Mechanical and thermal properties of cotton-bamboo fabric/glass fiber epoxy composites

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Abstract: Five-layer epoxy composites consisting of two outer layers made of glass fiber and three inner layers of cotton-bamboo fabric were obtained by compression molding. The influence of cotton-bamboo fabric/glass fiber content (35, 40, 45 and 50 wt%) and the order of stacking laminate layers on the mechanical properties (tensile, flexural, compressive, impact strength), thermal properties (TGA) and structure (FTIR, SEM) of the composites was investigated. The best mechanical and thermal properties were obtained with the content of 45 wt% cotton-bamboo fabric/glass fiber.

Keywords: cotton-bamboo fabric, glass fiber, epoxy resin, composites.

Właściwości mechaniczne i termiczne kompozytów epoksydowych wzmocnionych tkaniną bawełniano-bambusową i włóknem szklanym

Streszczenie: Metodą prasowania tłocznego otrzymano pięciowarstwowe kompozyty epoksydowe składające się z dwóch warstw zewnętrznych wykonanych z włókna szklanego oraz trzech wewnętrznych z tkaniny bawełniano-bambusowej. Zbadano wpływ zawartości włókna szklanego (35, 40, 45 i 50% mas) oraz kolejności układania warstw laminatu na właściwości mechaniczne (wytrzymałość na rozciąganie, zginanie i ściskanie oraz udarność), termiczne (TGA) oraz strukturę (FTIR, SEM) kompozytów. Najlepsze właściwości mechaniczne i termiczne uzyskano przy zawartości 45% mas. włókna szklanego.

Słowa kluczowe: tkanina bawełniano-bambusowa, włókno szklane, żywica epoksydowa, kompozyty.

In the field of material science, present generation researchers tend to show interest in natural fiber composites. During the past several decades, fiber reinforced polymer (FRP) composite material was used in several applications due to its advantages like easy manufacturing, light in weight, better strength, low cost, and resistance to corrosion [1—3]. In most of the applications, synthetic fibers like Kevlar, carbon fiber, and glass fiber were used primarily but researchers are trying to work on natural fiber composites due to concern on environment as governmental policies focus on using natural fibers [4]. As a result, in automotive industries, use of natural fibers significantly improved in all the applications day by day [5]. The key advantages of natural fiber reinforced composites are: low cost, environmental friendliness, availability of fibers, better strength-to-weight ratio when compared to synthetic fibers [6]. Lignin, cellulose, hemicelluloses and moisture content were found in the structure of natural fiber. When the fibers are exposed to wet conditions, they are capable to absorb moisture due to their hydrophilic nature [7]. Investigators made efforts to minimize the disadvantages found in hybridizing [8]. Fiber surface treatment on the natural fibers with synthetic fibers was found to improve adhesion on fiber surface and reduce demerits of natural fibers. However, to make fibers, less hydrophilic suitable chemical modification is made on the fiber surface to overcome the drawbacks of hydroponic nature of natural fiber. The lignin, hemicelluloses, and wax content in natural fibers were reduced by alkali treatment [9, 10]. Performance and properties of hybrid glass/natural fiber composites were studied by Cicala *et al*. [11], when used in the applications in manufacturing curved pipes. Natural fibers, when compared to glass fibers are lighter and cheaper but exhibit low mechanical properties. This issue can be solved by using hybrid fibers. Most of the researchers made studies on the natural fibers concerned on single reinforcement composites but composites were made hybrid by adding natural fibers with synthetic fibers which is comparatively cheap and easy to use.

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As a result, thermal properties and water resistance of the composites were observed to be improved after adding glass fiber into hemp/polypropylene composites. Modification and hybridization of glass fiber including fiber matrix were studied by Arbelaiz *et al*. [12] for developing flax fiber polypropylene composite. Basing on glass/flax ratio there was an improvement in tensile strength and modulus of hybrid glass/flax polypropylene composites. Durability of bamboo/glass fiber reinforced polymer matrix hybrid composites was studied by Thwe and Liao [13]. Tensile strength and elastic modulus of bamboo/glass fiber reinforced polypropylene hybrid composites were also studied. It was found that tensile strength and elastic modulus of the fiber got decreased after ageing of the fiber.

Hybrid composite of sisal/cotton fiber of woven mat was characterized by Sathishkumar *et al*. [14] and compared with 10, 20, 30, 40, and 50 wt% reinforced samples. From the results, composite with 40 wt% of sisal/cotton had better mechanical properties and vibration characteristics.

