Influence of alkali treatment on the mechanical and morphological properties of cotton/bamboo fibers

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Abstract

The current study focuses on the creation of epoxy composites with cotton/bamboo woven fabric reinforcement. The effect of alkali treatment with varying (1, 2, and 3 wt. %) of NaOH on mechanical characteristics such as tensile, impact, flexural, compression, and interlaminar shear stress is explored and compared to those of the untreated cotton/bamboo fabric. The composites were made using a compression moulding process with four different fibre loadings (30, 35, 40, 45, and 50 wt. %). The mechanical characteristics of the composites were studied and their structure was evaluated by using a scanning electron microscope (SEM). The cotton/bamboo/epoxy composite with 2wt. % NaOH at 45 wt. % fibre loading was found to have superior mechanical properties when compared to the others.

Introduction

Composite materials are the material which is made up of at least two elements with various properties, one of which acts as a reinforcement and the other acts as a matrix element. The reinforcement material should be selected in such a way that it will provide the required properties for the composites produced [1]. The matrix element must play the role of a binder, which ensures that it does not allow the reinforcement to move away from its original position. In the past, several researchers have used synthetic fibres like aramid fiber, carbon fiber, and glass fiber. These fibres pose a great risk to the environment, which has made researchers turn to natural fibre composites. Epoxy is one of the preferred polymer matrixes due to its characteristics like better tolerance to damage, higher mechanical properties, high thermal insulation and resistance to corrosion [2].

Natural fibres are those that are easily biodegradable in nature, and their availability is greater. These natural fibres can be extracted from different parts of plants, like stems, leaves, or bark. The end properties of natural fibre depend upon the place where they are grown and the chemical content of them. They include cellulose, hemicellulose, moisture, ash, and wax. Natural fibres, on the other hand, have poor adhesion to the polymer matrix, weaker mechanical characteristics, and lower moisture resistance than synthetic fibres, all of which affect the composites' behavior. Many research studies were conducted on plant fibres like flax, hemp, jute and many more. The properties of the natural fibres extracted can be increased by chemically treating the fibers. Wettability of the fibres must be increased such that there is proper bonding between the fibres and the matrix. According to the literature, surface treatment of fibres significantly increases the bonding between the fibre and the matrix, resulting in an increase of several properties. Alkali treatment is a typical chemical approach for improving fibre and matrix interface adhesion. This could help improve composite characteristics by allowing for better stress transfer between the fibre and the matrix. When the fibre is chemically treated, it can remove impurities, non cellulose content, amorphous content, and enhance the porous volume, which increases the bonding [3].

Rajeshkumar et al. [4] alkali treated Phoenix sp fibre that was reinforced in epoxy composites. The alkali content was varied at 5, 10, 15, and 20 wt.%. The output characteristics studied were mechanical and morphological characteristics. They concluded that the composites fabricated with 15 wt. % alkali treated

composites can be used for automotive-based applications and for light weight applications. Vilay et al. [5] treated bagasse fibre with alkali before reinforcing it in unsaturated polyester composites. They concluded that the alkali-treated composites showed an increase in flexural characteristics when compared with untreated fibers. In addition to that, it was found that water absorption characteristics decreased when the chemical treatment of fibres was carried out. Sharifah H.Aziz and Martin P[6] Ansell used long and random hemp fibres treated with 0.06 M NaOH, which were combined with polyester resin to form a polymer composite. Morphological studies revealed that treated kenaf and hemp fibres had fewer impurities when compared to untreated fibers. Hemp, jute, and kapok fibres were treated with various concentrations by Mwaikambo and Ansell [7] and found that when the sisal fibres were treated with 6 wt. %, there was a higher degree of crystallinity. Geethamma et al. [8] used NaOH (5 wt. %) treatment to remove the impurities in oil palm fibres and coir fibres in short form. Atiqah et al. [9] concluded that there was an increase in flexural, tensile, and impact tests when kenaf fibres were treated with 6 wt. % NaOH for a time period of 3 hours by the process of mercerization.

When natural fibres are selected in the form of chopped or random forms, they exhibit lower mechanical properties. The laminates that have continuous fibres as reinforcement revealed better interfacial bonding between them. Woven fabric is a type of continuous form where the reinforcement can be called woven fabric, which results in enhanced properties in the directions of warp and weft. The properties of plain fabric reinforced composites are determined by factors such as weft and warp direction, weave type, and matrix material [10]. In the case of textile fibers, the end properties depend upon the chemical structure of the selected material and the weave type of the material. The properties of the fibre are controlled by spinning, while the density of warp and weft controls the properties of the fabric [11].

