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Development and Characterization of Nigerian Long Bamboo Fibre-Reinforced Polymer Composites

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Abstract
Fibre-reinforced polymer composites materials have several applications as classes of structural materials. This is due to their ease of fabrication, relatively low cost of production. The fibre which serves as a reinforcement in reinforced plastics may be synthetic or natural. In the present work, investigation has been carried out to study the mechanical characterization of Nigerian long bamboo fiber-reinforced polymer composite, this is based on the fibre content of the developed composite material. The choice and use of bamboo fibre is based on the abundance of this natural fibre in Nigeria. The objective of this work is to study the effect of fiber loading and mechanical behavior of bamboo fiber reinforced epoxy composites. From the result obtained, it shows that, the mechanical properties of the developed composite material were found to be optimum volume fraction of fibre percentage of between 10% and 15%.

1. Introduction

Composites are formed when two or more materials with different properties are combined together. They are also high load bearing materials that could be called reinforcement imbedded in weaker material that is called matrix.

Generally, the properties of composites materials are superior in many respects, to those of the individual constituents. This has provided the main objective for this research, development of composite materials [16]. There are two categories of constituent materials, one is matrix and another is reinforcement. The primary function of the matrix is to transfer stresses between the reinforcing fibre/particles and to protect them from mechanical and /or environmental damage whereas the presence of fibre/particles in a composite improves its mechanical properties such as strength, stiffness etc. the objective is to take advantage of the superior properties of both materials without compromising on the weakness of either. The matrix materials can be metallic, polymeric or ceramic [10, 22].

When the matrix is polymer, the composite is called polymer matrix composite. The properties of polymeric composite materials are mainly determined by three elements such as the resin, the reinforcement such as particles or fibres and the interface between them which could be the filler. Reinforcements provide strength and rigidity, assisting in supporting structural loads [21]. The matrix or binder which could be organic or inorganic material maintains the position and orientation of the reinforcement. Significantly constituents of the composite retain their individual physical and chemical properties whereas together they combine to produce qualities that individual constituents cannot produce alone [17]. Reinforcements have extensively been made of inorganic (man-made fibre) such as glass and organic fibres such as carbon and amid. Recently, the rapidly increasing environmental awareness, geometrically increasing crude oil prices, growing global waste problem and high processing cost triggered the development concept of sustainability and reconsideration of renewable resources. The use of natural fibres derived from annually renewable resources, as reinforcing fibres in both thermoplastic and thermosets matrix composites provides positive environmental benefits with respect to ultimate disposability and raw material utilization [9, 14].

The advantages associated with use of reinforcement from natural fibres in polymer are their availability, non abrasive nature, low energy consumption, biodegradability and low cost. Also natural fibres have low density and high specific properties. The specific properties of these fibres are comparable to those of traditional reinforcement. A number of investigations have been carried out to assess the potentials of natural fibres as reinforcements in polymers [11].

Nowadays, natural fibre-reinforced polymer composites are increasingly being used for various engineering applications due to their numerous advantages. Natural fibres have been used to reinforce materials for over 3,000 years, more recently they have been employed in combination with plastics [20]. Many types of natural fibres have been investigated for use in plastics including flax, hemps, jute, straw, wood fibre, rice husk, wheat, barley, oats rye, cane (sugar and bamboo), grass reeds, kenaf, ramine, oil palm empty fruit bunch, sisal, coir, water hyacinth, pennywort, kapok, paper-mulberry, raphia, banana fibre, pineapple leaf fibre and papyrus [18]. They all have the advantages of renewable resources and low cost. Natural fibres are increasingly used in automotive and packaging materials, in some countries of the world that are solely agricultural dependent for instance Pakistan, Malaysia etc, thousands of tons of different crops are produced but most of their waste do not have any further utilization. These agricultural wastes include wheat husk, rice husk and straw, hemp fibre and shells of various dry fruits [1, 4].

