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Hybridization Effect of Sisal/Glass/Epoxy/Filler Based Woven Fabric Reinforced Composites

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Abstract Development of the Polymer based Composites from both natural and synthetic fibers is a sustainable alternative material for some engineering fields like automotive and aerospace. This work is aimed to incorporate the sisal and E-glass fabrics with the epoxy matrix and by adding silicon carbide filler to the sisal fabrics. Five different composite laminates were prepared by hand layup combined with vacuum bagging method as per laminate sequences. The physical and mechanical properties of composite laminates were evaluated according to ASTM. Results show that incorporation of E-glass and silicon carbide filler can reduce the voids and enhance the physical properties. As the amount of E-glass fibers slightly grows, tensile properties of composites grow. Effect of filler can enhance the flexural properties. Failure of composites mainly occurs due to the poor interfacial bonding between fabrics and matrix, fabrics pull out and fracture occurs in fabrics or matrix when load is applied.

Keywords Sisal fiber · Glass fiber · Vacuum bagging · Mechanical properties · SEM

Introduction

Innovation trends, nowadays, require the development of lightweight, sustainable, high perfomances materials by reducing, at the same time, the cost of the material itself. The growing utilization of biodegradable materials is one of the most significant advances in the field of materials science. In this context, natural fibers are proficient materials, because of their superior properties such as fairly good mechanical properties, low weight, low cost, high specific strength, non-abrasive, eco-friendly, and biodegradable features. The development of hybrid materials is necessary for replying to new industrial demands. For this reason, natural fiber composite materials can be considered engineering materials and manufactured for various applications including building and construction applications like roofing sheets, bricks, door panels, furniture panels, interior paneling, storage tanks, pipelines and automotive applications such as car doors, car interiors, dashboards, headliners, decking, parcel shelves, pallets, spare tyre covers, spare-wheel pan, seat backs, as well as in marine applications like boat hulls and fishing rods. The increasing use of natural fiber composite is also due to the awareness regarding product performances and to the competition in the global market for lightweight components. Their biodegradability is an additional advantage. Today, natural fiber composite materials appear to be the choice for many engineering applications [1–5]. Hybridization of natural fibers with synthetic fibers represents a great opportunity to enhance the properties of natural fiber composites. Glass fiber is the most commonly used natural fiber for hybridizing purposes due to its low cost, great availability and easy manufacturing process [6, 7].

Besides consolidate applications, new fields of utilization of natural fiber composites are currently under study. Ramesh et al. studied mechanical properties such as tensile strength, flexural strength and impact strength of sisal–jute–glass fiber

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reinforced polyester composites. The results indicated that the incorporation of sisal-jute fiber with glass can improve the material properties and lead to consider it as an alternate reinforcement material for glass fiber polymer composites [8]. Chand and Joshi investigated the mechanical properties of three different aging sisal fibers at different temperatures [9]. They observed that tensile strength, tensile modulus and toughness values of sisal fiber decrease by increasing temperature [9]. Ochi et al. discussed the behavior of kenaf/PLA (Poly Lactic Acid) composites with different fiber proportions [10]. Tensile and bending strength as well as Young's modulus increased linearly up to a fiber content of 50% [10]. Prasad et al. carried out the experimentation on tensile and flexural behavior of composites made by reinforcing the polyester resin matrix with natural jowar fibers. The results of this study indicate that using jowar fibers as a reinforcement in a polyester matrix may successfully result in a high performance composite material, in terms of high strength and rigidity suitable for light weight applications [11].

Mei-po et al. investigated on the hybridization of a glass fiber reinforced by using low cost short silk fibers as a medium to enhance its cross-ply strength. It was found that the addition of short silk fiber at 0.4% weight into glass fiber composite allows achieving better tensile and impact strengths [12]. Braga et al. analyzed the mechanical properties of raw jute and glass fiber reinforced epoxy hybrid composites. To improve the mechanical properties, jute fiber was hybridized with glass fiber. The results confirm that addition of jute fiber and glass fiber in epoxy increase the density, the impact energy, the tensile strength and the flexural strength [13]. Velmurugan et al. studied properties of palmyra/glass fiber (randomly mixed) hybrid composites. Two types of specimens were prepared, one by mixing the palmyra and glass fiber and the other by sandwiching palmyra fiber between the glass fiber mats. The mechanical properties of the composites were improved due to the addition of glass fiber along with palmyra fiber in the matrix. The glass fiber skin–palmyra fiber core construction exhibits better mechanical properties than dispersed construction [14]. Sreekala et al. determined the performance of mechanical properties of oil palm fiber with glass fiber and used phenol formaldehyde as resin. The investigation revealed that maximum mechanical performance occurs at 40% weight loading [15].

