wf + wm} \qquad (1)$$

Wf = Weight of fiber

Wm = Weight of matrix

Table 2: Laminate Designation as Per Stacking Sequence for Mechanical Properties

Laminates	Designations (Matrix)
L_A	BF + BF + BF + BF + BF (Polyester)
L_B	SF + SF + SF + SF + SF (Polyester)
L_C	BF + SF + BF + SF + BF (Polyester)
L_D	SF + BF + SF + BF + SF (Polyester)

Table 3: Laminate Designation as Per Stacking Sequence for Fracture Properties

Laminates	Designations (Matrix)
L_E	BF + BF + BF + BF + BF + BF + BF + BF + BF + BF + BF + BF + BF + BF + BF + BF = (16 BF)
L_F	SF + SF + SF + SF + SF + SF + SF + SF + SF + SF + SF + SF + SF + SF + SF + SF = (16 SF)
L_G	BF + SF + BF + SF + BF + SF + BF + SF + BF + SF + BF + SF + BF + SF + BF + SF = (8 BF + 8SF)
L_H	BF + SF + SF + BF + SF + SF + BF + SF + SF + BF + SF + SF + BF + SF + SF + BF = (6 BF + 10 SF)
L_I	BF + BF + BF + SF + SF + SF + BF + BF + BF + SF + SF + SF + BF + BF + BF + SF = (9 BF + 7SF)

3.2. Experimental Procedure

The tensile, bending and fracture tests are conducted using 100 kN Kalpak computerized Universal Testing Machine (UTM). The dimensions of tensile, bending and fracture test specimens are shown in figures 2–4. The tests are performed at room temperature, with crosshead speed of 1.5 mm/min. Four same types of tests are run for each type of composite and determined the average values and recorded the load–displacement curves for all tests. For tensile behavior, stress–strain curves are plotted. For fracture toughness, Critical stress intensity factor (KI_C) is determined.

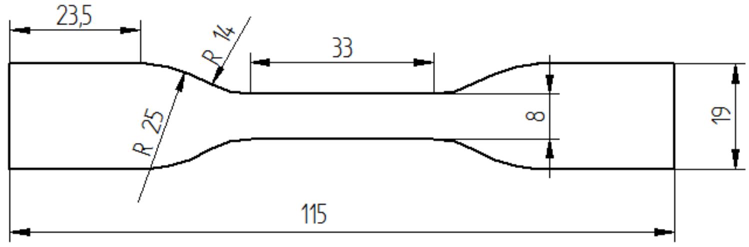

Figure 2: Dimension of Tensile Test Specimen.

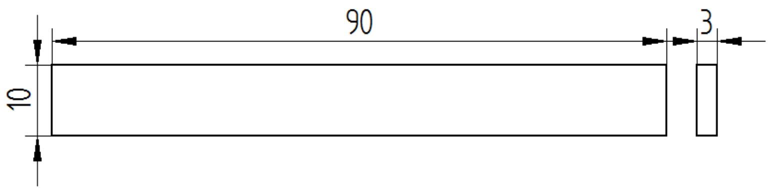

Figure 3: Dimension of Bending Specimen.

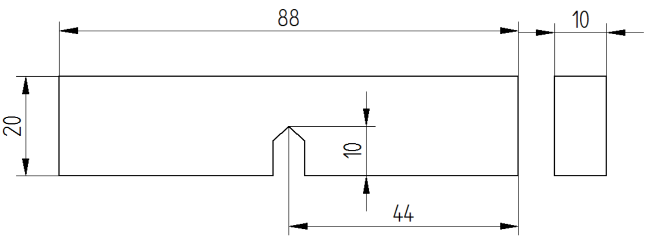

Figure 4: Dimension of Fracture (SENB) Specimen.

In order to establish a valid P_Q calculated a conditional result KQ. SENB specimen is laded and from the obtained result Load–displacement curve is drawn. The force PQ at a 5% secant offset from the initial slope is recognized by a particular variation from the linear portion is record. The value of K_Q is calculated from this force using equation no 2 [11].

$$k_Q = \left(\frac{P_Q}{BW^{1/2}}\right) f(x) \quad (2)$$

B = Thickness of specimen (mm), $X = a/w$ where ($0 > x > 1$)

W = Width of specimen (mm)

a = Length of crack (mm).

$$fx = 6x^{1/2}\frac{[1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2)]}{(1+2x)(1-x)^{3/2}} \quad (3)$$

Pq is explained in the load–displacement graph. For make it sure for the plain strain condition, the size criteria is validated by the equation (3).

$$B \cdot a(w-a) > 2.5\left(\frac{k_Q}{\sigma_{ys}}\right) \quad (4)$$

Where (w - a) = ligament

σ_{ys} =Yield stress of the specimen. If K_Q satisfies equation (4), then K_Q is equal to KI_C.