In the present era, cotton fibres are becoming a promising fibre when compared to other reinforcements. Cotton fibres can be a suitable replacement for wood based fibers [12]. Cotton fibres are preferred because they have great interfacial bonding between the fibre and the matrix. It can also act as a substitute for glass based fibres where the application of load is minimal. Bamboo fibres offer excellent qualities among natural fibres, which are used for making polymer composites. It can be chemically modified, which can be used for a variety of applications. It can be used in the form of strips or fibers [13].

From the widespread literature it was concluded that there are no works related to the treatment of cotton/bamboo hybrid treatments. In the present study cotton/bamboo (CB) hybrid composites were considered. Initially it was chemically treated with NaOH solution and it was reinforced in epoxy matrix. The manufactured composites were evaluated for mechanical (tensile, flexural, impact, compression & interlaminar shear strength) and thermal (thermos gravimetric analysis). The effect of alkali treatment is studied in detail in the present paper.

Experimental

Material selected, chemical treatment, manufacturing and testing of composites are discussed in the following section.

2.1 Materials

The simple woven cotton/bamboo fabric was made on a power loom in Eswari Text at Kanuvakarai, Coimbatore, Tamilnadu, India, with cotton threads in the warp and bamboo yarns in the weft direction. It has an average thickness of 0.37 mm and an average areal density of 168 gsm. Kovai Seenu and Company, Coimbatore, Tamilnadu, India, supplied the epoxy LY556 and hardener HY951 in a 10:1 weight ratio.

2.2 Alkaline treatment of CB fibers

During the surface modification process, alkaline treatment is the most widely used chemical treatment on natural fibers. In the process, the fabrics are soaked in NaOH of 1%, 2%, and 3% wt. at room temperature for 30 min. Then the fabric was washed in tap water. It was washed thoroughly so as to remove excess NaOH stuck to the fabric. Finally, the fabrics are cleaned with distilled water and allowed to dry in direct sunlight for a period of two days. Further alkaline treatment was performed for the distinct modification and disruption of hydrogen bonding in the network structure by increasing the roughness of the surface. As a result, the outer surface of the fibre cell wall with lignin, wax, and oil was removed after depolymerizing cellulose and short length crystallites. This resulted in better bonding due to more roughness in the fibre surface and an increased number of possible reaction sites because of the rise in the amount of cellulose on the surface of the fibre [14].

2.3 Fabrication of composite laminates.

The combined hand lay-up technique and compression moulding method were used to make woven cotton/bamboo fabric and epoxy laminates. To make it easier to remove the laminate once it had cured, a wax release agent was put on the mold's surfaces. Layers of resin-impregnated cotton/bamboo fabric measuring 270 mm X 270 mm X 3 mm were placed one over the other on the mold's surface until the necessary thickness was achieved. A roller was employed to ensure that the resin system was evenly distributed across the layer surface. Each laminate was cured at 80°C for 30 minutes under a pressure of 110 bar in a hydraulic compression moulding press. The laminate was then taken from the mould and allowed to dry for at least 24 hours at room temperature before being used. The moulding machine setup, treated and untreated fabricated composite laminates using the compression moulding machine, is shown in Fig. 1 (a-c).

2.4 Sample Preparation

All of the samples were produced in accordance with ASTM guidelines. A water jet cut was used to carefully cut the samples from the laminates, leaving an adequate allowance for finishing. The samples were finished with moderate quality abrasive paper to get the final dimensions. The specimen shape and test standards are described in detail in Table 1.

Table 1
Testing Standards and Sample dimension

Name of the Test	ASTM Standard	crosshead speed (mm/min)	Width (mm)	Thickness (mm)	Length (mm)
Tensile	D3039	2	25	3	250
Flexural	D790	2	13	3	127
Impact	D256	-	13	3	66
Compression	D3410	2	25	3	150
Interlaminar Shear Strength	D2344	1	6	3	18

2.5 Composite Laminate Testing

Except for the impact test, all of the tests were performed on the computer controlled Universal Testing Machine (UTM) KIC-2-10000, SR.No. 121101, which has a capacity of 100 KN. The force was measured using a load cell, and the result was recorded using data collection software. The impact test was carried out using a pendulum impact testing machine.