In Nigeria the scenario is not different as wheat husk, rice husk and straw, palm trees, bamboos, raphia, pineapple leaves etc, are lying waste in different agricultural fields. These agricultural wastes can be used to prepare fiber-reinforced polymer composite for commercial purposes. Among the various natural fibres, bamboo finds widespread use in housing construction around the world, and is considered as a promising candidate for housing material in underdeveloped and developed countries. Being a conventional construction material many decades past, bamboo fiber is a good candidate for use as natural fibre in composite materials [19]. Many studies focused on bamboo fibre is due to the fact that it is an abundant natural resources with overall comparative, mechanical properties advantages to those of wood. Bamboo is found in diverse climates, from cold mountains to hot tropical regions. They are found across East Asia, Northern Australia, West India and the Himalayas. They also occur in sub-Saharan Africa including Nigeria and in the Americas from the mid-Atlantic United States to Argentina and Chile [13, 15].

Bamboo is one material that has good economic advantages, it reaches its full growth in just a few years, and it is also one of the fastest renewable plants with a maturity cycle of 3 to 4 years. Although the utilization potential of this material for a number of applications has been explored, such superior mechanical properties have not been adequately well drawn for polymer-based composite. The mechanical properties of different natural fibres such as sisal, vakka, banana, bamboo were compared and it was found that the bamboo fibers have much higher tensile and flexural properties than other fibres [8, 2].

Bamboo fibres have emerged as a renewable and cheaper substitute for synthetic fibres such as glass and carbon, which are used as reinforcement in making structural components. They have high specific properties such as stiffness, impact resistance, flexibility and modulus, and are comparable to those of glass fibre. Bamboo can be used for reinforcement such as the whole bamboo, section, strips and the fibers. These various forms of bamboo have been used in applications such as low rise construction to resist earthquake and wind loads, bamboo mats composite in combination with wood for beam, and shear wall in low rise construction in addition bamboo fibre can be used as reinforcement with various thermoplastic and thermoset polymer [5].

Several researchers have investigated on different parameters bamboo including but not limited to their mechanical properties. However only scanty literature can be found the bamboo fibre obtained from Nigeria. The following are some examples;

[6] an effect of surface modification of bamboo cellulose fibers on mechanical properties of cellulose/epoxy composites. [7] thermal decomposition properties of bamboo and high density polyethylene composite with heat treated bamboo fiber. [10], Analysis of morphological and mechanical behaviours of bamboo flour reinforced polypropylene composites. [11] Erosion wear behaviour of bamboo fiber based hybrid composites. [12], study on the effect of chemical treatment on the mechanical behaviour of bamboo-glass fiber reinforced epoxy based hybrid composites. [13] mechanical, thermal and morphological properties of bamboo fiber reinforced polypropylene composites. [14], the mechanical properties of natural Fiber reinforced polyester composites. [15], Impedance-spectroscopy analysis of oriented and mercerized bamboo fiber-reinforced epoxy composite.

2. Materials and Methods

2.1. Materials

The materials used here included but were not limited to the following: Hydrogen peroxide, concentrated acetic acid, enamel bowl, oven, ladle, bamboo chips, weighing scale, water, plastic cup, bisphenol-A-diglycidlyl ether, poly vinyl alcohol, brush, polish (gel), metal bars of 300 mm x 3 mm, metal sheet, tile of 300 mm x 200 mm square area, weight of 8kg, thermometer, *p*H meter and a graduated cylinder.

In this work, long bamboo fibre is used as the reinforcement in the composites. The fibres were dried in an oven at a temperature of 65°C for 6 hours to remove moisture prior to composite making. The average thickness of each bamboo fibre is about 1.5 mm.

In the present work, long bamboo fibres (prepared in the Department of Wood Products Engineering, Cross River University of Technology, Calabar) were used as the reinforcing material in all the composites. Blemish free bamboo columns were obtained from CRUTECH environment and were manually cut to chips of 25 mm length. The moisture content of the bamboo was determined using gravitational method and the average moisture was calculated to be 20.5%.

Among the thermosets, the epoxy resins are widely used for many advanced composites due to their advantages such as excellent adhesion to a wide variety of fibres, good performance at elevated temperatures and superior mechanical and electrical properties. In addition to that, they have low shrinkage upon curing and good chemical resistance. Due to its several advantages over other thermoset polymers as mentioned above, epoxy (LY 556) was chosen as the matrix material for the present research work. It chemically belongs to the 'epoxide' family and its common name is Bisphenol-A-Diglycidyl-Ether (BADGE) or Diglycidyl of ether Bisphenol- A- (DGEBA).

