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Mechanical Property Evaluation of Sisal-Glass Fiber Reinforced Epoxy Polymer Composites

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Abstract

Polymer composites are capable of replacing conventional materials due to its various engineering advantages. Generally synthetic fibers such as fiber glass, aramid, etc. are used as a reinforcement which are carcinogenic to prolonged exposure to it. Replacing or reducing their usage by substituting with natural fibers are sustainable, harmless, cost effective, light weight and eco-friendly with comparable properties without compromise. Sisal is one such natural fiber extracted from the leaves of Agave Sisalana plants with good properties. Specimens are prepared with six different combination such as sisal, sisal-glass fiber and glass fibers with epoxy matrix at two different fiber orientation of 0/90° and ±45°. Mechanical characterization is done to assess its tensile and flexural strength, impact energy absorption capacity and hardness .The interfacial bonding characteristic, cracks and internal structure of the fractured surfaces are evaluated by Scanning Electron Microscope (SEM). It is found that the hybrid composite of sisal-glass-epoxy has better and comparable mechanical properties with conventional glass-epoxy composites.

Keywords: Polymer composite; Sisal fiber; Mechanical characterization; Fiber orientation.

1. Introduction

Glass Fiber Reinforced Polymers are extensively used in structural and automobile applications due to its better specific properties. However, glass fibers are carcinogenic in nature and long term exposure by the fabricators increases their health risk [1]. Fiber glass is advantageous due to light weight, strength and toughness. It is the bound duty of researchers to substitute with alternate materials from nature to reduce the toxicity and to improve sustainability. The natural fibers are extracted from plants such as sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, banana leaf, bamboo, wheat straw etc, and are used as reinforcement for polymer composites[2]. Their advantage lies in the fact that they are low cost, low density, high specific strength, biodegradability, renewability etc,. The applications of natural fiber–thermoplastic composites are in automotive, aerospace industries, structural application, etc.[3].Since the global warming potential (GWP) and toxicity of the environment are raising, it is high time to replace harm full synthetic fibers with natural fibers which can offer a hand for our sustainable living conditions. The properties of natural fibers are negotiable which makes them attractive to replace synthetic fibers in almost all applications [2].

Sisal fiber is one of the most widely used natural fibers available in plenty and has comparable properties. Sisal fibers are mainly used for manufacturing ropes which are used largely in marine and agriculture industry [4].The chemical compositions of sisal fiber are reported by several researchers [5-7]. Wilson [5] indicated that sisal fiber contains78% cellulose, 8% lignin, 10% hemi-celluloses, 2%waxes and about 1% ash by weight; but Rowell [6]found that sisal contains 43-56% cellulose, 7-9% lignin,21-24% pentosan and 0.6-1.1% ash. More recently, Joseph et al. [7] has reported that sisal contains 85-88%cellulose. High cellulose content will enhance the mechanical property of the fiber, whereas the presence of hemi-cellulose will do the opposite [8].The use of sisal fiber reinforced composite may have very low strength but hybridization along E-glass fiber will provide comparable strength.

In the present work sisal leaves were collected and the fibers extracted with standard procedures and then knotted and knitted as mat. Epoxy matrix laminates were prepared by hand layup method with E-glass, sisal mat and E-glass and with combination sisal plus E-glass at two different fiber orientation($\pm45^0$,$0/90^0$).Micro structural and mechanical properties were evaluated at standard test conditions and results compared. The results are encouraging which prompts industrialist to opt for hybrid natural reinforced polymer composite which reduces the toxic addition to the environment and reduces the health risk to the workers.

Table 1. Physical properties of sisal fiber and glass fiber[1, 3]

Physical Properties	Sisal fiber	Glass fiber
Density (g/cm^3)	1.41	2.56
Elongation at break (%)	6-7	1.8-3.2
Cellulose content (%)	60-65	-
Lignin content (%)	10-14	-
Tensile strength (MPa)	511-635	2000-3500
Young’s modulus (GPa)	12.8	70

2. Material Preparation

In this present investigation sisal (Agave sisalana) and glass fibers are used for fabricating the epoxy matrix polymer composite.