Disposal and recycling of glass fiber have been the very important issues [15, 16]. Use of natural fiber plays vital role in the environmental issues and in variety of applications [17]. Flexural, tensile, and impact strength of the materials got improved by incorporating natural fibers with glass fiber reinforced polymer (GFRP). GFRP placed at the end possessed good mechanical strength [18]. Use of natural fibers as reinforcement in polymer composites reduced the wear, and after processing, was less respiratory irritating and environmental risky [19].

In this work, using compression molding, composites based on epoxy resin were obtained, consisting of five layers, i.e. two outer layers (glass fiber) and three inner layers made of cotton-bamboo fabric. The influence of the glass fiber content and the order of stacking the laminate layers on the mechanical (tensile, flexural, compressive and impact strength), thermal (TGA) and structure (FTIR, SEM) properties of composites was investigated.

EXPERIMENTAL PART

Materials

The specifications of the cotton-bamboo fabric and glass fiber (E-glass) are shown in Table 1. Covai Seenu & Company, Coimbatore, India, supplied epoxy resin (Araldite LY556) with a density of 1.16 g/cm^3 and hardener with a density of 0.95 g/cm^3. The resin and hardener were mixed in 10:1 ratio to prepare the matrix system. Figure 1 shows the macroscopic images of the cotton-bamboo fabric and E-glass fiber.

T a b l e 1. Specifications of the cotton-bamboo fabric and E--glass

Parameter	Cotton-bamboo	E-glass
Density, g/cm^3	1.56	2.54
Weight, g/m^2	168	200
Thickness, mm	0.38	0.21
Warp breaking force, N	592.34	1300
Weft breaking force, N	502.68	1100

Composite laminate fabrication

In this study compression molding method was used to make the composite laminates. The specimens were prepared for 35, 40, 45, and 50 wt% reinforcement, and the percentage of different fibers was modified to fabricate different composites. Table 2 lists the stacking sequences. The mold surfaces were first coated with a releasing agent (wax) and fabric layers were laid one by one on the flat mold for the fabrication of composite materials, and then the epoxy resin was applied on each layer of fabrics and evenly distributed using brushes followed by hand lay-up. The top coat was placed on the laminated layers after the hand lay-up. Then the mold was closed and 1500 psi

a) b)

Fig. 1. Cotton-bamboo (a) and E-glass (b) fabrics

T a b l e 2. Laminate stacking layers

E-glass, wt.%	Stacking layers
35	G + C/B+ C/B+ C/B + G+ C/B+ C/B+ C/B+G
40	G + C/B+ C/B+ C/B+ C/B + G+ C/B+ C/B+ C/B+ C/B +G
45	G + C/B+ C/B+ C/B+ C/B + C/B+ G+ C/B+ C/B+ C/B+ C/B+ C/B +G
50	G + C/B+ C/B+ C/B+ C/B + C/B+ C/B + G+ C/B+ C/B+ C/B+ C/B+ C/B + C/B +G

G – E-glass, C/B – cotton-bamboo

(10.34 MPa) pressure was applied on it. Finally the fabrics have been fully cured with matrix, the temperature of 80°C for 1 hour was applied. After that, the laminates were taken out of the mold and cut into desired specimen dimensions.

Methods

The tensile tests were conducted using an universal testing machine (Kalpak Instruments and Controls model 121101, Pune, Maharashtra, India), with a crosshead speed of 2 mm/min in accordance with ASTM D3039. The ASTM D256 standard was used to conduct the unnotched Izod impact testing. For polymer composites, the highest energy of the hammer employed was 5 J. A Kalpak universal testing machine with a crosshead speed of 2 mm/min was used to measure flexural parameters in accordance with ASTM D790. The compression properties were determined using ASTM D 3410 Kalpak universal testing equipment with a 2 mm/min crosshead speed. Using a hydraulic cutter machine, all the specimens were cut due to ASTM standards.

An FTIR machine, Perkin-Elmer Spectrum 100 FTIR Spectrometer, was used to record the FTIR spectra of polymer composites in the range of 400 to 4000 cm^{-1}. To collect and identify the functional groups in the composite materials potassium bromide was used, and the materials were crushed into tiny pellets.

