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An approach to search the potentiality of node in bamboo strip reinforced composites

Mohammad Irfan IQBAL[1,2,*], Rashed Al MIZAN[2], and Ayub Nabi KHAN[2]

[1] *School of Textile Science and Engineering, Wuhan Textile University, Wuhan, Hubei, 430200, China*
[2] *Department of Textile Engineering, BGMEA University of Fashion & Technology, Nishatnagar, Turag, Dhaka, 1230, Bangladesh*

***Corresponding author e-mail:** irfan.iqbal@connect.polyu.hk

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Abstract

Bamboo has recently entered the composite sector with some attractive labels such as 'green'. The current commercial manufacturing method of bamboo composite removes the node's portion of bamboo culm during bamboo processing. This method generates a high amount of solid waste materials along with processing complexity and the scientific merit of this practice is also questionable. This research investigates the effects of culm nodes on bamboo based composite properties. In this study an approach to produce bamboo strips reinforced epoxy composites and their mechanical properties (e.g. tensile, flexural and impact properties) were reported. It was demonstrated that mechanical properties of composites slightly varied with nodes and internodes. As expected, the addition of bamboo strips has significantly improved mechanical properties of polymeric resin. Composites along with nodes part had the highest mechanical properties in terms of tensile strength, tensile modulus and flexural strength. In contrast, composites made with internodes showed the highest mechanical properties in terms of tensile strain and impact strength. However, the difference between their mechanical properties were not significant which revealed that bamboo node may be used as potential materials in bio-based composite industry.

1. Introduction

Bamboo fibers are gaining more and more attention in the world market due to their high strength, environmentally friendly nature, rapid growing properties, low cost, availability and sustainability. Bamboo belongs to the Poaceae family, a sub-family of Bambusoideae. A large variety bamboo fibers for instance, 1250 spices with 75 genera is available [1]. It has been considered for building material since the dawn of human civilization and also still extensively been used for a wide range of purposes, including household and industrial applications due to advances in processing technology and increased market demands [2]. As an abundant resource in China, bamboo has been being used in agriculture, handicraft, paper-making, furniture and architecture for thousands of years [3].

The synthetic fibers; for instance, fiberglass, carbon fiber, polyurethane, lead the composites industry due to their mechanical properties and low cost. The natural fibers usually used in composites for reinforcement are jute, kenaf, sisal, hemp, coir, straw, bamboo, banana leaf etc. Among them bamboo offers maximum mechanical strength and minimum density, which is 0.9 $g\cdot cm^{-3}$, compared with 1.45 $g\cdot cm^{-3}$ of jute and 2.5 $g\cdot cm^{-3}$ of fiberglass [4]. Although mechanical properties of bamboo are relatively lower than fiberglass, they are approximately 10 times cheaper than fiberglass [5] and have a much higher aspect ratio compared with wood fibers originating from pine is suggested by a number of studies [6]. Bamboo fiber is also known as 'natural glass fiber' [7,8] due to their outstanding specific properties. Bamboo itself is considered as a natural composite material in which cellulose fibers are implanted in the lignin and hemicellulose matrix giving maximum length wise strength. Cellulose (60%) is the main chemical constituent of bamboo. Another major constituent is hemicellulose and lignin [9]. Its microfibrillar angle is comparatively small (10-12°) [5]. Thus, it's obvious that bamboo has high tensile strength considering mentioned characteristics. Because of these superior characteristics of bamboo, it has been widely used as reinforcement. It shows maximum strength along the fibers and minimum across the fibers. The current availability of bamboo fibers is limited [10] and the extraction of undamaged long technical bamboo fibers having an internode length of about 25 cm is a challenge [11]. However, recently an attempt has been made to produce composites from bamboo strips by taking the advantage of the cohesiveness, since the cohesive strength of individual fiber is significantly lower [12].