Jarukumjorn et al. studied the effect of glass fiber hybridization on the properties of sisal fiber–polypropylene composites. Incorporation of glass fiber increases mechanical, thermal and water resistance properties [16]. Mishra et al. experimentally investigated the degree of mechanical reinforcement that could be obtained by introducing glass fiber into pineapple leaf fiber and sisal fiber reinforced polyester hybrid composites. They observed that tensile, flexural and impact properties of pineapple leaf fiber and sisal reinforced polyester composites are positively influenced by hybridization [17]. Latha et al. discussed the effect of stacking sequence of glass/bamboo fiber-reinforced epoxy on tensile and flexural of composites. Results indicated that the introduction of glass fiber in bamboo fiber composites enhances the properties resulting as hybrid composites. Altering layering sequence of bamboo plies significantly affects both tensile and flexural strengths [18]. Panthapulakkal et al. evaluated mechanical properties of hemp/glass fiber–polypropylene (PP) composite materials. In addition, they have observed that the addition of glass fiber into hemp–PP composites resulted in improved composites mechanical properties as also increasing the water resistance [19].

Table 1 Physical properties of sisal and E-glass fabrics

Properties	Sisal fabrics	E-Glass fabrics
Density (gm/cm^3)	1.35	2.54
Woven style	Plain	Plain
Weight (gsm)	160	380
Thickness (mm)	0.48	0.46
Wrap yarns (yarns/m)	810	600
Weft yarns (yarns/m)	810	600

Materials and Methods

Materials

In the present investigation, sisal fabric and glass fabrics were used as reinforcement material. Alkali treated plain woven sisal fabrics were supplied by Sri Lakshmi group exports and imports, Guntur, Andhra Pradesh, India. E-Glass fabrics of plain woven form were supplied by Suntech fiber Ltd., Bangalore, India. Mysore pure chemicals, Mysore, Karnataka, India, supplied silicon carbide whose particle size ranged from 20 to 75 μm was used as filler material. Epoxy resin, identified as Araldite LY556 (Manufacturer: Huntsman) of density 1.2 g/cm^3 with suitable hardener named as K6 (Manufacturer: atul Ltd) of density 0.98 g/cm^3, was used. Chemicote Engineers Bangalore, India supplied it. The physical properties of the sisal and E-glass fabrics are shown in Table 1. The physical properties of the silicon carbide are shown in Table 2.

Table 2 Properties of Silicon carbide filler

Physical Property	Silicon carbide
Density (gm/cm^3)	3.21
Flexural strength (MPa)	550
Elastic Modulus (GPa)	410
Compressive strength (MPa)	3900
Hardness (kg/mm^2)	2800