Thermogravimetric Netzsch STA 409 apparatus was used to test the thermal stability of composites. To avoid undesired oxidation, TGA measurements were performed on a 2–5 mg sample placed in an alumina pan and heated from 24 to 980°C at a rate of 10°C/min in a nitrogen environment with a constant flow rate of 50 ml/min.

SEM was used to analyze the surface morphologies of composites (CARL ZEISS V18 Model). The specimens were broken in liquid nitrogen and coated with gold before being analyzed.

RESULTS AND DISCUSSION

Tensile strength

Tensile properties of composites with various weight percentage of reinforcement (35, 40, 45 and 50 wt%) are presented. In Fig. 2 it is shown that tensile strength gradually increased with increasing of cotton-bamboo and glass fiber content up to 45 wt% at 128 MPa and thereafter decreased due to limited load transmission from the fiber and epoxy resin. Tensile strength of the 45 wt% composite was enhanced by 12% when compared to 35 wt%. It was due to combining cotton-bamboo which enhanced the tensile quality of composite laminate [20]. Furthermore, in glass fiber reinforced composites, the cotton-bamboo fiber improved the strength to a certain limit.

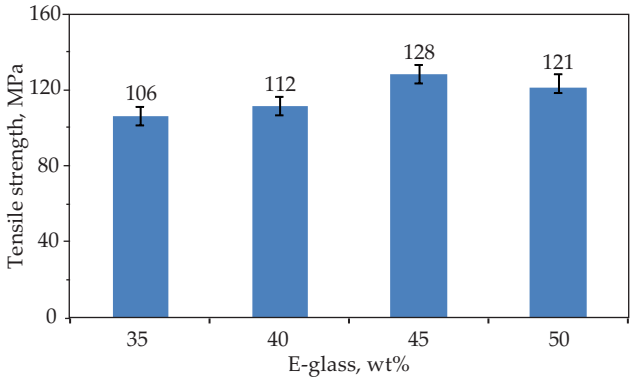

Fig. 2. Tensile strength of cotton-bamboo fabric/glass fiber composites

The integration of E-glass fabrics as top or bottom layers has resulted in a gradual improvement in tensile properties. Hybridization of two natural fibers with glass fibers improved tensile characteristics more than that of single natural fibers. As a result of all those findings, it is obvious that the composite's tensile properties were controlled by the strength of all hybridized fibers [21]. The addition of E-glass improved the tensile characteristics of composite laminates, and combining cotton-bamboo with glass fibers improved the ability to withstand additional tensile load [22]. Due to improved compatibility of fibers with polyester and greater strength, glass fiber was the predominant contributor for tensile strength in many composites. As a result, the outcome has increased by 45 wt%. Owing to the lack of resin, the tensile strength (121.45 MPa at 50 wt%) was reduced after adding the cotton-bamboo fiber.

Flexural strength

Figure 3 shows the flexural strength of composites with various reinforcement weight fractions. Increasing the amount of fiber loading increased the flexural strength of cotton-bamboo and glass fiber reinforced composite laminate.