The plain woven CB fabric composite laminates' mechanical properties were assessed using ASTM standards. The tensile test was carried out according to the D3039 testing standard, using the universal testing machine (UTM) crosshead speed set to 2 mm/min. The five samples were tested for the entire test, and the average value was used for analysis. Flexural testing was performed on the UTM in accordance with ASTM D790. The flexural strength was measured using the three-point bending method. An impact test was performed in an Izod impact tester according to ASTM D256. The compression test was carried out utilising a UTM with a cross head movement rate of 2 mm/min in line with ASTM D 3410. The composite's interfacial adhesion strength was calculated using a short beam shear (SBS) testing machine that followed the ASTM D2344 and had a cross head speed of 1 mm/min. Finally, SEM photographs of the broken surface of the tensile and impact test specimens were used to investigate the surface morphology.

Results And Discussions

The composites were manufactured by the process of compression moulding and the tests were carried out according to ASTM standards. The test results of all the results are reported in Table 2.

Table 2
Mechanical properties of epoxy composites with NaOH treated CB woven fabric

Sample Code	Average Tensile strength, (MPa)	Average Flexural strength, (MPa)	Average Compressive strength, (MPa)	Average impact Strength (kJ/m²)	Average ILS Strength (MPa)
CB30 UT	55.62	62.78	63.81	26.51	9.02
CB35 UT	64.17	75.55	73.04	29.92	11.39
CB40 UT	73.74	87.85	81.89	33.48	13.42
CB45 UT	85.37	103.02	90.85	37.05	15.91
CB50 UT	78.45	99.08	83.38	34.95	14.94
CB30 SH1	61.37	67.94	67.73	29.01	10.05
CB35 SH1	71.08	82.1	78.58	32.31	12.24
CB40 SH1	80.65	95.66	88.49	35.95	14.36
CB45 SH1	91.19	110.91	96.43	39.05	17.27
CB50 SH1	85.21	106.27	90.22	36.72	16.59
CB30 SH2	73.02	79.35	74.54	32.96	11.67
CB35 SH2	82.03	93.8	86.35	36.3	14.01
CB40 SH2	90.66	110.95	96.77	39.5	16.96
CB45 SH2	100.94	125.96	107.54	42.86	20.13
CB50 SH2	96.56	120.72	98.54	40.73	18.81
CB30 SH3	67.59	74.5	70.22	30.98	10.96

Sample Code	Average Tensile strength, (MPa)	Average Flexural strength, (MPa)	Average Compressive strength, (MPa)	Average impact Strength (kJ/m ²)	Average ILS Strength (MPa)
CB35 SH3	75.77	88.36	82.05	34.21	13.03
CB40 SH3	85.35	102.36	91.75	37.49	15.6
CB45 SH3	96.15	118.88	101.85	40.82	18.65
CB50 SH3	92.02	113.95	93.81	38.86	17.72

3.1 Tensile properties

Table 2 and Fig. 2 indicate the effects of fibre loading and alkali pretreatment on the tensile characteristics of CB /epoxy composites. The tensile strength of composites improves with increasing fibre content up to 45 wt. % for both untreated and alkali-treated fabric, and after that, the strength begins to decrease as the fibre content increases. This occurrence might be related to the fabric's ability to effectively carry stress to the matrix, particularly up to 45 wt. %. 2020. When the fabric percentage surpasses 45 wt. %, the polymer matrix content is insufficient to dissolve into the CB/epoxy composite, resulting in reduced tensile characteristics. This finding was supported by Obi Reddy et al. [15], Maheswari et al. [16], and Arthanarieswaran et al. [17]. The tensile strength of plain woven fabric (untreated and pre-treated reinforced epoxy) composite was consistently measured and the results are shown in Table 1. It shows that 2 wt. % NaOH is the optimum percentage observed from various studies [18]. The maximum tensile strength was observed from CB45SH2 when compared to 1 and 3 wt. % NaOH treated fabric and untreated fabric composite

Figure 2 shows that the tensile strength of the untreated composite CB45UT at 85.37MPa is measured at 45wt. % and that the CB45SH2 alkali treated composite has a maximum tensile strength of 100.94MPa. When there is increased alkali solution, the tensile strength is positively improved at the optimum level, but the result is decreased due to the high alkali concentration solution damaging the fabric.