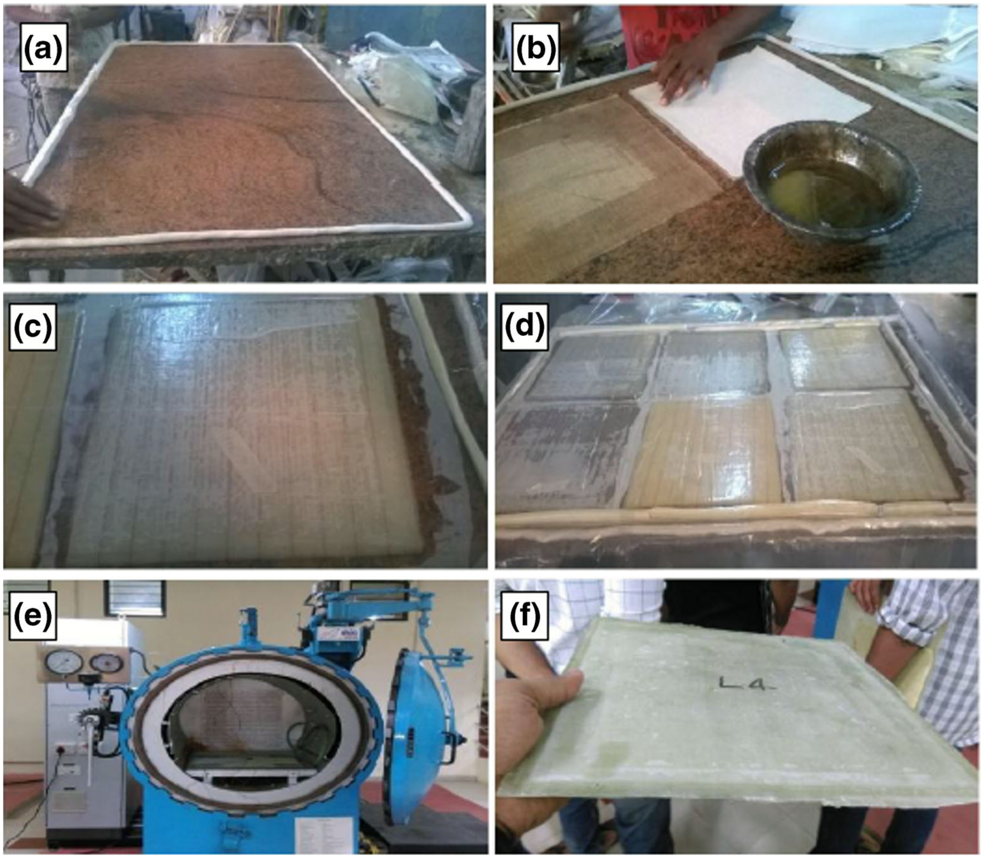

Fig. 1 (**a**) Sealing tape (**b**) Resin layup (**c**) breather and bleeder sheet (**d**) Vacuum bagging film sheet placing (**e**) Laminates placed in the autoclave (**f**) Cured laminate

Composite Fabrication

In this work, composite laminates were fabricated by hand layup followed by vacuum bagging method. Sisal fabrics and E- glass fabrics were cut in size of 300 × 300 mm^2 for the preparation of laminates. A measured amount of epoxy was taken in a different weight fraction of fiber, and then mixed with the hardener in the ratio of 10:1. Silicon carbide filler (2 g) was mixed with the matrix material using tip ultrasonicator to mix it properly. Five types of laminates were prepared namely A1, A2, A3, A4 and A5. For each laminate 6 samples were cut to get statistically significant data. After the hand layup, vacuum bagging method was used to create compaction pressure to consolidate plies or laminates and also to extract the moisture content, solvents and volatiles from composite laminates. After the complete bag mold set up, vacuum connector was used to connect bag and vacuum tubing. In the vacuum gauge, the vacuum pressure can be observed and extra resin and pressure was pumped out with the help of vacuum pump. Successively laminates were placed in the autoclave for several hours to get the curing process. After that, dried composite laminates were taken out from the autoclave. Figure 1 shows step by step procedure of laminate preparation.

Table 3 Laminate sequences and weight fraction of constituents

Laminates	Sequences	w (g)				W (%)			
		w_f			w_m	W_f			W_m
		w_g	w_s	w_{sc}		W_g	W_s	W_{sc}	
A1	G + G + G + G + G	180 ± 5	-	-	300 ± 10	37.5	-	-	62.5
A 2	S + S + S + S + S	-	75 ± 3	-	200 ± 10	-	27.28	-	72.72
A 3	G + S + S + S + G	72 ± 3	45 ± 2	-	250 ± 10	19.62	12.26	-	68.12
A 4	G + S + G + S + G	108 ± 4	30 ± 2	-	275 ± 10	26.15	7.26	-	66.59
A 5	S + S + S + S + S (With Filler)	-	75 ± 3	2	200 ± 10	-	27.07	0.722	72.208