2.1. Extraction of sisal fiber

The botanical name of sisal plant is Agave Sisalana and the leaves collected from Kanyakumari District, Tamil Nadu, India. They are soaked in water for 30minutes to allow microbial degradation. They are then washed in water and dried in natural sunlight to remove the moisture. The dried fiber bundles were clamped between wooden plank and a serrated knife is used to hand-pull the pulpy resinous material from fiber. The fibers are then segregated according to its size and knotted to increase its length. They are knitted into a mat by intertwining the fiber in a series of connected loops by hand work. Sisal fibers are traditionally being used in makes twine or rope by the same technique using some mechanical devices.

2.2. Glass fiber

Glass fiber mat is purchased from Amala Fibers at Bangalore. Fiber glass is cheaper, has good specific strength. It is widely used in automotive application, shipping industries, structural applications in all walks of life. However studies show increased health concerns to prolong exposure.DNA damage, cytotoxic effect, reduction in microvilli membrane, stimulation of T-cells, aggression in eosinophil activations, etc are a cause of concern for the workers handling glass fiber[8].The excellent properties offered by glass fiber economically favors its widespread application.

2.3. Composite Preparation

The matrix used for composite preparation by hand layup method is Epoxy LY556 with a solid density of 1.15–1.20 g/cm^3. The hardener HY951 (N,N'-bis (2-aminoethyl) ethane-1,2...C6H18N4) having density in the range of 0.97–0.99 g/cm^{3}is mixed with epoxy in the weight ratio of 20:1.The mold is made from MS Plate with the dimension of 300 mm × 300 mm × 3 mm. The mold surfaces are coated with wax in order to facilitate easy removal after composite preparation. The prepared mats are cut in such a way to maintain the fiber orientation angle of 0/90^o and±45^{o}as per the design. Six set of specimens with two fiber orientations are prepared with Fiber Glass(FG), Sisal(S), Sisal-Fiber Glass(S-FG) with epoxy matrix. Each specimen is prepared with total of 3 mm thickness having four layers of fibers in mat form. In the first case all the four layers are of glass fiber mat, and in the second case, all the four layers are of sisal fiber mat. However in the third case ,the hybrid composite is made with alternate layers of sisal and glass fiber mat. The layers of fibers are laid one above the other at the designed orientation by hand and epoxy resin hardener mixture is added in each steps. The epoxy resin is distributed to the entire surface by means of a roller and care is taken to remove the air bubbles formed during the processing by gently pressed it out. Finally the mold is kept under slight pressure for 24 hours to cure. The cured hardened specimen is cut into required sizes as prescribed by the ASTM standards for different tests. The six set of fabricated tensile test specimens are shown in Fig.1.