4. RESULTS AND DISCUSSIONS

4.1. Tensile Properties

The tensile properties of fabricated composite laminates for different stacking sequences were estimated on universal testing machine. Stress/strain and load/displacement curve were plotted based on the results generated during the test. figure 5 and 6 represent the load/displacement and stress/strain plots, respectively. Ultimate tensile strength (UTS) and tensile modulus of composite materials had studied using the equations (5) & (6) respectively.

$$\text{Ultimate Tensile Strength} = \frac{W}{bt} \quad (5)$$

$$\text{Tensile modulus} = \frac{m}{bt} \quad (6)$$

Where, W = ultimate failure load (N),

b = width of specimen (mm),

t = thickness of specimen (mm), and

m = slope of load-deflection curve at a linear region.

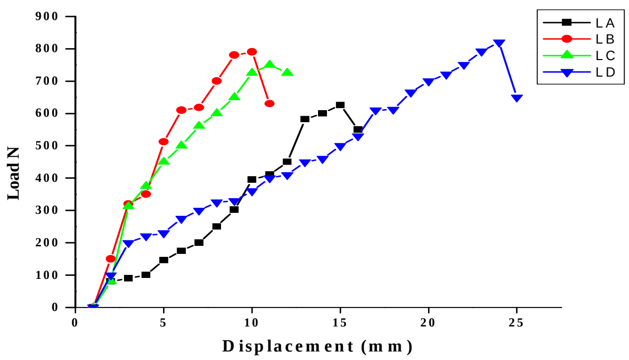

Figure 5: Tensile Load v/s Displacement Curve of the Composite Laminates.

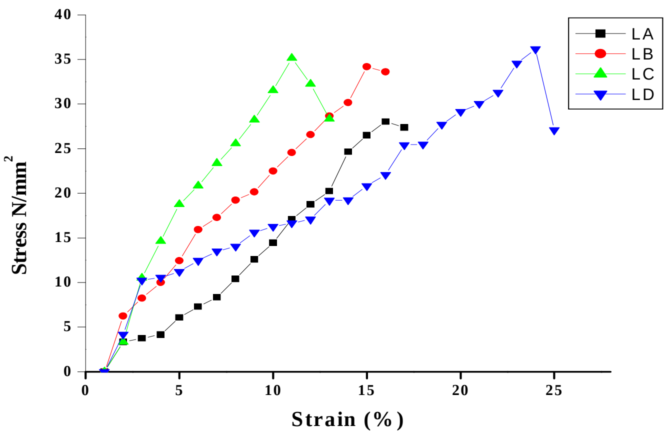

Figure 6: Stress vs. Strain Curves of Composite Laminates.

Figures 5 and 6 show the load displacement and stress strain curve of tensile strength of the composite laminates. It is noticed that sisal-banana (L_D) composite laminate exhibits better tensile strength as compared to other composite laminates. Increase in the tensile strength is due to better bonding, adhesion and uniform dispersion of the fibers in the matrix. Maximum load, maximum ultimate tensile stress, maximum tensile modulus found in composite laminate L_D compared to all other laminates. The hybrid laminate L_D yields better tensile load of around 788 N compared to other laminates. The ultimate tensile strength of laminate L_D is 35.11MP and tensile modulus is1.756 GPa which is greater than the other laminates. The ultimate tensile strength of hybrid laminate L_C is 30.41MPa and tensile modulus is1.684GPa which is lesser than the L_D laminate but more than that of L_A and L_B laminates. The tensile strength of laminate L_A and L_B made of pure banana and sisal are 23.76 MPa and 28.43 MPa, and modulus of 1.14GPa and 1.62GPa.

4.2. Flexural Strength

The flexural strength of fabricated composite laminates for different stacking sequences are estimated on universal testing machine. Load/displacement plot is plotted based on the results generated during the test. Figure 7 shows the load/displacement plot for the tested composite laminates.