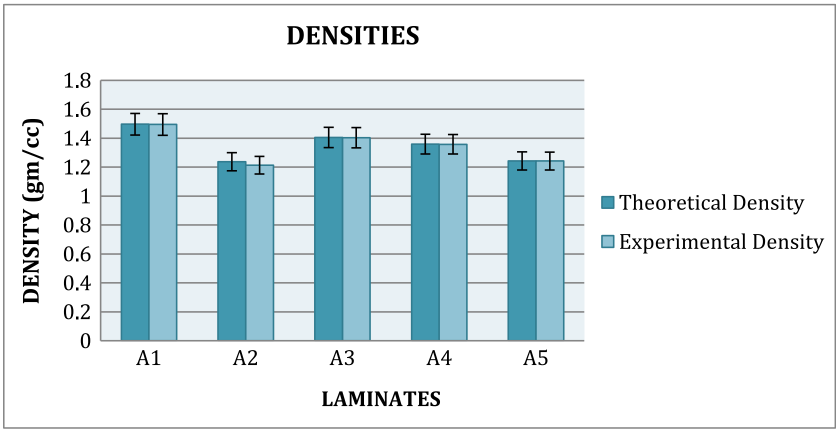

Fig. 2 Theoretical and experimental densities comparison of composite laminates

Laminate Sequence and Weight Fraction

The term weight fraction can be applied to any of the constituents. The presence of voids will also add to the total volume, but not the weight of the composite. After fabrication of laminates, it is necessary to find out the total weight of the laminates, for that quantitative description of constituents was used. Table 3 shows weights of sisal fabrics and glass fabrics for 300 × 300 mm^2 dimensions, epoxy resin and also silicon carbide considered before the processing. After that, the weight of the laminates was also determined. In general, for a composite containing any number of different constituents is:

$$\sum W_i = 1 \tag{1.1}$$

Where W_i is the weight fraction of constituent i.

Where w is the total weight of the laminate, w_g is the weight of E- Glass, w_f is the weight of fiber, w_s is the weight of sisal fabrics, w_{sc} is the weight of silicon carbide, w_m is the weight of matrix. W is the weight fraction, W_g is the weight fraction of glass, W_f is the weight fraction of fiber, W_s is the weight fraction of sisal, W_{sc} is the weight fraction of silicon carbide, W_m is the weight fraction of matrix.

Experimentation

For determination of voids in composites, ASTM D2734–94 [20] method was used. The tensile strength and flexural strength of the composites were evaluated using 100 KN Kalpak computerized Universal testing machine of model KIC-2-1000-C in accordance with the ASTM D638–03 [21] and ASTM D790–07 [22] standards. They were carried out at a crosshead speed of 2.5 mm/min, span length of 70 mm and at room temperature 25 °C. A The Izod impact test was executed on specimens' dimension of 63 × 12.7 × 3 mm^3, in accordance with the ASTM D256 [23] standards. Vickers microhardness tests were carried out using Matsuzawa Make-MMT-X7A hardness testing machine. Microhardness tests were executed by using a square