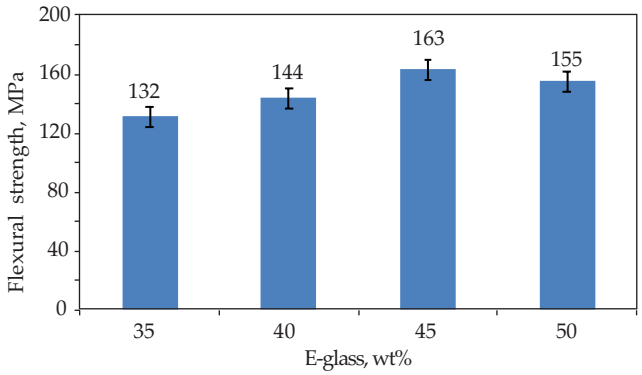

Fig. 3. Flexural strength of cotton-bamboo fabric/glass fiber composites

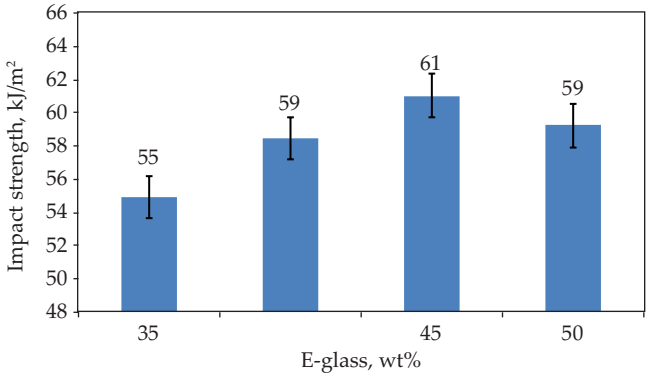

Fig. 4. Impact strength of cotton-bamboo fabric/glass fiber composites

The density of the fiber and fiber dispersion improved the strength quality when the amount of fiber loading was increased [23]. However, when fiber loading exceeded 45 wt% at 163.02 MPa, it began to decrease because the flexural strength of the composite was also impacted by the strength of the fiber. Moreover, due to the different stacking sequences, the flexural strength results varied significantly.

The composite with glass fiber at the ends provided exceptional results than its counterparts, as shown in Fig. 3. Because maximum stress was produced at the outermost layers during flexural testing, adding the glass fiber at the end resulted in the glass fiber sharing the maximum stress. As a result, 45 wt% reinforced composite had relatively better flexural strength than other specimens [2]. When flexural strength was examined at 50 wt%, it was found to be 155.08 MPa, which was 5% decreased when compared to 45 wt%. When glass fiber was added, it reduced rather than strengthened the structure. It was due to natural fibers enhanced affinity for absorbing resin as well as an increase in natural fiber content for a certain weight fraction of resin [24].

Impact strength

Experiments showed that adding a small quantity of cotton-bamboo to the mixture improved bonding, enhanced the area under stress-strain curve, and improved impact strength [6].

The overall brittleness of the material increased with the percentage of cotton-bamboo content, which is more brittle than glass fiber, while impact strength was reduced [25]. However, combining the right quantity of natural fiber with glass fiber could improve the composite's total impact strength. In Fig. 4 the experimental results of impact testing on composites with various reinforcement weight fractions are depicted. The impact strength increased as the fiber loading increased. Fiber pull-out, fiber de-bonding, and fiber fracture caused fiber reinforced composites to fracture during impact testing [6]. During impact failure, fibers pull-out lost more energy than fiber fracture.

The main reason of impact failure in fiber reinforced composites was the fiber pull-out. As the percentage of fiber in a composite increased, more energy was required to cause it to fail, resulting in higher impact strength. Because more energy might be dissipated as the fiber loading increased, impact strength also increased. As such, it took more energy to pull fiber out of a woven mat and using glass fiber mat considerably improved impact strength [26]. For the samples with 45 wt% fiber loading, maximum impact strength value of 61 kJ/m^2 was achieved. As a consequence, it was obvious that combining glass fiber with cotton-bamboo fiber increased impact strength to a maximum and thereafter decreased the outcome [13]. As a result, the impact strength of 59 kJ/m^2 was found to be in case of the 50 wt%.

Compression properties

Buckling occurs when material's fibers open up or become misaligned, causing the link to break. As long as the beam remains straight, compression testing that uses a long column straight beam with a rectangular cross-section applied to a compressive axial load can be analyzed using tension or compression load theories. However, buckling theory must be applied if the deflection suddenly becomes large and leads to catastrophic failure [17]. Figure 5 shows that compression strength of cotton-bamboo and glass fiber composites increased up to 45 wt% was 125.85 MPa, while the strength of composite lami-

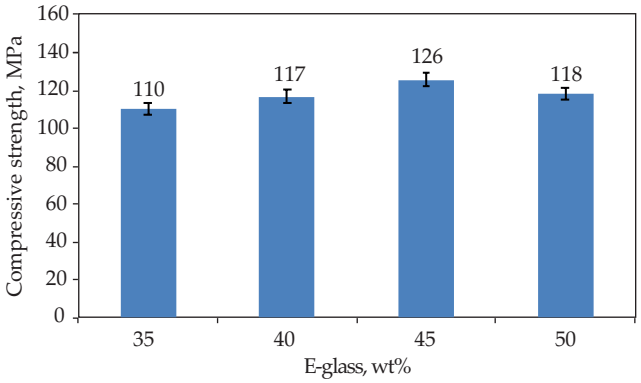

Fig. 5. Compression strength of cotton-bamboo fabric/glass fiber composites

nates diminished as a result of buckling failure. Because of the uniformity of fibers and strong bonding between fiber and matrix, the maximum compressive strength was noticed when cotton-bamboo and glass fiber composites were created [27, 28]. The force was evenly distributed among the fibers in that state, and the compressive strength was at its maximum. The load transfer capacity among the fibers got diminished when the fiber loading was reduced.