The worldwide demand for wood fibers seems to be endless [13]. Hence, bio-based materials other than wood are getting attention to lessen the harvesting demand on forests and assist in flourishing resource

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conservation. Bamboo is an economical and fast-grown resource with favourable physical and mechanical properties compared to some common wood materials like softwood and hardwood [14]. Bamboo has great potential as an alternative to wood for many applications [15-17]. Since 20th century, bamboo has received increasing attention for industrial applications, especially as raw material for wood-based composites, such as particleboard (PB), medium density fiberboard (MDF), hard fiber board (HB), plywood, oriented strand board (OSB), zephyr board, laminated bamboo lumber, parallel strand lumber (PSL) and oriented strand lumber (OSL), inorganic-bonded board (i.e., cement), wood plastic composites (WPC).The reasons of using bamboo strips as the alternative raw materials for wood composites are for their fast growing nature, high productivity, quick maturity and high strength with advancement in processing technology [18].

There is a large volume of published studies describing the performance of bamboo strips as reinforcement for composites. Polyester resin composites using bamboo strips as reinforcement were prepared by treating Alkali (10-25%) treatment of bamboo strips [19]. Moreover, in order to improve mechanical properties alkali treatment (1-25%) also followed at room temperatures for 30 min long was also followed [20]. A number of authors have considered bamboo strip to manufacture unidirectional bamboo-epoxy laminates of changing the numbers of laminae and assessed their mechanical properties [20,21]. The moisture absorption properties of bamboo strips along with their effect on the interfacial shear strength of bamboo–vinyl ester composites had been investigated [22]. To understand and compare the influence of different chemical treatment (silane, alkali, oxidation and acetylation) on the moisture absorption performance of same composites has also been carried out [23]. Bamboo–polyester composites were developed by hand lay-up method using treated (alkali) and untreated bamboo strips [24]. Furthermore, novolac based bamboo composites were prepared after mercerizing the bamboo strips with NaOH with various concentrations (10, 15, 20 and 25%) [25]. Thermal and Weathering properties of alkali treated bamboo strips of novolac composites have also been reported [26]. Apart from these, detailed report on the dynamic mechanical and thermal properties of untreated and treated bamboo strip-reinforced novolac composites has been examined [27].

So, all these studies highlight the applications of bamboo strips as a reinforcing material for different composites. However, there is a very limited body of literature especially regarding epoxy-based composites from bamboo strips along with a node's portion. Hence, current research focuses on to evaluate the feasibility of bamboo strips along with nodes as a potential reinforcement material for epoxy-based composites applications.

2. Experimental

2.1 Materials used

The matrix was prepared by using commercially available epoxy resin difunctional diglyci-dyl ether of bisphenol-A (DGEBA, trade name: E51) with curing agent Triethylenetetramine which were obtained from China National BlueStar (Group) Co. Ltd. The mechanical properties of E51 are given in Table 1. The bamboo strips used as the starting materials were procured from local markets in the middle part of China with a typical length of 74 cm. The strips had an average length of 74 cm. The average distance between the nodes was 20 cm, 16.5 cm at the top and 20 cm at the bottom. The width and thickness of bamboo strips were 4.7 mm and 1.8 mm respectively. The strips were classified into two categories: without nodes or only internodes and with nodes situated in middle of strips. All specimens were tested in standard air-dried condition.

Table 1. Mechanical Properties of epoxy used in bamboo strips reinforced composites.

Property	**Epoxy (E)**
Tensile Strength (MPa) ±STD	50±5
Strain to Failure%±STD	1.5±0.2
Flexural Strength (MPa) ±STD	4±0.9
Impact Strength ($KJ \cdot m^{-2}$) ±STD	7.5±0.8

2.2 Sample preparation

The 3-layer laminated bamboo composites were manufactured from bamboo strips along with node and without node by simple hand lay-up process. To fabricate the composites, the layers of bamboo strips were arranged as shown in Figure 1. Note that only strips used as third layer were consisted of node and without node part alternatively. The epoxy E51 (E) with curing agent Triethylenetetramine was used as matrix. The epoxy was mixed with curing agent in the ratio of 100:10 by weight recommended by the manufacturer. To make the composites one strip is laminate against another with epoxy resin followed by placed over die cavity and finally coated with resin.

