Original Article

Study on mechanical characteristics of woven cotton/bamboo hybrid reinforced composite laminates

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A B S T R A C T
In this study, two fabrics namely cotton/cotton woven fabric having cotton yarn in both warp and weft direction; and cotton/bamboo woven fabric with cotton yarn (warp direction) and bamboo yarn (weft direction) were selected. Compression moulding method has been used to fabricate cotton/cotton and cotton/bamboo woven fabric reinforced composites with epoxy resin as a matrix material. The mechanical properties of cotton/cotton and cotton/bamboo reinforced composites had been compared under five different fiber loading conditions (30, 35, 40, 45 and 50 wt.%) and the fractured morphology was analyzed using scanning electron microscope. It was noted that cotton/bamboo reinforced composite with 45 wt.% fiber loading exhibited the best mechanical properties namely tensile, flexural, impact, compression, and inter laminar shear stress (ILSS), due to its weft direction of bamboo yarn.

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1. Introduction

Polymer composite material (PMC) is broadly used in various industrial applications as a result of its advanced properties and has occupied every functional area namely household items, construction, automotive industries and aerospace [1–3]. Glass, kevlar and carbon fiber reinforced composites do have advanced mechanical properties but are non-biodegradable, non-renewable, non-ecofriendly and can cause human health issues. The natural fiber reinforced composites were developed because of its ability to reduce or replace manmade synthetic fibers in many engineering applications. Due to the ecofriendly nature, renewability, non-abrasiveness, low cost, correction resistance, light weight and easy process ability [4–6], it attracts the attention of many researchers all over the world. Natural fiber laminates are of three common type's namely random oriented, continuous and woven mat [7]. Many researchers analyzed the effect of fiber length, fiber loading and some other properties of a discontinuous or random oriented fiber reinforced com-
posites with different fiber loadings, i.e., 25, 30, 35, 40 wt.%, and reported that the composite laminates exhibit the best mechanical properties when the composite reinforcement is fabricated with fibre loading of 35 wt.% and fiber length of 30 mm [8,9].

The chopped or random oriented fabrics exhibited lower mechanical properties owing to discontinuous and randomly oriented in nature [10]. Continuous fiber reinforced laminates were developed so as to improve interfacial bonding strength between the constituents of the composites. The unidirectional structure is the simplest form of continuous fiber matrix. Experimental research works related to these composites were reported in various literatures [11,12]. The complex form of continuous fiber reinforcement is woven fabric [13,14] which provides good integrity and stability in both warp and weft directions such that it has more balanced properties. The mechanical properties of plain woven fabric reinforced laminates depends upon many factors like reinforcement material in both warp and weft direction, weave type, amount of fiber loading and type of matrix material [15]. The response of the textile material depends mainly on the material properties like chemical structure of the raw material, physical properties and constructional parameters (warp and weft density of yarn, and weave type). The fiber properties and the type of spinning controlled the yarn properties, while the fabric properties are also influenced by the warp and weft density of the woven fabric and weave. Similarly, the mechanical properties are also influenced by the weaving conditions. While fabricating the fabric, all the above mentioned parameters were considered effectively to achieve high quality and high strength of fabric.

Cotton/cotton and corresponding hybrid reinforced composite laminate were selected in this study. Bamboo is woven in weft direction along with cotton in warp direction inside cotton/bamboo fabric in order to minimize the cost because of higher yarn density. This study deals with the investigation effect of different wt.% on the mechanical properties namely flexural, tensile, impact and compressive strength on both cotton/cotton and cotton/bamboo reinforced laminates.

2. Materials and methods

2.1. Fabrication of composites

LY556 (Bisphenol A) epoxy and HY951 (Triethylenetetramine) hardener with a mixing ratio of 10:1 were used as a matrix material. It is a two component system with low viscosity for curing at room temperature, which was supplied by Covai Seenu & Company, Coimbatore District, India. The composite was fabricated using compression moulding process and in this process, a steel mould of dimensions 270 mm × 270 mm × 3 mm was used to fabricate composites. The release agent was applied for easy removal of the laminate and reinforcement fiber layers were kept inside the mould. The required amount of matrix resin was applied by using simple hand layup method. The curing of moulding process was performed at a pressure of 10.35 bar and the mould was heated at a temperature of 80 °C for a period 1 h and left for cooling at room temperature. In this study, different weight proportions (30:70, 35:65, 40:60, 45:55, 50:50) of cotton/cotton and cotton/bamboo composites have been considered. However, the formation of specimens were found same for all the experimental research.

2.2. Tensile test

The tensile properties of cotton/cotton and cotton/bamboo composites were tested according to ASTM D3039 standard [16] using KALPAK computer control universal testing machine (UTM) with a cross head movement rate of 2 mm.min⁻¹ to test the specimens of composites. The test was conducted using five specimens.