The tensile strength of composite materials with different NaOH concentrations (1, 2 and 3 wt. %) treated fibres is shown in Fig. 2. The tensile strength of composites improved as the NaOH concentration increased up to 2 wt. %, but as the treatment was at 3 wt. %, the strength values decreased. When compared to the CB45UT composite, the maximum increase in tensile strength was seen for 2 wt. % NaOH treated CB45SH2 composites, which was roughly 15.4 wt. %. The increased interfacial bonding caused by the alkali treatment is the primary explanation for the improved strength of the 2 wt. % CB/Epoxy composite when compared to the untreated CB/Epoxy composite. The surface roughness of the CB fabric improved as a result of alkali treatment, resulting in enhanced mechanical interaction with

the epoxy matrix. During the alkali treatment, the main wall of the CB fabric, which is the crystalline area of the parent cellulose, dissolves. The surface roughness of CB fabric is enhanced due to the destruction of lignin and hemicelluloses linked to the yarns. As a result, the surface topography of untreated CB fabric transforms into an uneven surface with tiny undulations when it is exposed to NaOH. The contact area increases as the surface roughness increases, ensuring improved mechanical interaction with the polymer matrix [19].

Poor wettability and interfacial bonding are the reasons for the poor strength of the CB/Epoxy composite treated with NaOH. The presence of hydroxide and polar groups in CB textile fabric might cause moisture content and poor matrix/fabric interactions. Micro-cracks can occur at the matrix/fabric interface as a result of inadequate interfacial bonding, resulting in a low tensile strength value. The poor strength of CB/Epoxy composites treated with 3 wt. % NaOH is due to fibre surface degradation produced by the greater alkali concentration. This resulted in poor interfacial bonding and reduced fibre characteristics, which decreased the tensile properties. These composite tensile strengths, however, are still much greater than the untreated CB/Epoxy composite.

3.2 Flexural properties

Figures 3 illustrate the flexural characteristics of untreated and NaOH-treated CB/epoxy composites as a function of fibre loading. The flexural properties increase with increasing fibre content up to 45 wt. %, then reduce for both untreated and treated fibres, as shown in the figures. The results obtained in the flexural tests also followed the trend of tensile strength. The reduction in flexural characteristics as fibre content increases might be attributed to fibre gathering, which affects composite discontinuities and worsens fabric/polymer matrix adhesion. This finding is in accordance with Maheswari et al. [16]. CB45UT and CB45SH2 exhibited maximum flexural strengths of 103.02 MPa and 125.96 MPa, respectively. The 2 wt. % alkali treated woven fabric has a higher flexural strength of CB45SH2 at 125.96 MPa when compared to 1 wt. % and 3 wt. % NaOH treated. The obtained results were in accordance with the results suggested by Satishkumar et al. [20].

The CBSH composites are significantly better than the CBUT composites in terms of flexural strength. Flexural strength increased as the amount of NaOH treatment was increased from 1% to 2 wt. %. The higher weight percentage of NaOH treatment resulted in a decrease in trend. Overall, the 2 wt. % NaOH treated CB/Epoxy composite had the maximum flexural strength. The improvement was up to 15% greater than on CB45UT and CB45SH2, a composite that was treated with 2 wt. % NaOH.

It is generally known that CB fabric has a higher modulus material, and surface modification improves the interfacial adhesion between the polymer matrix and the fabric. When the stress required to produce the same deformation as an untreated CB/Epoxy composite is increased by up to 2%, the stress required is considerably greater. As a result, the flexural properties of all composites treated with 1–2 wt. % NaOH were greater than those of the untreated CB/Epoxy composite.

The decrease in flexural strength of the CB/Epoxy composite materials treated with 3 wt. % NaOH is attributable to fibre surface degradation caused by the high alkali content. If it is processed using a high-concentration NaOH solution, the removal of an excess amount of lignin and hemicellulose can take place, which can damage the final cell wall. A similar trend was observed in the literature [21].

3.3 Impact properties

Figure 4 presents the impact strength of composites as a function of fibre content and surface modification of CB/epoxy. The impact strength of untreated and treated fibre reinforced epoxy composites rises as the fibre content increases, up to 45 wt. %, but when the fibre content grows beyond this, the strength begins to drop. The description for this might be that fibres can only absorb energy up to a certain degree of fibre concentration[11]. The maximum impact strengths of CB45UT and CB45SH2 were 37.05 kJ/m² and 42.86 kJ/m², respectively. The alkali treated composite has a 15.88% improvement over the untreated composite. Rajendran and Mysamy et al. [22] found a similar pattern of results.