In this way 3 layers of laminate stacked together to form one sample of unidirectional laminated bamboo composites. The hot-pressing technique executed in the laboratory for the manufacturing of composites. This ensured that the excess resin was squeezed out. According to the manufacturer the samples were cured for 4 h at 80°C for cross linking of epoxy. After being cured, laminates were cut into specific shapes (250 ×4.7×6.5 mm) for mechanical tests. The bamboo strip reinforced composites (BSRC) classified into two categories: without nodes or only internodes (BCWON) and with nodes in middle of strips (BCWN).

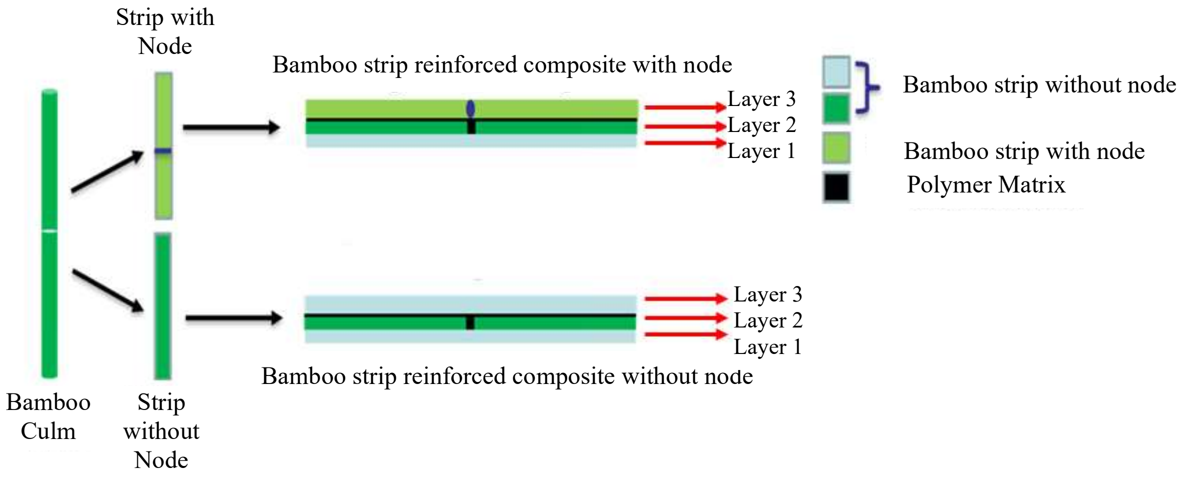

Figure 1. Schematic configuration for layer arrangement of bamboo strips for preparation of composite.

2.3 Surface morphology

A scanning electron microscope (JSM-6510LV, voltage: 20 kV) was used to investigate the surface morphology of the fibers to uncover the structural variation in terms of compactness and fiber orientation of both node and internode portions along the bamboo culm. Before observation, the samples were coated in gold by ion sputtering.

2.4 Mechanical properties

In this study, three mechanical properties; for instance, Tensile, Flexural and Impact properties were evaluated as these properties have significant influence on ultimate performance of composite materials. For each mechanical property 10 samples were considered randomly, and their averages were reported.

2.4.1 Tensile Testing

Tensile testing was carried out using an Instron 2712 pneumatic grips machine, ISO 11566 was followed to determine tensile properties. The specimen geometry was 250×4.7×6.5 mm. The gauge length was 150 mm and the cross-head speed was 50 mm·min^{-1}. The tests were carried out until the materials got broken. The samples with Jaw break were not taken into consideration for the analysis.

2.4.2 Flexural Testing

Loading nose and its supports were arranged, and finally three-point bend tests were performed with samples of 100×4.7×6.5 mm dimensions. Flexural strength was received from auto generated computer sheet through a software called WinWdw inbuilt in universal testing machine equipment as per procedure given in ASTM-D7164 standard. The gauge length was 50 mm and the cross-head speed was 10 mm·min^{-1}. The ratio of support span to thickness was maintained as 20:1 so that breakage arises at the outer surface of specimens for higher bending moment.

2.4.3 Impact Testing

For impact behaviour test specimens without notch were 60 mm long and the cross-section was 4.7 mm× 6.5 A 7.5 J pendulum was used to break the specimens. The impact energy was note down. The final impact strength was obtained from dividing the impact energy by the cross-sectional area. The unit of the impact strength was KJ·m^{-2}.