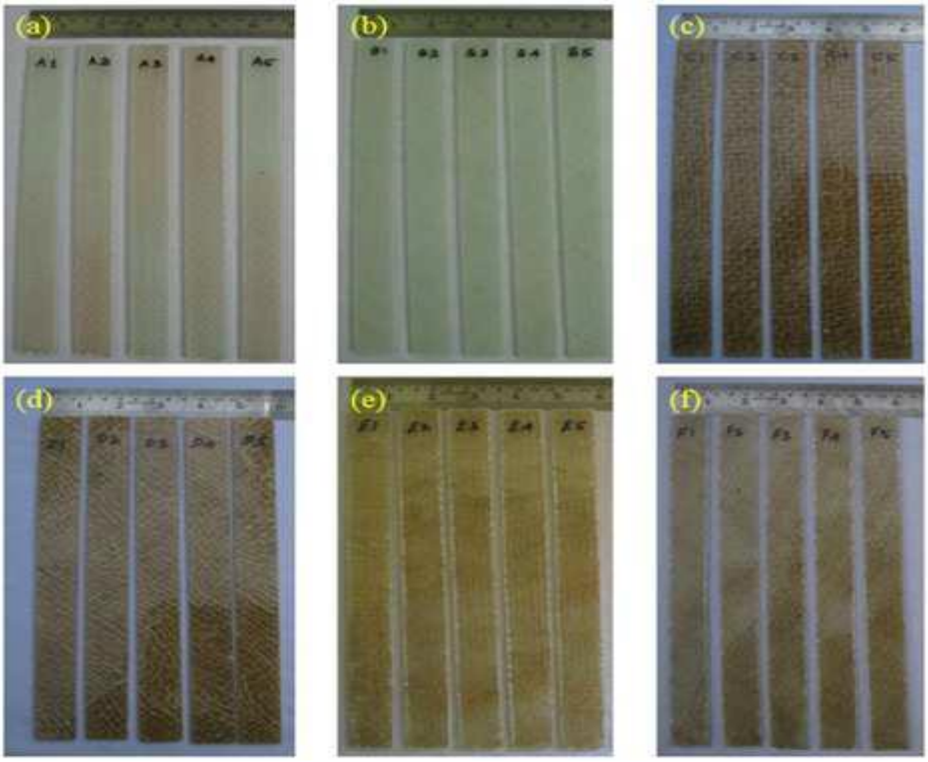

Fig.1 Fabricated tensile test specimen with the following combinations (a)Glass+Epoxy 0/90° (b) Glass+Epoxy ±45°(c) Sisal+Epoxy 0/90° (d) Sisal+Epoxy ±45° (e) Sisal+Glass+Epoxy 0/90° (f) Sisal+Glass+Epoxy±45°

3. Material Characterization

3.1. Tensile Test

Specimens are prepared according to the ASTM D 3039/D3039M-08 standard [9] using a saw cutter and the edges are polished by using emery paper before doing the mechanical testing in the UTM.

The tensile test specimen specification is 250 mm×25 mm×3 mm with a gauge length of 100 mm. It is tested in a 50 kN Universal Testing Machine (UTM) with computerized control and data acquisition facilities. The specimens are subjected to tension, until it fractures and the elongation of the specimen in the gauge section is recorded against the applied force. Five specimens are tested for each test condition and the average values are noted along with standard deviation for analysis. Fig.1 shows the tensile specimens of each condition before testing.

3.2. Flexural Test

The flexural specimens are also prepared with smooth edges with a dimension of 58 mm×12.7 mm×3 mm as per the ASTM D790-10 standards [10].The 3-point flexure test is the most common flexural test for composite materials. It is performed by measuring the crosshead position of the deflected specimen with respect to load. The testing process is performed by placing the specimen in the universal testing machine and applying force to the specimen until it fractures. The average flexural strength and modulus are noted at 5 % of strain for five specimens to each set of specimens.

3.3. Impact Test

Similarly the impact test specimens are prepared according to the ASTM D256-10 standard [11]. The machine is loaded with the specimen and the pendulum is allowed to strike it until it fractures. The energy needed to break the material is measured easily using the impact test. The test can also be used to measure the toughness of the material and yield strength. The effect of strain rate on fracture and ductility of the material can be analyzed by using the impact test.

3.4. Hardness Test

The hardness test specimens are prepared according to the ASTM D785-08 standard [12].Hardness is tested in a Wilson Rockwell 574 Tester, model number R574/T. Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied. Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex. Therefore, there are different measurements of hardness such as scratch hardness, indentation hardness, and rebound hardness. Hardness is dependent on ductility, elastic stiffness, plasticity, strain, strength, toughness and viscosity.

4. Results and Discussion

In the present study natural fiber, sisal is added along with the glass fiber as a reinforcement to make polymer composite material and their effect on mechanical properties is evaluated and compared. The orientations of the fibers are changed with 0/90° and ±45° to observe the effect of orientation on composite properties. Mechanical testing are done with standard test procedure and the results compared. The tensile, flexural and impact testing of six different fiber combination epoxy matrix composite is fabricated and the average result of five specimen for each test is presented in Table 2.