Figure 4 further shows that, due to surface modifications by NaOH pretreatment, the impact energy of all treated composite samples was higher than that of the untreated composites. This is due to a stronger interfacial contact between the fibres and the matrix, which has increased the composite's capacity to absorb more energy while simultaneously preventing fracture propagation [23].

The energy absorbing capacity of the specimen decreases when there is more than 45 wt.% of fibre content at the various energy levels. Due to the lower percentage of resin, both delamination and interlayer failure influence the total absorbed energy capacity of the CB/Epoxy fibre content, which is found to change the failure mechanism of composite laminates [24]. But the impact energy level depends on the amount of fiber, the type of failure mechanism, and the mechanical properties of both the fibre and the matrix.

3.4 Compression properties

The compressive strength of the pre-treated plain woven fabric composite is shown in Fig. 5. It is observed from the result that compressive strength increases with an increase in the fibre content up to 45 wt. % and after that, the compressive strength reduces at the critical point, where the stress transfer between fibre and matrix is greater. So at the critical point, the maximum compressive strength has been achieved. The result proves that a 2 wt. % NaOH (CB45SH2) treated composite has an optimum percentage greater than a 1% or 3 wt. % treated composite laminated which also matches with the results suggested by Venkata Reddy et al. [25].

The interfacial interaction between the epoxy resin and the fabric was critical in determining the composite material's compression characteristics. Figure 5 and Table 1.1 show the compressive strengths of all the composites. Chemical treatment decreased the hydrophilic character of the cellulose fibre and increased the fibre matrix interfacial adhesion, resulting in better compressive properties [26].

The maximum compressive strength is achieved from the result at CB45SH2 of 107.54MPa. When compared to an untreated composite, 16% of the compressive strength is increased. During NaOH treatment, the fibre diameter is reduced, and so the aspect ratio (fiber length/diameter) is increased. Therefore, the surface area is increased and the bonding is improved. Since the alkaline solution is more than the optimum level, excess delignification of fibre takes place, and this causes the fibre damage [27].

3.5 ILS Strength properties

The SBS test is used to determine the ILS strength of untreated and alkali-treated plain woven cotton/bamboo fabric reinforced composites under various fibre loading conditions the results are tabulated in Table 2 and the same is shown in Fig. 6.

Figure 6 shows that 2 wt. % NaOH treated was observed as the optimum percentage. The alkali treated plain woven fabric composite has recorded better ILS strength and it increased from 17.91MPa for CB45 UT to 21.13MPa for CB45 SH2, i.e., it has a 15% increase. It is observed that for morphological modification, NaOH treatment plays a vital role in removing hemicelluloses and lignin .

The improved ILS strength value of woven fabric epoxy composite after the alkali process is also attributed to the fact that alkali treatment produces better adhesive characteristics for the woven fabric surface by removing impurities and protecting the outer surface of the fibre which is similar to the results reported by Noorunnisa Khanam et.al. [28]. This offers a rough surface topography in accordance with the fiber. So the alkali treatment increases the ILS strength because of mechanical interlocking. The interfacial shear strength between fibre and polymer matrix improves as there is surface morphological modification. The wettability of the NaOH treated fibres is better and it generally is the outcome of higher bonding through the mechanical interlocking with resin and rough surface fiber. After NaOH treatment, it also leads to fibre bundle fibrillation, i.e., breakage of the composite fibre bundle into small fibers, which increases the positive surface area available because of contact with resin. Similar kind of reports were also reported by Mansour Rokbi et al. [29].

3.6 THERMOGRAVIMETRIC ANALYSIS OF COMPOSITE

The imperative thermogram for the untreated and different concentrations of NaOH treated (1%, 2%, and 3 wt. %) CB composite is shown in Fig. 7. The thermal properties like degradation and stability of the CB reinforced epoxy composite are analysed using the thermogravimetric method. The range of the temperature is maintained at 30–800°C. The chamber heat for the volatile outlet was taken as a 3.5% weight loss. The progress of weight loss in different heating conditions was used.