2.4.4 Statistical analysis

The average of the values and the comparisons of different properties between nodes and internodes of the strips have been calculated using SPSS software at 5% level of significance.

3. Results and discussion

3.1 Fiber morphology

The extracted bamboo fiber morphology is observed by SEM. From Figure 2, it can observe that the bamboo fibers extracted are composed of several elementary fibers. Though, it can be named as fiber, but it is found as a bundle of bamboo fiber.

Due to high amount of crystallinity in the elementary fiber of raw bamboo, it has higher physical bond to attach the fiber in a bundle form. This reason also supports by the Figure 2(a), where only the node portion has disorientation among the elementary fiber rather than without node portion. Thus, the fiber in bamboo strip with node portion get bind alternately with large crystalline zone means to produce bundle fiber in extraction, Figure 2(b). The microscopic view of the bamboo fiber with node, clearly indicate the rougher surface than the fiber of without node. This can also be determined that, in node area the elementary fiber is oriented isotopically, which indicates higher amorphousness in the node area. The Figure 2(b) also shows the structure of node portion, from which it is clearly determine that the rougher surface has more locking point, can help to produce physical bond with polymer matrix.

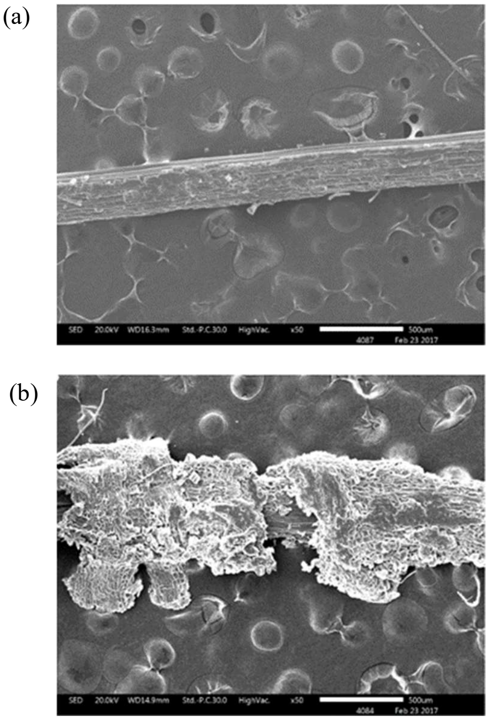

Figure 2. (a) SEM Photograph of Bamboo fiber without Node (b) SEM Photograph of Bamboo fiber with Node.

However, the fibers were found in bundle form and had very rough surfaces, unsuitable for conventional textile applications rather than most suitable for engineered composite structure in the viewpoint of mechanical locking with polymer matrix.

3.2 Strip morphology

The morphological observation of bamboo strip shown in Figure 3. From Figure 3(a) exposed that bamboo strips without node have more interesting topography, where in node portion it gives highly disoriented fibrillar structure rather than the portion having plain structure.

From the close view of the structure also shows rougher topography with isotropic void. This may be reason of mineral conservation unit for bamboo tree [28]. From Figure 4, it is clearly showing; some route develops in the node portion. During the initial stage of this route development can affect lignocellulose deposition in this portion, which is also a reason of this molecular disorientation in the node portion. From Figure 3(b) revealed that the structure of bamboo strip without node had smoother and compact structure. The crystallinity of fibril arrangement also clearly observed, which was generated by natural deposition of lignocellulose in an oriented pattern, is an evidence of the bamboo genome programming [29]. In both figure of with node and without node, it has evident of some holes like cavities on both pictures, which could be due to parching moisture from vascular cells of waste bamboo [28]