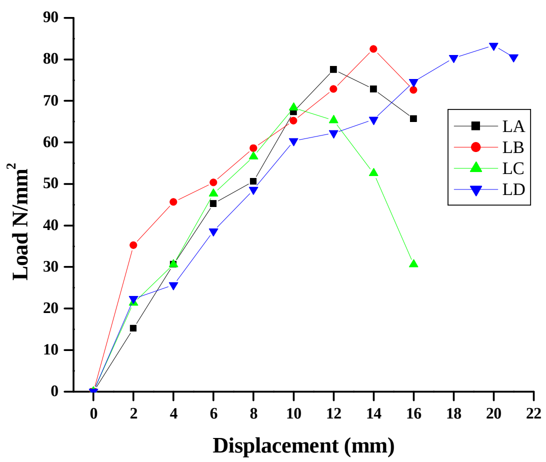

Figure 7: Flexural Load v/s Displacement Curves of the Composite Laminates.

Figure 7 shows the load displacement curve of the composite laminates. It is observed from the results that, banana-sisal polyester (L_D) composite laminate exhibit improved flexural strength compared to other composite laminates. Maximum load, maximum flexural strength, maximum flexural modulus found in composite laminate LD compared to all other laminates.

It is observed from the figure 7 that L_A and L_B laminates exhibit flexural strength of 106.71 MPa and 142.84 MPa respectively. Further, adding banana fiber to the sisal leads to enhance flexural strength (L_C =148.80 MPa and L_D=166.26 MPa). From figure 7 it is absorbed that hybrid composite laminates L_C and L_D exhibit improved flexural strength compared to L_A and L_B laminates, L_D composite laminate exhibits better flexural strength compared to other laminates. It is observed from the results that the maximum load of around 80 N, maximum flexural strength of around 166 Mpa. Maximum flexural modulus of around 9.1 GPa.

4.3. Fracture Toughness

4.3.1. SENB (Single Edge Notch Beam)

The fracture properties of fabricated composite laminates for different stacking sequences were estimated on universal testing machine. For each laminate four tests were conducted. Load/displacement plots were plotted based on the results generated during the test as shown in figure 8.

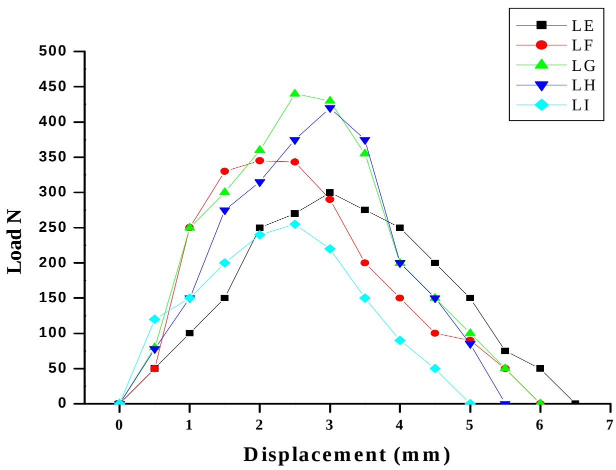

Figure 8: Load Displacement Curves of SENB Samples.

Figure 8 shows load displacement curve of the composite laminates. It is observed from the results that, banana-sisal polyester (L_G) composite laminate exhibit maximum stress intensity factor (KI_C) compared to all other composite laminates. Single edge notch beam fracture toughness specimens used have a/W = 0.45, B = 20 mm, W =88 mm. Using the above data and formulae, the values of fracture toughness (KIc) obtained are tabulated in table 4.

Table 4: Results of Fracture Toughness Testing

Specimen	Pmax(N)	PQ (N)	KIc $MpaM^{1/2}$	$\sigma_{yieldMpa}$
L_E	270	250	0.40	45.74
L_F	345	332	0.53	49.84
L_G	440	432	0.69	52.12
L_H	415	408	0.65	55.14
L_I	255	241	0.38	50.72

It is observed that, banana-sisal polyester (L_G) composite laminate exhibit improved fracture toughness strength compared to other composite laminates. The Maximum fracture toughness is found in composite laminate LD when compared to all other laminates. Maximum stress intensity factor KIc is 0.69Mpa $m^{1/2}$.