2.2. Methods

Extraction of Long Bamboo Fibre

The extraction of fibre from their plants was done using maceration method.

Composite Fabrication

There are several methods of fabricating composite and the method employed here was the hand lay-up method.

The resin (Bisphenol-A-diglycidyl ether) was obtained from Bristol Scientific Company Limited Lagos.

A mould having dimensions of 300 x 300 x 3mm was used.

Polyvinyl alcohol and wax were used to polish the surface of the mould. They both served as releasing agents that made it easy during demoulding of the composite. The resin, Bisphenol-A-diglycidyl ether (BADGE) and the hardener were measured into a beaker in a ratio of 2:1

The cast was post cured using a light load of 8.72 kN/mm^2.

The mould was closed for curing at a temperature of 25°C for 24 hours at constant pressure. The cast was also post cured again in air for 24hours after removal from the mould. Samples were prepared according to ASTM standard for each mechanical parameter and then taken to the laboratory for test. Utmost care was taken to maintain uniformity and homogeneity of the composite since reproducibility is somewhat difficult in hand layup method that was used.

Table 1. *Sample composition.*

Sample	Composition	
	Volume fraction fiber (%)	**Volume fraction of Epoxy (%)**
1	0	100
2	5	95
3	10	90
4	15	85
5	20	80
6	25	75

Flexural Test

The test sample was dimensioned to standard according to ASTM testing code ASTM D7264, (4mm thickness x 13mm width x with a length of 300mm. The sample was placed on a three point fixture, while the machine applied forces of varying degrees on the samples, this went on until the sample deflected as shown in Figure 2. The flexural strength, maximum flexural stress, maximum strain and stress at strain of the sample can be calculated from the data generated from this test.

Flexural Strength of Composite

FT = Flexural strength

The flexural strength is calculated with the formula

$$FT = pl/bd^2 \qquad (1)$$

Where p=maximum load applied (N), l = length of specimen (mm), b=width of specimen (mm) and d=thickness (mm)

Tensile Test

According to ASTM D5083 tensile test measures the force required to break a reinforced thermoset plastic specimen and the extent to which the specimen stretches or elongates to that breaking point.

The specimens were prepared according to ASTM D5083. This standard is recommended for tensile testing of reinforced thermosetting plastics. The sample was placed in the grips of the universal testing machine and pulled until deformation occurred as shown in Figure 1. An extensometer was used to determine the elongation. The tensile strength was calculated using the following relation;

Tensile Strength of Composite

The formula for tensile strength is given as:

Hardness Test

There are several hardness tests. The brinell hardness test was used to determine the hardness of the composite. ASTM B933-09 is a standard testing method which was used to carry out this test.

Hardness Value of Composite

The hardness value of the composites were determined using the Brinell hardness number equation (2)

BHN = Brinell hardness number which is given by the formula:

$$\frac{P}{\frac{\pi D}{2}\left[D-\sqrt{D^2-d^2}\right]} \quad (2)$$

Where P = constant axial force, D= Brinell bulb diameter and d=depth of indentation.

Compression Test

Compressive test determines n-plane compressive properties by applying the compressive force into the specimen at wedge grip interfaces.

This test was carried out using ASTM D3410 standard. The sample was loaded into the machine and a force was gradually applied until the sample deformed.

Compression Strength of Composite

$$\text{Compressive strength} = \frac{\text{maximum compressive force}}{\text{cross sectional area}} = \frac{F}{A} \quad (3)$$

3. Results and Discussion

This chapter presents the results and discussion of the mechanical characterization of Nigerian long bamboo fibre reinforced epoxy (Bisphenol-A-diglycidyl ether) composites. The mechanical behaviour of long bamboo fibre reinforced epoxy composites with different loading parameters of fibre is presented.