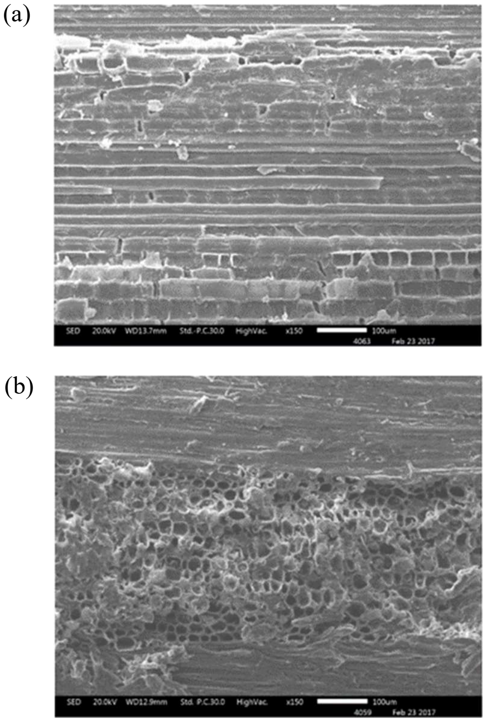

Figure 3. (a) SEM Photograph of Bamboo Strip without Node (b) SEM Photograph of Bamboo Strip with Node.

Figure 4. Route and branch develops in the node portion with their CT-scanned images [30].

3.3 Mechanical Properties

3.3.1 Tensile properties

For any composite structure the tensile strength is a crucial property to use it in its application area. Also, this is simplest way of understanding the composite suitability. So, the effect of node on bamboo fiber loading on the tensile strength for bamboo reinforce composite (BRC) is shown in the Figure 5(a). From morphology section, it is already clear that bamboo without node portion have more crystalline than that of with node portion. So, the strength distribution also is higher in crystalline zone than that of non-crystalline. Quite similar observation is observed by [31] in the tensile strength of other fiber reinforced polymer composite.

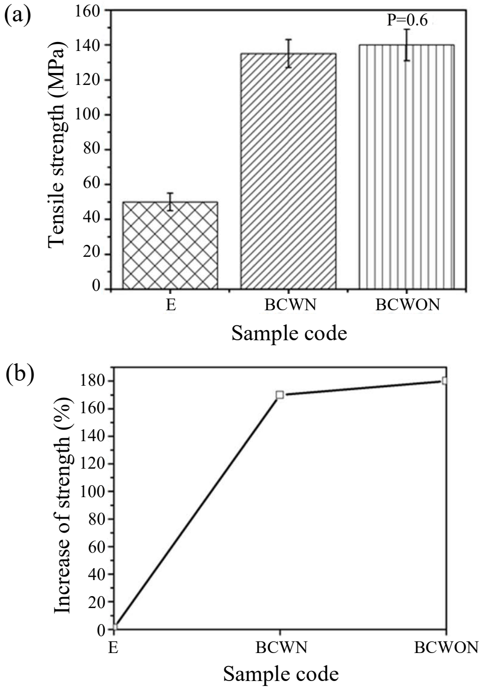

Figure 5. Tensile properties; (a) tensile strength (b) tensile strength increment pattern than pure epoxy of Bamboo strip reinforced composites with and without node.

Indeed, it can be a general assumption that bamboo strip reinforcing composite without node give better result than that of with node one. But the Figure 5(a) reveal different concept, it is observed that the tensile strength of both composite (BCWN, BCWON) have no sharp difference. Moreover, the strength increment of the composite shown in Figure 5(b), which has also been similar for both types of composite. This is due to, bamboo strip with node have rougher morphology (Figure 2 and 3), which gives enhanced interfacial bonding with epoxy to bamboo fiber at node portion. Furthermore, the structure of the node portion gives enough mechanical locking zone for the epoxy polymer. Importantly this will make the BCWN a good competitor of BCWON. In addition, the rougher surface of bamboo with node can traps more resin than that of former one. This can readily improve the properties of composite with node compare to the composite without node. Alternatively, BCWON composite have no such kind of advantage of rougher surface like BCWN, but it has crystalline zone, which obviously a good contributor to tensile strength of composite.

Moreover, Figure 6(a) represents the tensile moduli of BCWON are slightly greater than that of BCWN. This because of, the fibers in bamboo internodes are arranged uniformly, while node portions are arranged in disoriented manner and showed higher amorphous zone that gives an adverse effect on its modulus. It is believed to be the reason for negligible tensile modulus at bamboo fiber loading with or without node in the composites.