4.1. Tensile Properties

The samples are tested in the universal testing machine in tensile mode until it and break at its ultimate strength. It is obvious that the glass-epoxy (0/90°) composite has shown the best strength with an average value of 242.6 MPa. The glass-sisal-epoxy hybrid composite is also exhibiting similar trend with better tensile strength. The tensile strength of sisal fiber reinforced polymer composites at 0/90º fiber orientation has drastically reduced by 82% in comparison with glass-epoxy (0/90º) composite. However, the tensile strength of hybrid composite of glass-sisal-epoxy (50:50) at 0/90º has shown only a reduction of around 28.9% in comparison with glass fiber composite. The density of glass fiber is 2.5 g/cm^3 and that of sisal is around 1.5 g/cm^3. The addition of 50% natural fiber along with glass fiber increases the specific strength of the composite material and the weight reduction achieved is appreciable which enables the material to be used structural application without compromising on the strength.

Table 2. Mechanical properties of different composite samples.

Sample	Composites	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J/cm^2)	Rockwell Hardness (HRLW)
A	Glass+Epoxy 0/90°	242.6±14.63	224±26.07	17.74±0.75	95.9±3.54
B	Glass+Epoxy ±45°	67.4±4.33	112±60.99	22.46±0.75	98.5 ±3.94
C	Sisal+Epoxy 0/90°	42.8±2.38	64±8.94	1.31±0.18	56.7±1.36
D	Sisal+Epoxy ±45°	33.4±6.54	56±8.94	1.88±1.15	52.7 ±1.05
E	Sisal+Glass+Epoxy 0/90°	172.4±7.92	240±70.71	14.8±1.68	76.1±2.88
F	Sisal+Glass+Epoxy±45°	64.2±3.03	128±10.95	19.21±1.78	85.3±8.66

The tensile strength of sisal fiber reinforced epoxy composites at ±45° fiber orientation has significant strength reduction in comparison with 0-90° fiber orientation. However, there is not much variation in strength for the hybrid glass-sisal-epoxy composite in comparison with glass epoxy composite (Fig. 3). But the pure sisal-epoxy (±45°) composite strength is very low at 33.4MPa. This result shows glass-sisal-epoxy (±45°) composites performance for multidirectional load condition is very well comparable with the sisal-epoxy (±45°).

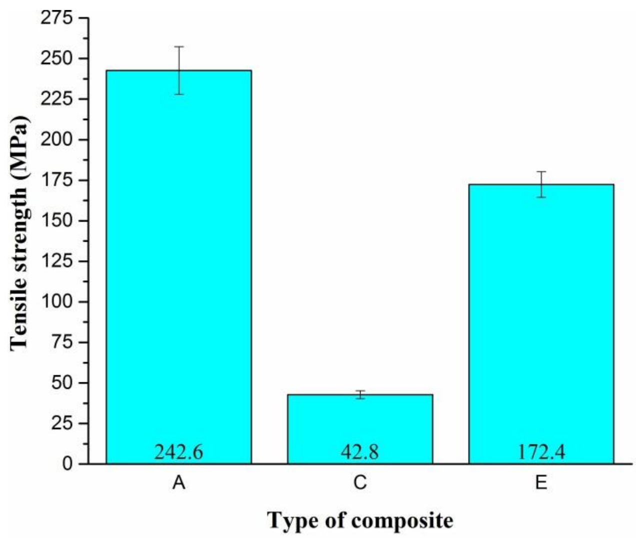

Fig.2 Tensile strength comparison of composite materials at 0/90° fiber orientation

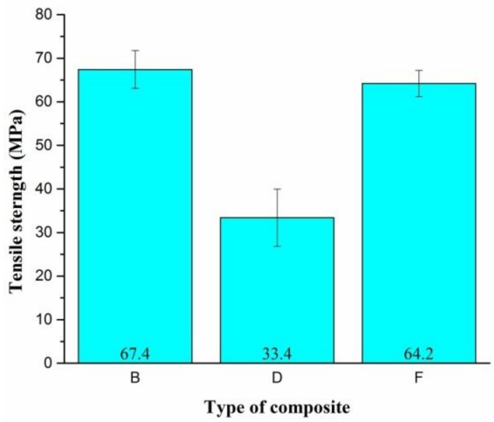

Fig. 3 Tensile strength comparison of composite materials at ±45° fiber orientation