5. MORPHOLOGY STUDY

5.1 Scanning Electron Microscope (SEM) of Tensile Test Samples

The failure morphology of the fabricated composites after tensile testing was studied through scanning electron microscope (SEM). The SEM images of the samples undergo of tensile test is presented. The tensile specimen had fracture, which has takes place by the application of uni-axial tensile load. The fracture in the SEM indicates the fiber fracture which is pulled out from the specimen and also the dislocation of fibers. The SEM images of the produced samples are presented in figure 9 (LA, LB, LC & LD). The SEM images of LA laminate in figure 9 reveals the presence of more voids (±20µm size) near fibers area which are formed due to fiber pulled out and also observed the few micro cracks, fiber fractures and resin rich area. This types features are formed maybe due to the laminated of only banana fabrics. In SEM images of LB laminate in figure 9 covers the rough surface area along with the fiber fracture and transverse fibers. This types of features are formed maybe due to the laminated of only sisal fabrics. In SEM images of LC laminate in figure 9 exhibits the sisal and banana fibers fractures along with transverse fibers and few voids are presented due the fiber pull out. In SEM images of LD laminate in figure 9 also exhibits some sisal and banana fractures but in the present SEM images show some surface cover with rough area, void (10–20 µm width) are formed due to fiber pull out, tight bonds and also have resin rich areas.

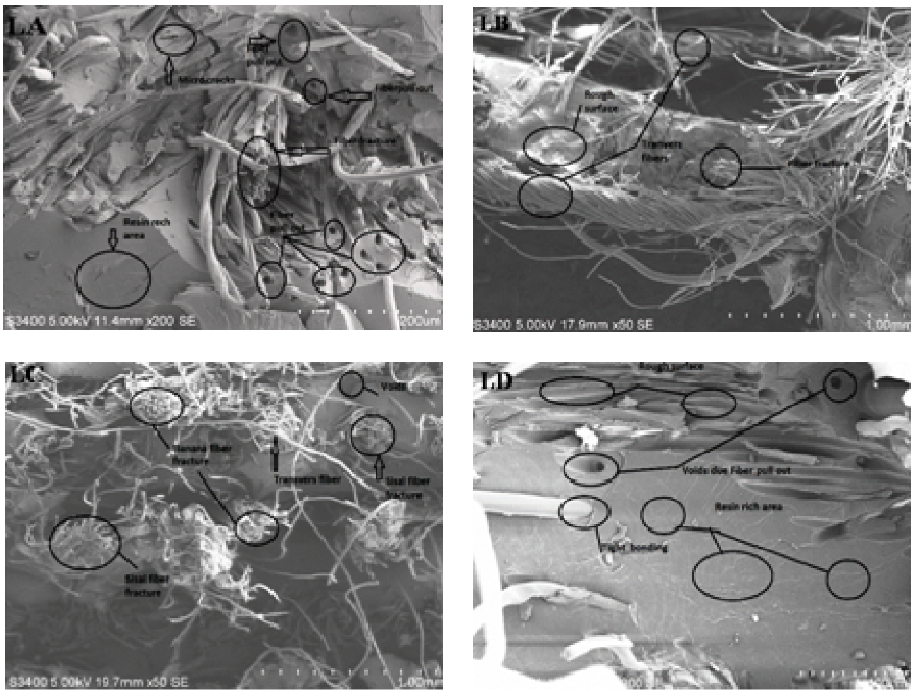

Figure 9: SEM Micrograph Images of Samples LA, LB, LC and LD.

5.2. Scanning Electron Microscope (SEM) of Fracture Test Samples

The SEM micrographs of fractured features for SENB failed samples (LE, LF, LG, LH & LI) are shown in figure 10. It can be seen that the evidence of fiber fracture and void are formed due to the fiber pull out in SEM image of LE. A few tight bonding between the fiber and matrix with transverse fibers along with the fiber fracture and voids formed due to the fiber pull out in SEM image of LF. In SEM image of LG, many voids (width 10-15 µm) are noticed which are formed due to the fiber pull out and also observed the fiber bending structure, tight bonding between the fiber matrix, poor bonding and transverse fibers.