FTIR

FTIR analysis was carried out using Elmer Spectrum RXI FTIR spectrometer at the wavenumber range of 400 to 4000 cm^{-1} and the corresponding transmittance percentage is plotted in Fig. 6. Based on FTIR analysis the covalent bonding information was found out. Transmittance proportion without water was found to be maintained at the equal percentage with decreasing the wavenumber up to 3369 cm^{-1} and increasing wavenumber up to 823 cm^{-1}, which was found to be a minimum percentage of transmittance. De-esterification is a process used to eliminate hemicellulose content during NaOH treatment. Absence of absorption band indicated the removal of hemicellulose content [29] and carbonyl stretching caused by acetyl group in hemicelluloses [30, 31].

Carbonyl group at 1604 cm^{-1} represented the group of lignin components [32]. Reduction in the hydrogen bonding removed hydroxyl group from the solution carboxyl and hydroxyl groups with hydrogen bonded on the surface of the natural fibers fatty acids were discovered in the group at the range of 3000 cm^{-1} to 3600 cm^{-1} showing the reduction of hydrogen bonded hydroxyl group on the way of the treatment of natural fiber with NaOH [29]. Broad peak band at 3360 cm^{-1} indicated hydroxyl functional groups. Those hydroxyl groups could be formed from hemicellulose and lignin. Range from 1000 cm^{-1} to 1500 cm^{-1} increased hydroxyl concentration can be observed. The hydroxyl concentration was said to be from the breakdown of hemicelluloses [29]. Diminishing intensity at the range of 1250 cm^{-1} referred to the dissolution of hemicelluloses. Functional groups of alkenes (cellulose and lignin) and carboxylic ones were denoted to O-H stretching and C-H stretching at the range of 2900 cm^{-1}. In case of treated cotton-bamboo fibers, the vibration peak became weaker due to removal of part of cellulose and lignin. Band peak of 2934 cm^{-1} attributed to C-H vibration of cellulose and hemicellulose was observed [33]. Hydrogen bonds between hydroxyl groups and natural fiber components like hemicelluloses, cellulose, and lignin were dissolved using alkaline solution. De-fibrillation indicated the process of dissolving fiber bundles into smaller fibers. It also removed hemicelluloses, waxy layers, and adhesive pectins that tended to bind fiber bundles together as core's pectin and hemicelluloses rich sheets [29].

TGA

Figure 7 shows the percentage of mass *versus* temperature curves indicating that increase in bamboo fiber content increased mass loss as a function of temperature. 35 wt% of cotton-bamboo/glass fiber reinforced composite exhibited the better TGA result. Composite lost only 1.56% until the temperature reached up to 100°C and at 200°C 7.96% weight loss was corresponding to the removal of solvent in polymer matrix. Weight loss was approximately 70.38% between 200°C to 500°C due to degradation and volatilization of cotton-bamboo/glass fiber present in epoxy composite. The linear mass loss up to 950°C of 23.5% original mass was maintained.

Figure 7 shows the TGA result of 45 wt% cotton-bamboo/glass fiber reinforced with epoxy composites as well. At the initial weight, the composite lost only 1.36% until the temperature reached up to 100°C while at 200°C the weight loss was already 6.19% corresponding to the removal of the solvent in polymer matrix. In composite, the weight loss was approximately 67.93% between