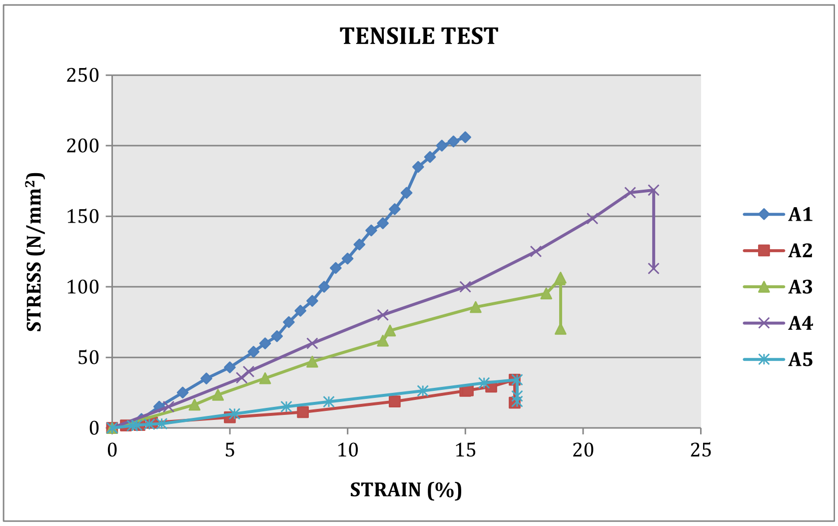

Fig. 3 Tensile stress vs strain curve of the composite laminates

Table 4 Tensile properties of the composite laminates

Laminates	Peak load (N)	UTS (MPa)	Tensile modulus (GPa)
A1	6283.138	346.636	1.2837
A2	955.759	33.119	0.2014
A3	2301.632	108.224	0.5322
A4	3371.206	168.820	0.7216
A5	1024.174	31.853	0.2219

based right pyramid shaped diamond indenter of 1000 HV, with an apical angle of 136°, under a load of 100 gf and dwell time equal to 15 s. The Vickers hardness values were directly recorded by digital tester.

Six identical specimens from each composite laminate were tested to obtain statistically significant results. For each property evaluated one representative specimen was reported in the graphs.

Results and Discussions

Density and Void Fraction

The volume of voids in the composite laminates was obtained from the difference between theoretical and experimental densities. The presence of voids may cause reduction of physical and mechanical properties of the composites. The composite made of filler (A5) shows a smaller amount of voids (0.042%) compared to all the other composites, due to the better compatibility between epoxy resin, filler and sisal fabrics. It can be observed that an increase of E-glass in composites leads to a reduction of voids, in laminates A1, A3 & A4. The pure sisal fabrics composite laminate (A2) presents a higher amount of voids (1.954%). It can be concluded that the incorporation of glass and filler can reduce the voids and enhance the physical properties of composites. Figure 2 shows theoretical and experimental densities comparison of composite laminates.

Microhardness

Results of microhardness tests show for A1 laminate a value of 24.57 HV, for A2 laminate 16.11 HV, for A3 laminate 13.39 HV, for A4 laminate 17.25 HV and for A5 laminate a value of 20.02 HV. It can be observed that laminate A1 shows the highest hardness value, because it is entirely made of glass fabrics. On the other hand, laminate A5 shows good hardness value, probably due to the silicon carbide filler content.

Tensile Properties

The stress vs strain curve of composite laminates is presented in Fig. 3. All the curves behave linearly upto the failure of composites due to fabrics structure of reinforcement in the matrix. The laminate A1 yields more stress if compared with all other composite laminates. The laminates A3 and A4 show slightly higher stress compared with A2 and A5 laminates, because A3 and A4 laminates were prepared with E-glass. The laminates A2 and A5 show similar stress vs. strain trend. The stress-strain behavior of composites is directly dependent on weight fractions of fabrics and laminates voids fraction.

Table 4 presents tensile strength and tensile modulus of composite laminates. The tensile strength and modulus of laminate A1 made of pure E-glass are 347 MPa and 1.25 GPa respectively. These values are greater than the tensile strength and modulus of the other laminates. The tensile strength of pure sisal fabrics laminate (A2) and sisal fabrics laminate with filler (A5) are of 33 MPa