After evaporation from the sample, the weight loss is expected to be approximately 3.5%. The hydrogen chains in the reinforcement dissolve the heat energy into different chains [30]. The second deterioration and therefore weight loss in the CB fabric reinforcement occurred due to heat debasement of polyose and glycosylamine linkage from the fibers. The starting and final debasement heat for the sodium hydroxide specimen are better than the untreated CB fabric specimen, and further, during the (NaOH) treatment, the

impurities are removed from the fiber, so treated composites have better preliminary degradation temperature when compared to untreated ones [31]. Through the thermal debasement process, the poor interfacial bonding of lignin degrades rapidly, and the thick aromatic ring adhesion degrades at high temperatures. Therefore, the minor lignin content fibre degradation occurred at high temperatures [32]. Table 3 presents the initial and final degradation temperature values.

Table 3
Thermal degradation parameters of CB fabric composite

Sl. No.	Sample Name	Degradation Temperature (°C)	
		T _i	T _f
1	UT Cotton/Bamboo	245.43	426.43
2	1% NaOH Cotton/Bamboo	249.03	430.28
3	2% NaOH Cotton/Bamboo	253.08	452.86
4	3% NaOH Cotton/Bamboo	247.29	447.19

The third phase of weight reduction was due to the cellulose deterioration from the fibre. The maximum weight reduction was noted at the final degradation temperature region. The alkali treated CB composite maximum degradation temperature was higher when compared to the untreated one. The 2 wt. % NaOH treated samples have better thermal properties than the other samples. For the 2 wt. % NaOH treated sample, preliminary degradation started at 253.08°C and the final degradation was noted at 452.86°C. The untreated composite had the lower degradation temperature, with an initial temperature of 245.43°C and a final temperature of 426.43°C. The residue of the different combinations of CB composite is 10.75%, 12.32%, 9.68%, and 10.36%. Among the four different combinations of the composite specimen, the 2 wt. % NaOH treated CB reinforced epoxy composite observed better thermal properties because of interfacial bonding with fibre and resin.

3.7 SEM ANALYSIS

The SEM analysis of the composites produced are explained in the following sections.

3.7.1 Untreated CB Fabric/Epoxy Composite

Figure 8–10 illustrates a SEM image of the composite's untreated cotton/bamboo fractured surface following impact and tensile tests. When compared to all the weaving structure composite laminates, this CB45UT weight percentage has the highest strength. In comparison to CB30UT fabric composite laminates, CB45UT fabric composite laminates have the highest load carrying capacity. When it comes to detecting characteristics in composite materials, fabric-resin bonding is critical. The most fabric is used, and there is good strength stress transmission between the fibre and the resin, so the greatest strength is achieved. The fabric's surface is what determines the composite qualities.

Interlocking structures exist between the warp and weft yarns in plain woven fabrics. However, crimped fibres have a tendency to have reduced strength when subjected to tensile loading due to the increased stress on the matrix. A crack between the matrixes occurs as a result of this effort.

As a result, the CB30UT composite has a lower tensile strength than the CB45UT composite. Weft yarn has better strength than warp yarn because each warp yarn crosses with weft yarn in the woven fabric composite. Yarns in the warp direction have a lower cover factor because of their presence. The yarn in the weft direction has smaller numbers than the yarn in the warp direction. Similar kinds of results were also reported by Junior et al. [33].

3.7.2 2% NaOH treated CB Fabric/Epoxy Composite

The SEM fractograph image shown in Fig. 11–13 is a 2% NaOH treated CB fractured composite test specimen. Due to the NaOH treatment, the impurities are removed and the yarn surfaces are rough when compared to the untreated composite sample. This indicates that impurities cause fibre pullout and failure in interfacial bonding of fibre and resin.

The fractograph structure identifies the homogenous mixing and perfect alignment of fiber with resin, which has better bonding. It is also observed that the stress transfer between fibre and matrix materials has enhanced the mechanical properties of composite laminates.

The bending of the yarn indicates that the load is applied to the top surface of the composite specimen and is clearly expressed in the SEM image. It is further noticed that the impurities are reduced and hence fibre pullout is less and fibre tearing is reduced because the NaOH treated fabric improves the adhesion between fabric and matrix. Shibato *et al.* [34] (2005) reported that the raw fibre composite stuck together but exhibited a crack after NaOH treatment, and this is known as fibrillation. Due to NaOH treatment, the raw fibre present in hemicelluloses is dissolved. The fibrillation means increasing the rough surface area so that effective contact between fibre and matrix can enhance the bonding.