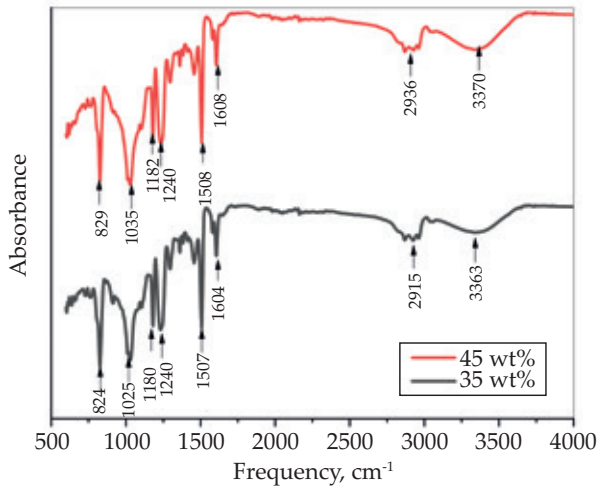

Fig. 6. FTIR of cotton-bamboo fabric/glass fiber composites

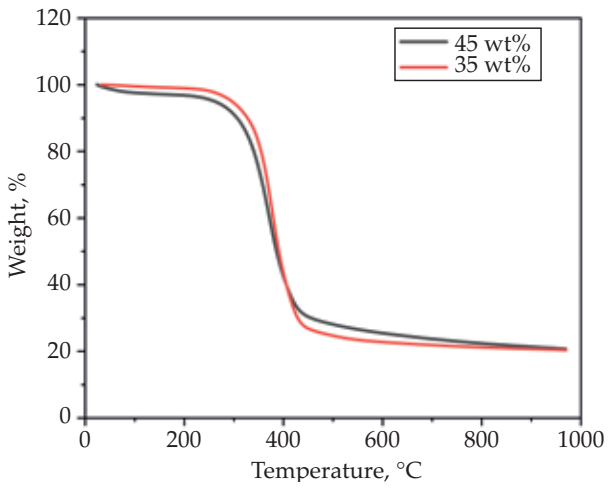

Fig. 7. TGA curves of cotton-bamboo fabric/glass fiber composites

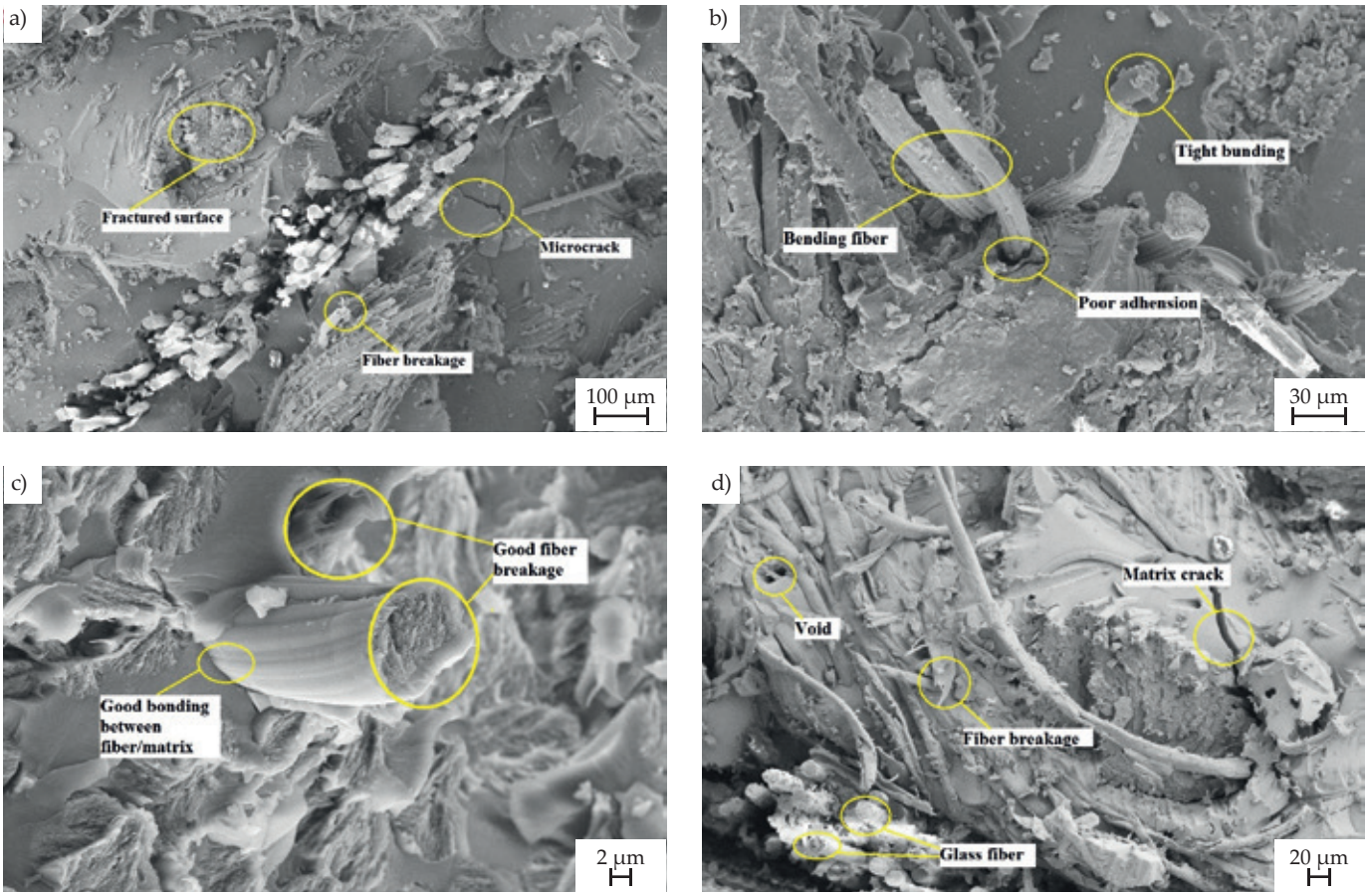

Fig. 8. SEM images of cotton-bamboo fabric and glass fiber composites: a) 35 wt %, b) 40 wt%, c) 45 wt%, d) 50 wt%

200°C to 500°C because of degradation and volatilization of epoxy cotton-bamboo/glass fibers and the mass loss up to 950°C was linear, the final residue was 24.58% of original mass [34].

SEM

The SEM examination was performed to investigate the failure surfaces of composite structures, namely the fiber/matrix interface of the samples. The samples for SEM were cut using diamond cutter. Before examination, the scanned region was uniformly coated with a layer of gold. The sputtering of material was carried out to make the material conductive.

Figure 8 shows SEM micrographs of fabric-reinforced composite laminates made of cotton, bamboo, and E-glass that were subjected to an impact test. Figure 8a shows crack formation at the macro level. The crack was found to be caused by an improper adhesion between the fiber and the matrix, as well as inefficient load transmission between the fabric layers. Figure 8a also shows the fracture surface and fiber breaking in the composite specimen. Figure 8b shows bending of fibers and tight binding. The sample was subjected to impact loading but due to tight binding, caused by better interfacial region, the composite's ability to absorb energy during fracture propagation improved and resulted in the composite's impact strength. Furthermore, all tested hybrid composite laminates with glass skin layers did not generally fracture into two halves [35]. Glass fibers in the outer layers helped building a stronger bridging rupture and reduced stress distribution in the natural cotton-bamboo fibers. Figure 8c shows the good adherence between fiber and matrix. The load was transferred to stiff fibers *via* shear stress at the interface. The fracture behavior was influenced by the interfacial