Fig. 4 Flexural load vs displacement curve of the composite laminates

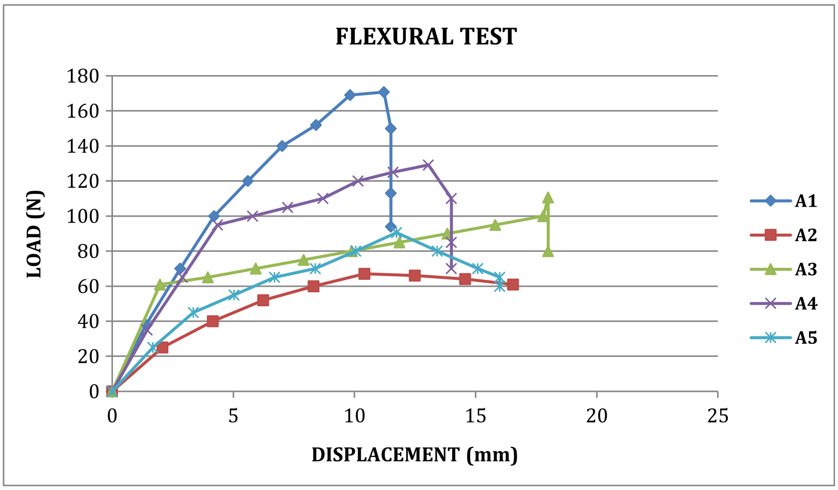

Table 5 Flexural properties of the composite laminates

Laminates	Peak load (N)	Flexural strength (MPa)	Flexural modulus (GPa)
A1	170.812	318.753	20.831
A2	67.012	124.642	7.704
A3	110.647	205.643	12.720
A4	129.149	241.216	14.958
A5	90.536	168.396	10.430

and 32 MPa respectively. Their tensile moduli are 0.20 GPa and 0.22 GPa, respectively. It confirms that the addition of filler into laminates can increase both the tensile strength and tensile modulus. The hybrid laminate A3 shows better tensile strength and modulus than previous laminates, they are of 108 MPa and 0.53 GPa, respectively. The laminate A4 consists of three layers of E-glass so it shows a gradual increase in tensile strength up to 169 MPa. It can be assessed that increasing in glass layers in laminates leads to increase the tensile properties.

Flexural Properties

Figure 4 shows the flexural load vs. displacement curve of the composite laminates. The pure E-glass composite laminate A1 withstands the highest value of flexural load, equal to 170 N. The flexural load of laminate A3 is quite high yielding the value of 110 N. The laminate A4 reaches 129 N that is higher than the values obtained by A2, A3 and A5 laminates. The laminates A2 and A5 report the lowest values of flexural load, even if the effect of filler in the composites can enhance the flexural properties as observed in A5 laminate.

Table 5 presents the flexural strength and modulus of composite laminates. Pure E-glass composite laminate (A1) shows the highest flexural strength and modulus equal to 319 MPa and 21 GPa, respectively. Laminates made with E-glass fabrics have a higher flexural strength than laminates made by only sisal fibers. The hybrid laminate A4 shows very good values of both flexural strength and modulus equal to 241 MPa and 15 GPa. This reveals that the flexural properties are also affected by hybridization of E-glass. A similar trend is also observed in hybrid laminate A3. It, in fact, shows flexural strength and modulus equal to 206 MPa and 13 GPa, respectively. The flexural strength and modulus of pure sisal fabrics with filler laminate (A5) are 168 MPa and 10 GPa, respectively. They are higher than the pure sisal fabrics laminate (A2). These lowest values of flexural properties may be attributed to fabrics/fabrics interaction, voids and dispersion problems.

Impact Strength

It is observed that the impact strength of composite laminate A1 is higher than the other laminates (Fig. 5). In particular, A4 laminate shows better impact strength than A2, A3 and A5 composites. The increase in impact strength, for laminates A1 and A4, is due to the content of glass fabrics and also to fabrics/matrix good bonding. Laminate A2, A3 and A5 exhibit poor impact strength due to the poor interfacial bonding between fabrics and matrix as well as fabrics pull out. A1 laminate, made of glass fabrics, shows impact strength up to 1470.5 J/m. A2 laminate, made by pure sisal fabrics, shows impact strength up to 147.1 J/m. A3 laminate, made both by glass fabrics and pure sisal fabrics, shows impact strength up to 653.5 J/m. A4 laminate, made both by glass fabrics and pure sisal fabrics, shows impact strength up to 976.1 J/m. A5 laminate, made by pure sisal fabrics with 0.722% of silicon carbide filler, shows impact strength up to 112.4 J/m.