4.2. Flexural Properties

Flexural strength is defined as a materials ability to resist deformation under load. Fig.4& Fig. 5 shows the comparison of flexural strength among the five different type of specimen prepared with different combination of fibers at two different orientations. It can be observed that the sisal fiber in combination with glass fiber actually increases the flexural strength and modulus irrespective of fiber orientation, i.e. on both cases (0/90º) and (±45º). However, the flexural strength of sisal-epoxy is very low with 71.42 % reduction at 0/90° orientation and 50 % reduction at ±45° fiber orientation. The hybrid epoxy composite of sisal-glass fiber offers better stiffness at reduced weight is an added advantage for natural fiber based hybrid epoxy composite. The higher Young's modulus value of glass fiber is superimposed on this hybrid composite for providing better flexural strength.

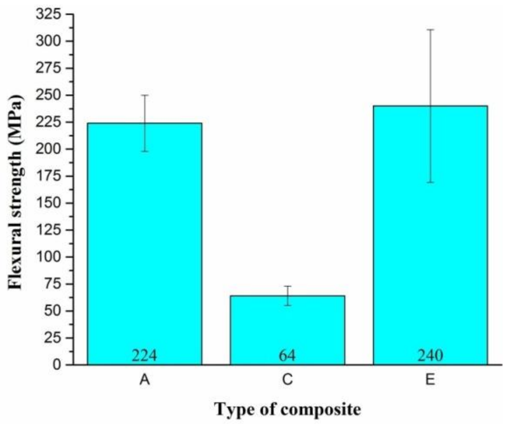

Fig. 4 Flexural strength comparison of composite materials at 0/90° fiber orientation

4.3. Impact Properties

Izod impact testing was conducted on all specimens as per ASTM standard methods to determine the impact resistance of materials. The energy absorbed by the material on impact is found out by the reading obtained from the portable izod impact testing machine. The results of izod impact test are presented in Fig. 6 and Fig. 7. The results indicate that the maximum impact strength is obtained for glass-epoxy composites. However there is no significant reduction in the energy absorption capacity for the hybrid sisal-glass-epoxy composite material in both fiber orientation methods of fabrications. But it can be noted that pure sisal-epoxy fiber has very low energy absorbing capacity with the reduction of more than 70% in comparison with glass-epoxy composite material.

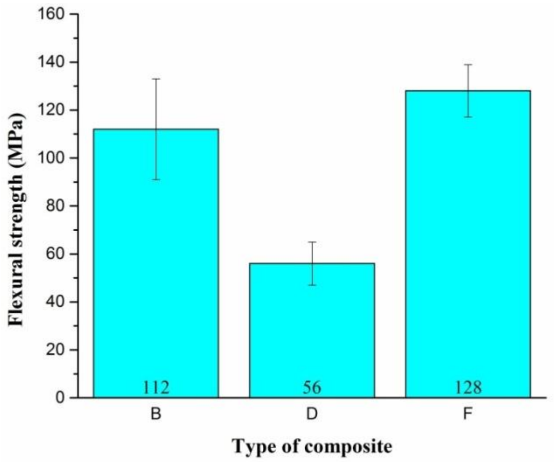

Fig. 5 Flexural strength comparison of composite materials at ±45° fiber orientation

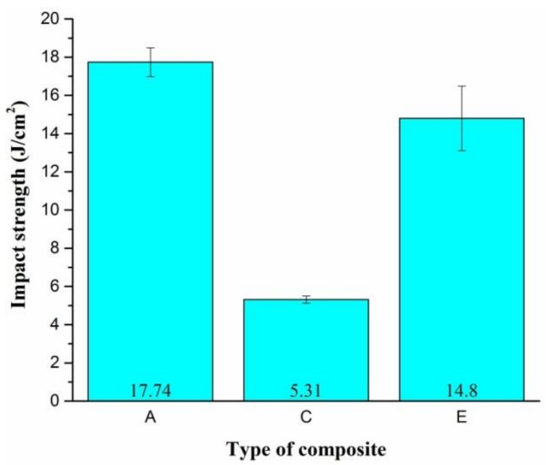

Fig. 6 Impact strength comparison of composite materials at 0/90° fiber orientation