3.7.3 3% NaOH treated CB Fabric/Epoxy Composite

Figure 14–16 shows the SEM fractograph fractured specimens of 3 wt. % NaOH treated composite laminates. The images identified the fibre pullout, void, crack and fibre peel off because of poor bonding between fibre and matrix since a high percentage of NaOH treatment damages the fibre surface topography [35]. This damage leads to poor interface adhesion and wettability, and this guide to decreasing the characteristics of composite laminates and also the mechanical properties.

When the higher NaOH concentration is reached, excess delignification of natural fibre occurs, resulting in a weaker or damaged fiber. The mechanical properties decreased suddenly after crossing a certain optimum level of NaOH concentration. The higher alkali solution damages the cotton fibre and its structure, which results in the reduction of mechanical mechanical properties which also matched with the results suggested by Mwaikambo and Ansell [36].

The low interfacial fiber-resin bonding was responsible for a large amount of fiber being removed from the matrix as there was poor fibre matrix miscibility and adhesion. This phenomenon becomes responsible for the propagation of transversal cracks through the brittle polyWhen the magnification of the SEM microscope was increased, it further revealed traces of decohesion of fiber from the matrix. This, along with the hindrance of the fibers, expedited the propagation of cracks through the brittle matrix. These factors reveal that clustering or agglomeration of fibers ends in a weak interface with the matrix, thereby decreasing the mechanical properties of the composites. Similar kind of report was also reported by Thiruchitrabalam and Shanmugam [37].

Conclusion

The untreated and NaOH plain woven cotton/bamboo fabric composites were fabricated by hand layup process combined with compression moulding process. The composites were tested for the characteristics and the following conclusion was made.

1. The plain woven fabric CB45UT composite exhibited better mechanical properties like tensile, flexural, impact, compression and interlaminar shear stress composite laminates.
2. Due to the NaOH treatment fiber, surface areas are rough and impurities are removed. So the interfacial bonding between fibre and resin improved and, therefore, better mechanical properties were achieved.
3. CB/epoxy composite (N3035) has tensile, compressive, flexural, impact strengths and interlaminar shear stress of 100.94 MPa, 107.54 MPa, 125.96 MPa, 42.86 kJ/m², and 20.13 MPa, respectively.
4. The optimum 2 wt. % NaOH treatment of the CB/epoxy composite demonstrates better mechanical properties. The tensile, compression, and impact (16%), flexural, and interlaminar shear stress (15%) improved when it was compared to untreated CB composite laminates.
5. The SEM image shows that the CB/epoxy composite with 2 wt. % NaOH treatment and 45 wt.% fibre content has improved mechanical properties.
6. Bonding between the epoxy resin and the fabric, fibre pull-out, fibre breaking, and voids in the composite were all shown by SEM micrographs.

Declarations

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Figures

(a) Compression Molding Machine

(b) Untreated CB fabric composite sample

(c) NaOH treated CB fabric composite sample

Figure 1

1Hydraulic compression moulding machine

Figure 2

Tensile strength of UT and alkali surface modifier Cotton/Bamboo fabric composite

Figure 3

Flexural strength of UT and alkali surface modifier CB fabric composite

Figure 4

Impact strength of UT and alkali surface modifier CB fabric composite.

Figure 5

Compressive Strength of UT and alkali surface modifier CB fabric composite

Figure 6

ILS strength of UT and alkali surface modifier CB fabric composite

Figure 7

TG curve for CB fabric composite

Figure 8

SEM fractograph of the tensile tested broken sample (CB30 UT)

Figure 9

SEM fractograph of the tensile tested broken sample (CB45 UT)

Figure 10

SEM fractograph of the impact tested broken sample (CB45 UT)

Figure 11

SEM fractograph of the tensile tested broken sample (CB45 SH2)

Figure 12

SEM fractograph of the flexural tested broken sample (CB45 SH2)

Figure 13

SEM fractograph of the impact tested broken sample (CB45 SH2)

Figure 14

SEM fractograph of the tensile tested broken sample (CB45 SH3)

Figure 15

SEM fractograph of the flexural tested broken sample (CB45 SH3)

Figure 16

SEM fractograph of the impact tested broken sample (CB45 SH3)