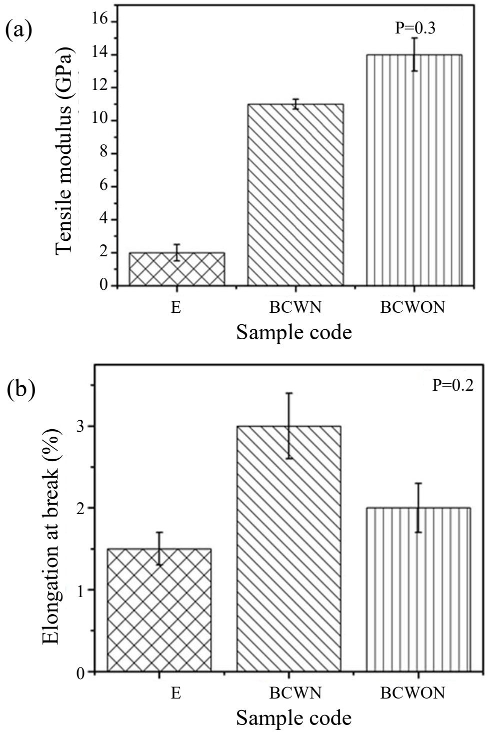

Figure 6. Tensile properties; (a) tensile modulus (b) elongation at break of bamboo strip reinforced composites with and without node.

The elongation of develop composite was observed from Figure 6(b), where the elongation of BCWN have better elongation than that of BCWON. This is also an effect of amorphous arrangement in node portions. It is believed that amorphous molecular arrangement in node portion get extended during tensile loading will affect the elongation of the respective composite. There are several researchers also finding the similar result for amorphous fiber has higher elongation than that of crystalline one [32-34].

Therefore, the difference in Tensile Strength (P=0.6), Tensile Modules (P=0.3) and Strain to Failure% (P=0.2) has not been found statistically significant between nodes and internodes.

3.3.2 Flexural properties

From Figure 7, shows the results of the flexural tests conducted on BSRCs of nodes and internodes. The flexural strength of BCWN reported some while lower value than that of BCWON, which can be clear from the molecular anatomy from Figure 8.

Thus, the bamboo fibrils are oriented in a compact structure, which will prevent it to bend against the force parallel to cross section of the bamboo strip. Hence this will increase the flexural strength of the composite BCWON than that of BCWN. Generally it can find that the crystalline zone (without node) portion have 3.53 bundle·mm^{-2}, where this value is 2.44 bundle·mm^{-2} for node portion [33] Therefore, the bending behaviour of the bamboo composite had a correlation with the vascular bundle distribution in bamboo, the higher flexural strength reported due to the higher vascular bundle density in the respected reinforcing strip in the composite.

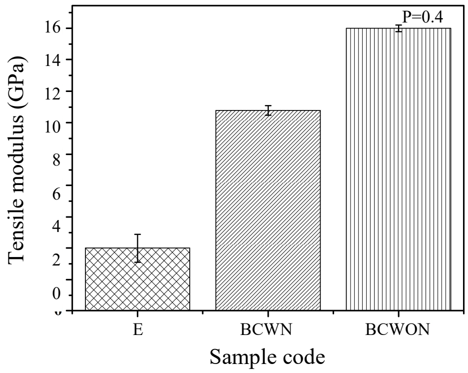

Figure 7. Flexural strength of bamboo strip reinforced composites with and without node (adopted for bamboo from: Rubin 2008) [35].

However, Paired Student's t-tests are also used to determine statistical significance. The difference in Flexural Strength (P=0.4) has not been found statistically significant between nodes and internodes.