2.3. Flexural test

Computer controlled KALPAK universal testing machine tested all the flexural properties of test specimens using ASTM D 790-03 standard [17] with a cross head movement rate of 2 mm.min⁻¹. Further, strain gauge was used in measuring the deflection of the specimen with computer interface and also the flexural strength was evaluated. Similar to the tensile testing, each testing had five identical specimens and the average value was calculated.

2.4. Impact test

The Izod impact testing machine has been used to test the impact properties of all specimens in accordance with ASTM D256-05 standard [18]. The impact strength was directly measured from the machine. Similar to tensile and flexural tests, five test samples were in use during testing and finally the average value was obtained.

2.5. Short beam shear test

ILSS estimated the interfacial adhesion strength of the composite and it was determined by using short beam shear testing machine according to ASTM D2344-16 standard [19] with the cross head speed of 1 mm.min⁻¹. A set of five specimens were subjected to short beam shear test and the mean value was considered. ILSS was calculated using the following relation.

\[ \text{Interlaminarshearstrength}(\text{ILSS}) = \frac{(0.75 \times P)}{(b \times t)} \]

P = peak load in N, b = specimen width in mm and t = specimen thickness in mm.

2.6. Compression test

The test was performed in accordance with ASTM D 695-02 standard [20] using KALPAK universal testing machine with 2 mm.min⁻¹ movement rate of cross head. The gauge readings were noted for five specimens to evaluate the mean value. The specimens were cut in the shape of rectangular strips with a circular saw placed in the testing machine and compressed until it gets fractured. The compression force has been recorded as a function of displacement and also the compressive strength of the specimen was evaluated.
2.7. SEM analysis

The micro-structural failures of the tensile, impact and flexural fracture like fiber matrix debonding, fiber pullout and some other interfacial properties such as voids, cracks and fiber break of cotton/cotton and cotton/bamboo composites had been analyzed using VEGA BTE SCAN (SEM). The surface images were captured at an accelerating voltage range of 10–20 kV. Furthermore, the crack propagation of fracture and toughness of the specimen were also determined. The test specimens were cut and mounted on aluminium stubs with double sided adhesive tape and sputter coated with thin layer of gold to make the sample conductive.

3. Results and discussions

The development of textile material mainly depends upon the physical and mechanical properties of yarn and fabric. The warp, weft linear density of the woven fabric and types of weave pattern depend on fiber and spinning yarn properties. The effect of weaving conditions relies on weft up force, weaving speed, warp insertion rate, way of shed opening, tension in warp and weft and number of threads used in reed [21–23]. Table 1 shows the test result of fabric and it is observed that both cotton/cotton and cotton/bamboo fabrics have variation of strength in warp and weft direction. The warp and weft strength of cotton/cotton fabric has a difference of 24 % and cotton/bamboo fabric experiences variation of 15 %.

The type of wave is the major factor that influences warp strength. Addition of bamboo along weft direction enhances the strength of fabrics along weft direction [24]. This study used lyocell or bamboo yarn along weft direction with cotton yarn as a yarn material and concluded that addition of lyocell or bamboo improves the mechanical properties of the fabrics. As expected, the high tensile force in plane wean occurred because of maximum number of interlocking points. Hence, more friction was experienced between yarns and also observed greater tensile strength in warp direction. When calculating the linear density of yarn in both the direction, it can be seen from the result that warp direction cotton yarn has high breaking strength and weft direction cotton yarn records low breaking strength. The result is that the tensile strength of the fabric is less because both yarns have similar linear density. For cotton/bamboo fabric, the linear density is higher for bamboo yarn. It is noted from Fig. 1 that the cotton/bamboo

![Fig. 1 – Tensile test of cotton/bamboo fabric (a) before breakage (b) after tensile fracture.](image)

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fabric has broken from the middle of the fabric. The cotton yarn has low elongation compared to bamboo yarn. So, there is a less friction between warp and weft yarns [25].

3.1. Tensile strength of cotton/cotton and cotton/bamboo fabric

The tensile strength of plain woven fabric reinforced composites mainly relies on various factors namely fiber orientation, length of fiber, strength, fiber content, fillers, bonding between fiber and matrix and weave style [26,27]. From Fig. 2, it is noted that strength of cotton/cotton composite material remains 48.92 MPa at 30 wt.% fiber loading and lower mechanical strength is owing to the weak bonding of fiber and matrix [28].