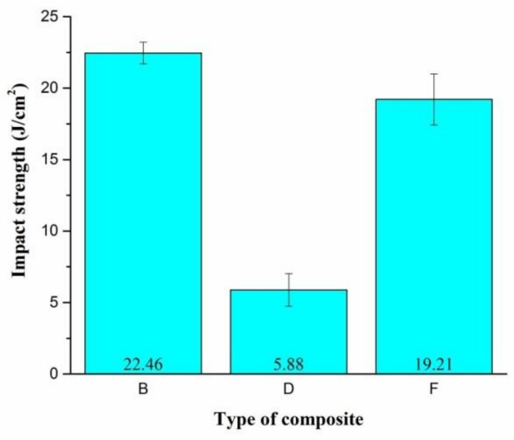

Fig. 7 Impact strength comparison of composite materials at ±45° fiber orientation

4.4. Hardness

Fig.8 & Fig. 9 shows the comparison of hardness among the five different type of specimen prepared with different combination of fibers at two different orientations. Hardness of a particular sample refers to its stiffness or resistance of being broken to have its shape changed permanently when load is applied to it. It is an indication of the composite to resist crack propagation when subjected to a sudden impact. Hardness of a composite depends on the distribution of the filler into the matrix. The results indicate that the maximum hardness is obtained for glass-epoxy composites. However there is no significant reduction in the hybrid sisal-glass-epoxy composite material in both fiber orientation methods of fabrications. But it can be noted that pure sisal-epoxy fiber has low energy absorbing capacity with the reduction of more than 40% in comparison with glass-epoxy composite material.

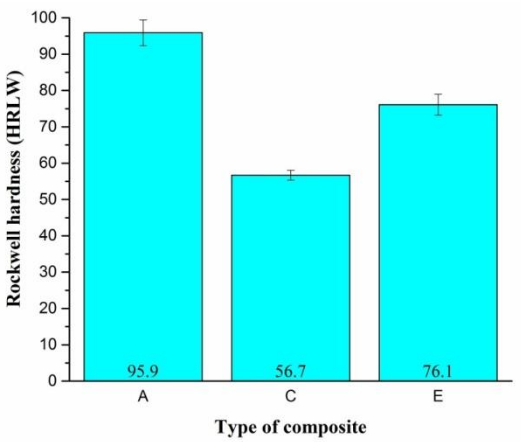

Fig.8 Hardness comparison of composite materials at 0/90° fiber orientation

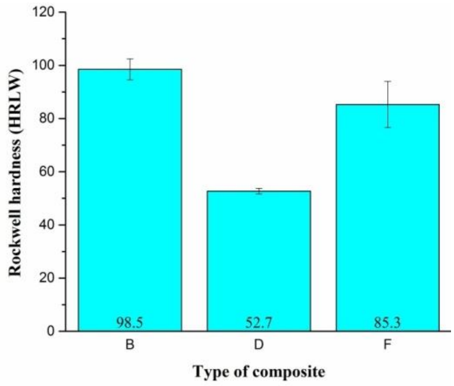

Fig. 9 Hardness comparison of composite materials at ±45° fiber orientation

4.5. Scanning Electron Microscopy (SEM) analysis

The surface morphology of the fiber reinforced polymer composite (FRPC) material is visualized through scanning electron microscopy (SEM). The SEM images are observed for the surface structure, cracks, fiber pullout and interfacial properties of the fractured surface of the composite material. Specimens are prepared by coating with conducting material such as platinum before visualizing the surfaces in SEM. The fractured tensile test specimen surfaces are shown in Fig 10(a) and Fig 10(b). From the fig. 10(b) it is clear that the fiber fracture, voids and fiber pullout are the major reason for reduced tensile strength of natural fiber composite when compared with glass fiber reinforced composite. The interfacial adhesion between matrix and fiber is one of the important factors for the effectiveness of flexible interphase. The good adhesion between reinforcing fiber and epoxy interphase result in high impact strength improvement for sisal-glass fiber reinforced polymer composites (Fig. 10(c) & 10(d)).