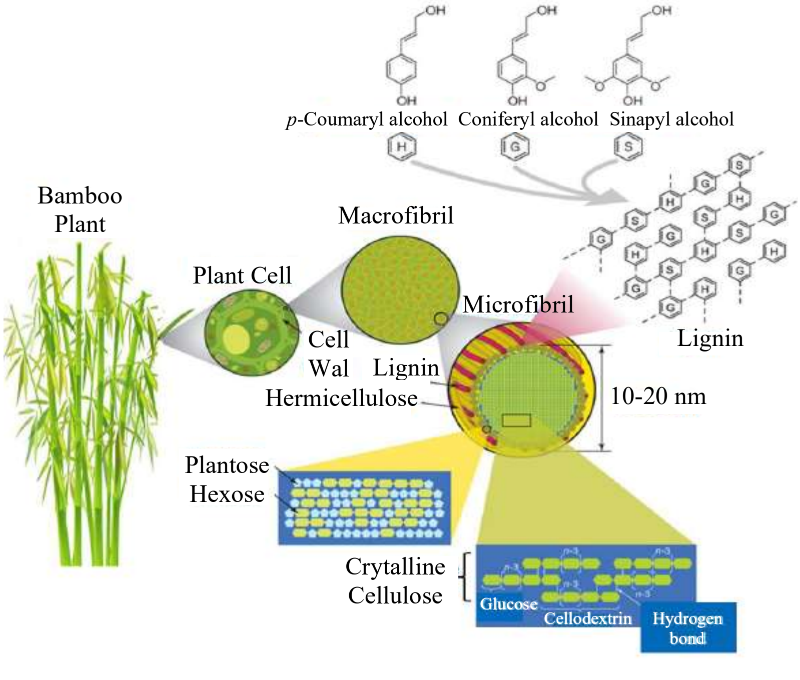

Figure 8. Structure of the lignocellulose (adopted for bamboo from: Rubin 2008) [35].

3.3.3 Impact properties

Impact strength is defined as "the ability of a material to resist fracture under stress applied at high speed" [36]. The Pendulum type impact test provides a record of the impact event. Figure 9 implies the results of impact tests conducted on specimens of BCWN and BCWON. The pretty similar result also finds in previous research of bamboo composite [11].

From The reported result, it can observe that the impact strength has not a sharp difference between both types of composite. Thus, filling of all the void by epoxy resin in node area would be the reason of taking high impact force in BCWN. In addition, to node area the molecular chains are disoriented will provide some residual stress already develop in the node area [37,38]. This is because the node area gives a similar result like without node reinforcement, where the bamboo fibril are more oriented subjected to give good impact strength.

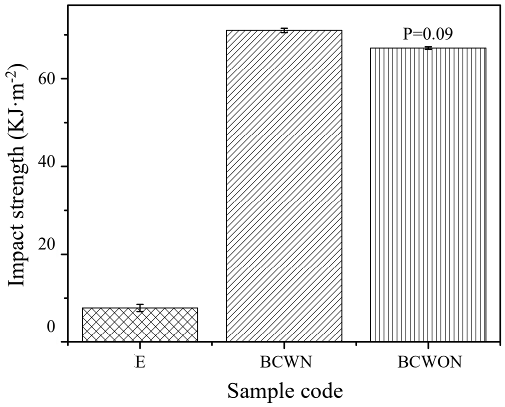

Figure 9. Impact Properties of bamboo strip composites with and without node.

Paired Students t-tests are used to determine statistical significance. It is apparent from the Figure 8, nodes cause a small increase in strength from 67 KJ·m^{-2} (SD = ±0.5) to 71 KJ·m^{-2} (SD = ±0.3) which is not statistically significant (P = 0.09). These results suggest that the nodes have only a minor effect on the impact properties of the strips. In consequence, the significant effect could be obtained for high frequency of the nodes along the culm and more compact structure in the nodes [39].

4. Conclusions

The bamboo strips reinforced epoxy composites were prepared and their mechanical properties for instance: tensile, flexural and impact studied. The effect of culm nodes of the bamboo strips on these properties was studied. This study has shown that:

1. All the criteria of mechanical properties slightly vary with nodes and internodes. The BCWON and BCWN were found to demonstrate good mechanical properties than other synthetic and bio fibers reinforced composites.
2. The second major finding, the addition of bamboo strips has significantly improved mechanical properties of epoxy resin.
3. There is a small decrease in flexural strength of BCWN as well as impact strength of BCWON. However, The Bamboo Strips-Epoxy laminated composites with node or without node, did not show any comparable mechanical properties. So, there is no need to cut off the node during fabrication of composite.
4. However, the properties revealed from the characterization imply that these composites have a lot of potential for structural and non-structural applications.

As the composite material is lower in cost and easily available, it could be a good replacement for traditional wood in terms of indoor and outdoor applications for example; door panels, furniture, housing, packaging, transport and automobile body etc. along with daily life applications like decking, fencing, and dustbin etc.

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