Tensile strength of cotton/cotton composite records increase with further increase in wt.% of fiber loading and reaches a maximum of 76.92 MPa at 45 wt.% of fiber loading such that the strength does not get increase after increasing the fiber content beyond the critical fiber loading content [29]. After critical point, the matrix material is insufficient for effective bonding between fiber and matrix [8]. SEM image shows micro-crack initiation because of poor adhesion level of fiber. The cotton/bamboo composite follows the same trend like cotton/cotton composite but it experiences increase in tensile strength of 85 MPa at 45 wt.% of fiber loading as shown in Fig. 2. Since the bamboo fiber has higher load carrying capacity than cotton fiber, the result of difference in tensile strength shows cotton/bamboo composite has enhanced property.

SEM micrograph is used to analyze the fracture surface of cotton/cotton and cotton/bamboo tensile tested specimen. A bonding between fiber/matrix has vital role in identifying properties of composite laminates and high strength is achieved by maximum usage of fiber and adequate stress transfer between fiber and matrix. SEM image of tensile fracture surface of cotton/cotton and cotton/bamboo is shown in Figs. 3 and 4. The cotton/cotton composite fiber experiences matrix debonding, crack initiation, voids and fiber pull out as noted in Fig. 3. Cotton/bamboo composite has less fiber pull-out, torn fiber and good bonding between fiber and matrix as in Fig. 4. Cotton/bamboo fabric shows denser and tightly packed weave than cotton/cotton fabric. The tensile properties of bamboo yarn are higher compared to cotton yarn as indicated in Table 1. The property of composite mainly depends upon the structure of the fiber [26]. In the woven fabric, warp and weft yarn create an interlocking structure but more stress created in the matrix crimped fibers tend to lose strength under tensile loading. In this effect, a crack is initiated in the matrix. So the tensile strength of cotton/cotton is reduced when compared to cotton/bamboo composites.

3.2. Flexural strength of cotton/cotton and cotton/bamboo fabric

The three-point flexural test analyses the bending nature of the composite. The bending strength of composite laminate is mainly due to sequence of compression and shear strength. Fig. 5 gives the flexural strength of cotton/cotton and cotton/bamboo plane woven fabric hybrid composites. The flexural strength of cotton/cotton fiber reinforced laminate gets increased as a result of increasing amount of fiber loading. When increasing the amount of fiber loading, the density of the fiber and fiber distribution enhances with elevated strength properties [15]. But, beyond 45 wt.% at 82.08 MPa, the fiber loading result decreases because of insufficient effect in bonding between fiber and matrix [41]. The cotton/bamboo composite follows the same trend like cotton/cotton as mentioned in Fig. 5. As such, flexural strength has enhanced with increase in fiber loading upto a critical point of 45 wt.%. But, it starts to decrease when there is increase in fiber loading since the flexural strength of the composite is also influenced by the strength of the fiber [26]. The bamboo/cotton exhibited higher flexural strength at 107.02 MPa. The SEM image of cotton/bamboo structure shows good bonding between fiber and matrix as fiber structure is important in the properties of composite laminates [30].

In plain weaving pattern, the effect of cotton yarn (warp direction) and bamboo yarn (weft direction) constitutes an interlocking structure. The result indicates that yarns in warp and weft direction are noted with higher bending load capacity (Fig. 7). The flexural properties of cotton/bamboo composite are mainly because of arranging high strength fiber in proper direction [31,32]. The SEM image of cotton/cotton and cotton/bamboo composite fracture bending surface is shown in Figs. 6 and 7. It is noted from Fig. 6 that fiber pullout, voids and fiber dislocation are identified due to improper ratio between fiber and matrix. Thus, it led to less flexural properties between cotton/cotton composite [33]. The cotton/bamboo composite has good bonding between fiber and matrix as shown in Fig. 7 and this is due to proper ratio between fiber and matrix which results in high flexural strength [34].

3.3. Impact strength of cotton/cotton and cotton/bamboo fabric

The capability of material to resist fracture under the sudden applied load at same velocity (or) speed is called impact strength. The impact properties of laminated composites are
based on the factors like fracture toughness, fiber pull out on friction force, inter laminar and interfacial strength between fiber and matrix [35,43]. Fig. 8 shows that impact strength of the cotton/cotton woven fabric laminates which is gradually increasing the fiber loading up to 45 wt.% and further the value decreases. In the same way, cotton/bamboo composite laminate strength increases up to 45 wt.% as 32.3 KJ/m². In the same woven pattern, the impact strength of laminates with different types of fiber influences parameter interface between fiber, matrix and dimension of composite laminates [36].