3.1. Results

Tensile Test Results

The tensile values of the composites during the tensile test according to the fibre contents were plotted as shown in Figure 1

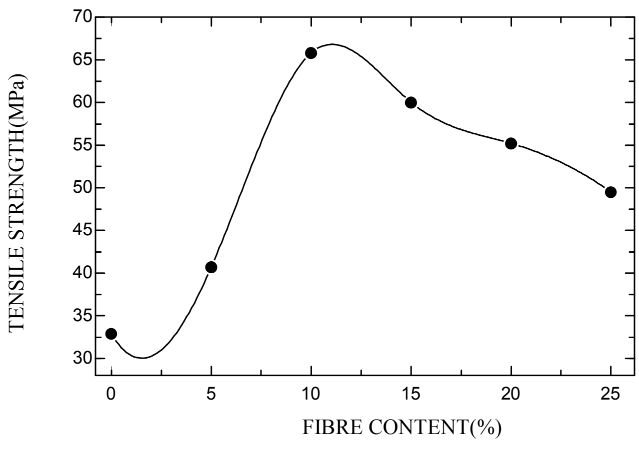

Figure 1. *Tensile values of Composite material.*

Flexural Test

The material could be used for cyclic loading applications hence the need for flexural test. The values of the flexural test for the developed materials were determined and plotted as shown in Figure 2.

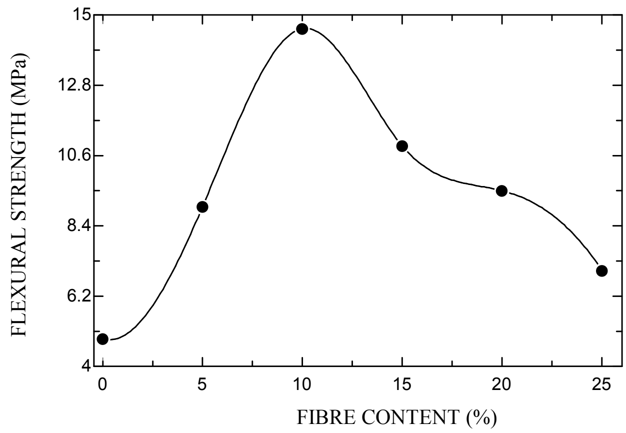

Figure 2. *Graph showing the plot of flexural strength against fibre content.*

Compression Test Result

The compression result for the composite material were calculated and the values recorded and plotted as shown in Figure 3

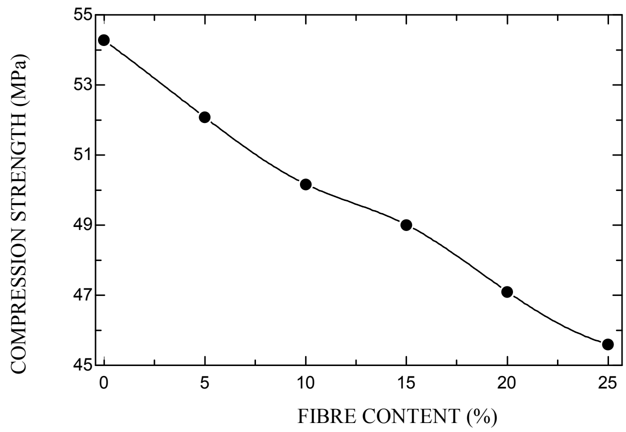

Figure 3. *Graph of compressive values against the fibre content.*

Hardness Test Result

Hardness tests were carried out on composite material and the hardness value of the materials determined using the Brinell Hardness Number (BHN). Figure 4 shows the graph of Hardness values in relation to the fibre content of the composite.

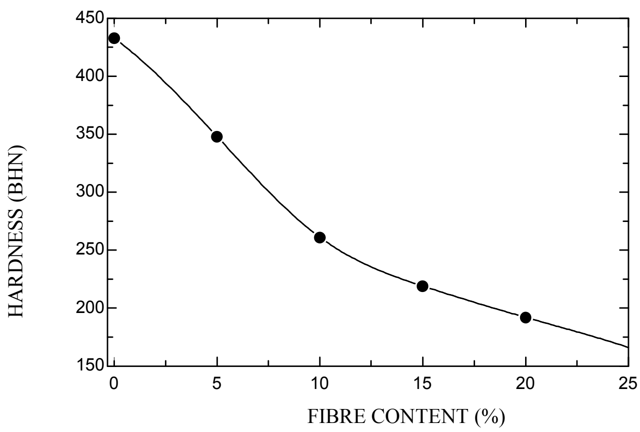

Figure 4. *Ggraph of Hardness values plotted against fibre content.*

The mechanical properties of the developed composite according the fibre content are shown in Table 2.