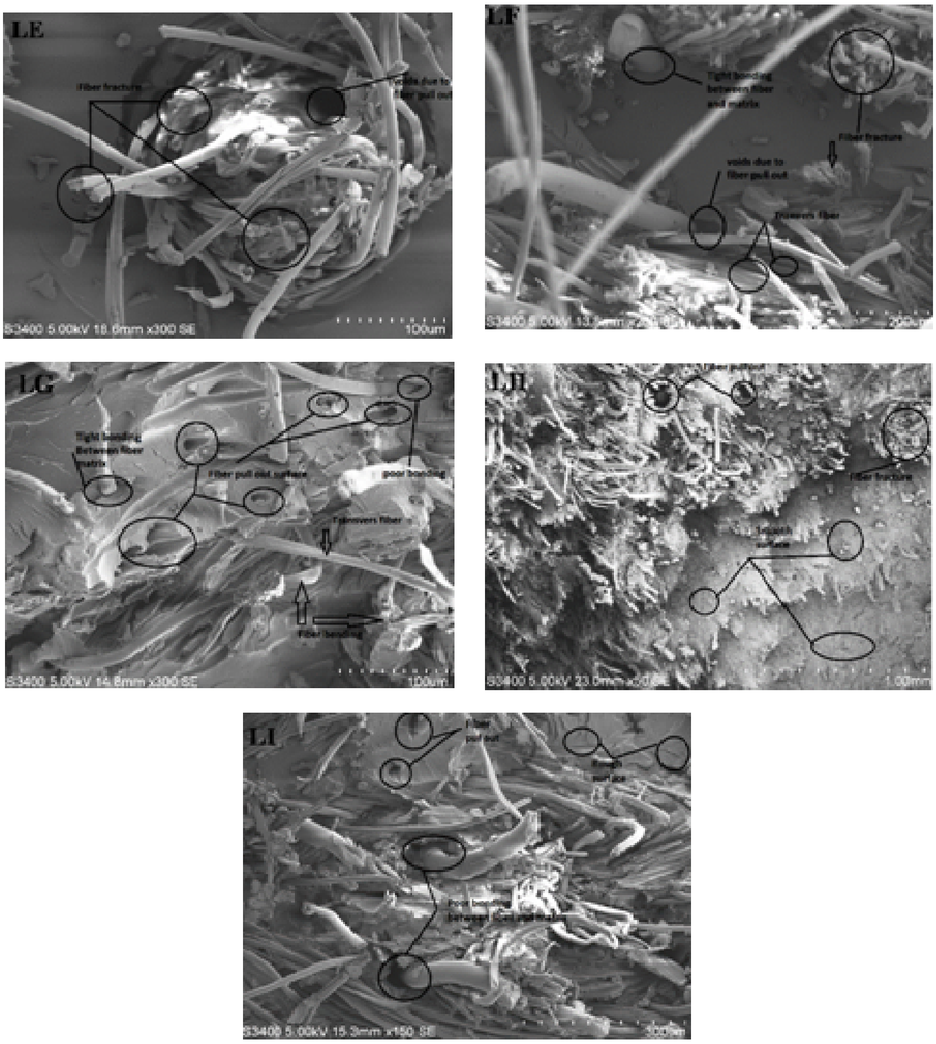

Figure 10: SEM Micrograph Images of Samples LE, LF, LG, LH and LI.

In SEM image of LH observed the presence of smooth surface and fiber fracture along with this, voids are observed which are formed due to the fiber pull out. There are poor bonding between the fiber and matrix are observed along with rough surfaces and few voids ranging from 10 to 30 µm are seen which are formed by the fibers are pulled out each others.

6. CONCLUSIONS

A hybrid composite of multilayered has been prepared successfully by reinforcing with light weight, low cost and eco-friendly sisal fibres with banana fibers using matrix of polyester resin. It is noticed that sisal-banana (LD) composite laminate exhibit better tensile strength as compared to other composite laminates. From the results, observed clearly that, both the tensile strength and modulus are improving with increase in sisal fiber. Maximum tensile load of around 788 N and maximum ultimate tensile strength of around 35.11 MPa and maximum tensile modulus of around 1.756 GPa. It is observed from the results that, banana-sisal polyester (LD) composite laminate exhibit improved flexural strength compared to other composite laminates. Maximum load of around 80N and maximum flexural strength of around 166 MPa and maximum flexural modulus of around 9.1 GPa. It is observed that, banana-sisal polyester (LG) composite laminate exhibit improved fracture toughness strength compared to other composite laminates. The Maximum fracture toughness found in composite laminate LD compared to all other laminates. Maximum stress intensity factor KIc is 0.69 $MPa \cdot m^{1/2}$.

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