strength. This technique was requiring strong fiber-matrix adhesion [36]. Figure 8d shows that widely separated fibers in yarns could limit fiber pull-out by surrounding interlinked fiber yarns. That owed the low interfacial bonding of cotton-bamboo natural fibers compared to the higher surface adhesion of glass fiber with epoxy resin. It is clear from these experiments that 45 wt% composite strong interfacial adhesion is responsible for improved impact properties.

CONCLUSIONS

In the current study cotton-bamboo/glass fabric reinforced epoxy composite laminates were obtained by compression molding with various laminate stacking sequences. When compared to other composite laminates, the cotton-bamboo/glass fiber composite has improved mechanical characteristics at 45 wt% fiber loading. Tensile, impact, compression, and flexural characteris-

tics of cotton-bamboo with glass fiber composites obviously increased up to 45 wt% and then began to decrease as fiber loading increased above 45 wt%. The mechanical properties of composite laminates were impacted by the stacking sequence and fabric adhesion levels, as well as the sequencing of high strength fiber layers in the composite laminates. When compared to other composite laminates, the composite laminate with glass with cotton-bamboo fiber layer as skin, outer, and core layers had better mechanical qualities (45 wt%). Tensile, flexural, compression, and impact strength increased by 17%, 32%, 12%, and 10%, respectively, when compared to 30 wt% cotton-bamboo/glass fiber composite laminates. The thermal stability of the cotton-bamboo composite with glass fiber reinforcement improved significantly. The deterioration temperature of the composite with 45 wt% fiber content started at 319°C and terminated at 514°C. When comparing the cotton-bamboo with glass composite to another composite combination, the thermal degradation range increased to 35 wt% fiber content. The SEM pictures of the composite samples revealed improved surface adhesion and enhanced fiber-matrix interaction.

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