The strength and structure of individual fiber plays a key role in the strength of laminates and bamboo yarn has high strength compared to cotton yarn. Hence, it is observed that impact strength is owing to properties of the individual fiber used during hybridization in the polymer matrix system rather than using other parameter. The surface voids, crack fiber pull out and poor bonding that exist between fiber and matrix are
the main causes of low impact strength of composite material. The SEM fracture surface of impact specimen is shown in Figs. 9 and 10. Fig. 9 indicates that cotton/cotton composite has fiber pullout, broken fiber, dislocation and peel off as the failure mechanism in the case of impact loading [37,44]. The weak bonding between fiber and matrix occurred due to fiber pullout and voids in the composite laminates. In Fig. 10, bending of fiber denotes impact load and cotton/bamboo composite had no fiber pullout, thus resulting in good bonding between fiber and matrix and increased impact strength of the composite. The presents of enriched resin around the fiber restricts the sliding motion of fiber by shearing action at the interface [15].

### 3.4 Short beam shear strength of cotton/cotton and cotton/bamboo fabric

ILSS is the essential property of the material which is used in large number of engineering applications. The short beam
shear test was used to determine the ILSS of cotton/cotton and cotton/bamboo composite with various fiber loading conditions. Fig. 11 shows that cotton/cotton composite strength enhance with increase in the fiber loading up to 45 wt.% and maximum value occurs as 15.85 MPa. Addition of more fiber decreases the strength values. Because of maximum shear stress applied in the natural plane, the yarns have more stress as there exist tightly woven fabric. As a result of tight weaving, strength reduction may occur because of the formation of micro buckling, matrix crack and void located at the inter laminar legion of composite [38]. Inter laminar shear strength has enhanced with increase in fiber content up to 45 wt.% as 17.91 MPa. The result shows reduction in strength of woven fabric composite. The cotton/bamboo composite could exhibit better properties compared to cotton/cotton composite. ILSS mainly depends on essential properties of matrix and interfacial bonding between fiber and matrix [39]. Tensile loading of un-notched laminate can generate free edge delamination before fracture and reduction. ILSS also increased the strength of the laminate in tensile direction [40].

3.5. Compression strength of cotton/cotton and cotton/bamboo fabric

Fig. 12 shows the compressive strength values for cotton/cotton and cotton/bamboo composites. Cotton/cotton composite has slight increase in strength upto 45 wt.% as 72.93 MPa and further the strength of composite laminates decreases as a result of buckling failure. The same trend follows in the cotton/bamboo composites too. In this observation, the maximum compressive strength occurs when cotton/bamboo composite has 90.85 MPa at 45 wt.% and this is due to homogeneity of fibers and good bonding between fiber and matrix [41,42]. In this state, the stress is equally distributed among the fibers and at this conditions, the maximum compressive strength is achieved [45]. At reduced fiber loading condition, less fiber content causes decrease in load transfer capacity among the fibers.

4. Conclusions

In this present study, cotton/cotton and cotton/bamboo composite laminates were fabricated successfully with increase in fabric loading content (wt.%). The effect of mechanical properties on different fiber loading was investigated. The following conclusions are arrived: Cotton/cotton fabric has 24 % difference in tensile strength along warp and weft direction but cotton/bamboo fabric has much lower difference of about 15 % only. Effect of weaving pattern and selection of yarn in proper direct ion enhances the mechanical properties of composite material. Cotton/bamboo composite exhibits enhanced mechanical properties at 45 wt.% fiber loading when compared with cotton/cotton composite. Tensile strength of cotton/cotton and cotton/bamboo composites generally increases upto 45 wt.%, it starts decreasing with increase in higher fiber loading beyond 45 wt.%. Compared to cotton/cotton composite laminates, 14.58 % increase in tensile strength was observed for cotton/bamboo composites. Flexural strength of cotton/cotton and cotton/bamboo composite laminates dramatically increasing upto 45 wt.% and then decreases with increases in fiber loading. Flexural strength of cotton/bamboo increased by 23.3 % compared with cotton/cotton composite.

Inter laminar shear stress of cotton/cotton and cotton/bamboo composites enhances with increases in fiber loading upto the critical point of 45 wt.% and then decreases gradually. The impact strength, inter laminar shear stress of cotton/bamboo composites are 17 % and 11.5 % higher when compared to cotton/cotton composite. Compression strength of cotton/cotton and cotton/bamboo composite laminate has slightly increasing value upto 45 wt.%, further the strength of composite decreases. The cotton/bamboo composite has 19.72 % improved in compression strength compared to cotton/cotton composite. SEM micrographs show that there are fiber pullouts, broken fiber, fiber dislocation, peel off, matrix crack void etc. in the prepared composite. Based on the analysis, cotton/bamboo composite at 45 wt.% fiber loading exhibits better fiber matrix addition when compared to cotton/cotton composites.
Conflict of interest

The author(s) declare(s) no conflict of interest for publishing this manuscript.

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