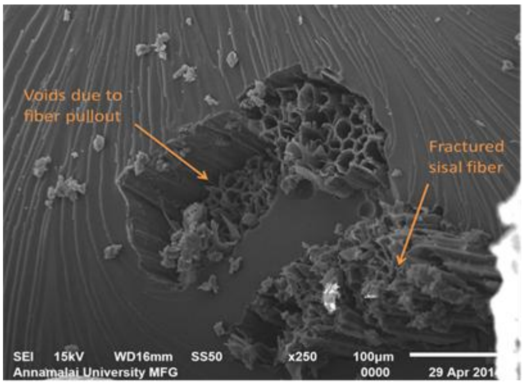

Fig. 10(a) SEM image of the fracture surface of sisal FRPC at 0/90°fiber orientation after tensile test

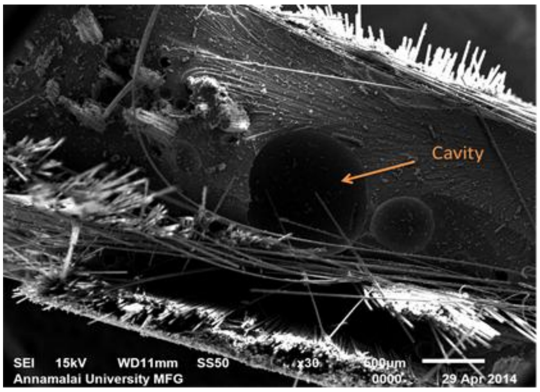

Fig. 10(b) SEM image of the fracture surface of glass+ sisal FRPC at 0/90° fiber orientation after impact test

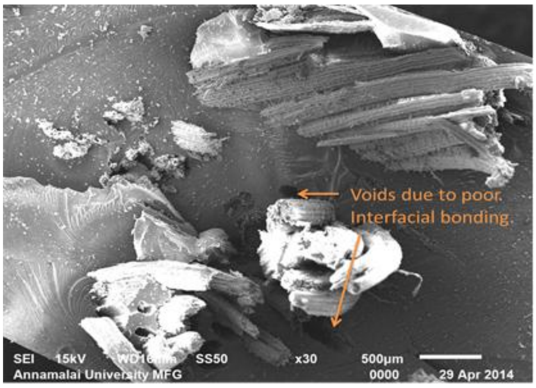

Fig. 10(c) SEM image of the fracture surface of sisal FRPC at ±45º fiber orientation after tensile test

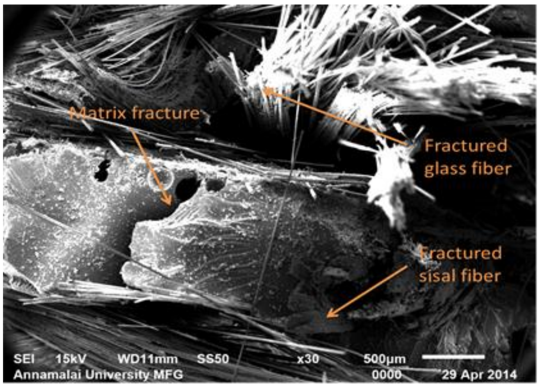

Fig. 10(d) SEM image of the fracture surface of glass + sisal FRPC at ±45º fiber orientation after impact test

5. Conclusion

The fabrication and mechanical characterization of natural fiber reinforced hybrid composites provides new hope for replacing harmful synthetic fiber. The natural fiber sisal composite is tested for its ability and found that it has a very low load carrying capacity in comparison with glass fiber polymer composite. However, it is observed that the 50-50 combination of glass-sisal fiber at both orientations such as 0/90° and ±45°yielded better specific properties. The hybrid sisal-glass-epoxy composite have shown better flexural strength and modules than glass-epoxy at both fiber orientation. Marginal decreases in mechanical properties are due to poor interfacial bonding between matrix and sisal fiber, which is evident from SEM analysis.

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