Scanning Electron Microscopy Analysis

Figure 6 shows the internal defects of specimen A2. In Fig. 6(a) it can be observed that fiber pull out occurs where fracture takes place and fracture is localized close

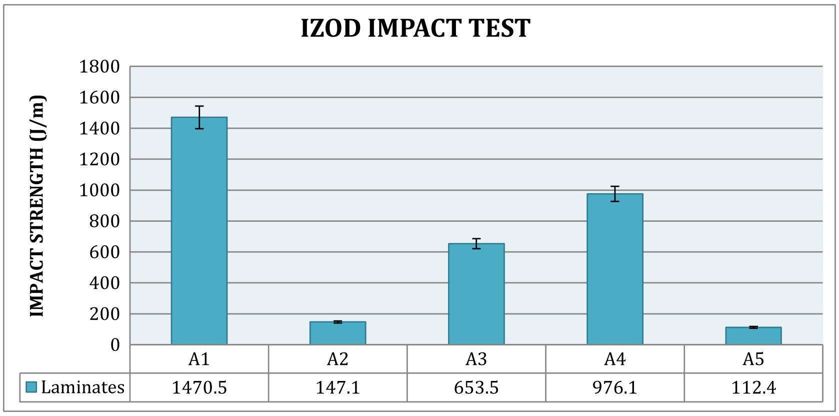

Fig. 5 Comparison graph of impact properties of composite laminates

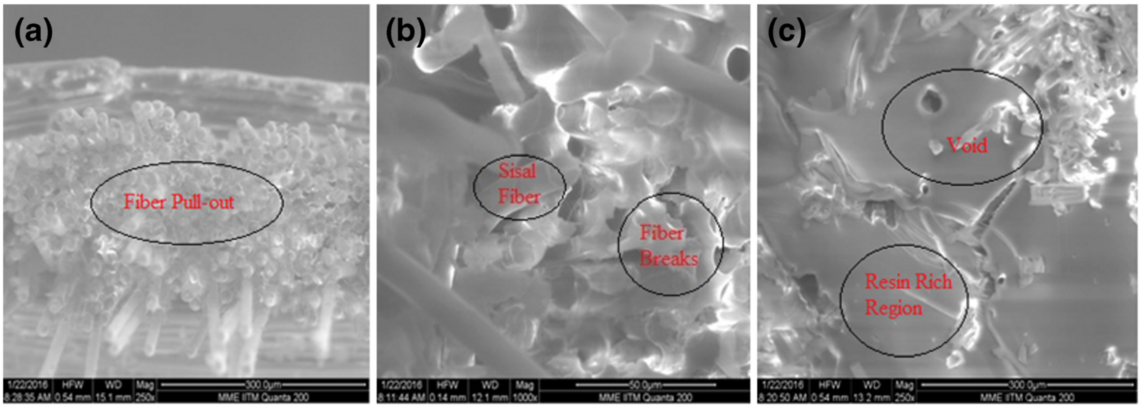

Fig. 6 Scanning electron micrographs of composite specimens after tensile test

to the matrix. The more the bonding between fibers and matrix increases, the more the tensile performance increases as well. Figure 6(b) shows fiber breaks and tearing, which indicates possible better interaction with the matrix. Pull out of micro-fibrils can be attributed to the ductile property of fibers. Figure 6(c) shows fabrics and resin rich areas as well as voids present in laminates. Smoother fracture surfaces are observed in the resin rich areas. Gaps between fabrics and matrix occur due to the fiber diameter and manual alignment of the fabrics. Voids are generated near the cross over areas during the resin infusion process.

Conclusions

An experimental study carried out on sisal/glass/epoxy/filler polymer based composites led to the following conclusions:

- The composite made of sisal fabrics with filler has a less voids than pure sisal fabrics composite. It can be observed that an increase in E-glass in composites leads to reduction of voids in laminates. The pure sisal fabrics composite laminate has the largest amount of voids.c Hence, it can be concluded that the incorporation of E-glass and filler can reduce the voids and enhance the physical properties of composites.
- Increasing glass layers may lead to increase the tensile properties. The better adhesion between reinforcement and the matrix increases properties, decreases fiber pull out and reduces voids present in the composites.
- The effect of filler in the composites can enhance the flexural properties, as observed in A5 laminate.
- The impact strength of composite laminate A1 is higher than the other laminates. A4 laminate shows better impact strength than A2, A3 and A5 composites.
- Internal cracks, fiber pull out, abraded surface and voids were observed by SEM. Pure sisal reinforced composites show worst interfacial bonding between matrix and fibers. However, the hybrid composites show less fiber pull out and voids.

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