Table 2. *Mechanical Properties of Nigerian Long Bamboo Fibre- Reinforced Polymer Composite with different fibre loading.*

Sample number	Volume fraction of fibre (%)	Mechanical properties					
		Tensile strength (MPa)	Compression strength (MPa)	Flexural strength (MPa)	Hardness (BHN)	Impact strength (J)	Modulus of elasticity (GPa)
1	0	32.89	54.28	4.86	433	0.845	0.971
2	5	40.70	52.08	9.00	348	1.000	1.440
3	10	65.80	50.17	14.57	261	1.184	1.736
4	15	60.00	49.01	10.90	219	1.367	0.857
5	20	55.20	47.10	9.50	192	1.667	0.633
6	25	49.50	45.60	7.00	166	1.890	0.429

3.2. Discussion

In this research work, the method of fibre extraction used was the maceration method.

The tensile strength of the developed material was determined using the data generated during the tensile test. This was done for all the categories of the fibre content. The applied force versus extension as shown in Figures 1 was plotted for material developed.

The tensile strength of the developed material was determined to be 65.79 MPa. This shows that between the values of 100 N and 200 N load applied to the materials, there is great resistance to stretching force till the failure finally occurs. Theoretically the maximum allowable load that can cause permanent deformation to this epoxy material is 100 N. From the foregoing it shows that the long bamboo fiber reinforced composite can withstand twice the strength of the unreinforced composite before fracture while in service. This result is in agreement with [3] who found that the tensile strength of natural fibre increased with reinforcement of natural fiber. It is of special interest to note that the observed ultimate tensile strength of the composite lies between AboCast 50-3/Abocure 50-17 Epoxy (Tensile strength 65.84 MPa) and Aluminum alloy 1080A with (tensile strength of 60 MPa) as shown in Table 2. The developed material can be used where cast iron and aluminum alloy 1080A can be used. The material will also have chemical and corrosion resistance.

Flexural strength test was carried out on the material to find out its ability to resist deformation under load. This test was carried out on the developed material. In this test different magnitudes of forces were applied as plotted and shown in Figure 2 with corresponding deflections or deformations. For the material the maximum force which it could withstand was 14.57Mpa beyond which the material was completely deformed. The graph shows also that even when the load was removed there was still further elongation of the material which showed its plasticity level.

The compressive strength test was carried out to determine the force that can deform the material. The results of the compressive test are represented in Figure 3. It can be observed from the graph that higher the fibre reinforcement the lower the compressive strength that the developed material can withstand.

Hardness is a property of a material which measures its resistance to localized deformation in terms of penetration, indentation, scratching and abrasion. Hardness test is one of the best tests giving an indication of the material to resist indentation. Figure 4 shows the information about the hardness test carried out on the developed material. The values obtained showed that the developed reinforced material had lower value when compared to the unreinforced material.

4. Conclusion

Natural fibres, when used as reinforcement, compete with such conventional fibres as glass fibre, graphite etc. Several natural fibre composites reach the mechanical properties of glass fibre composites, and they are already applied in areas such as; in automobile and furniture industries. Till date, the most important natural fibres are Jute, flax, bamboo and coir. Natural fibres are renewable raw materials and they are recyclable.

The following conclusions can be drawn from the present research.

i. It has been observed that the mechanical properties of the composites such as micro-hardness, tensile strength, flexural strength, impact strength etc. of the composites are also greatly influenced by the fibre fraction and type.
ii. The bamboo is known in Nigeria only for domestic use, this research has proved that it can be successfully utilized to produce composite by bonding with suitable resins to obtain value added products.
iii. The modification of fibre significantly improves the fiber matrix adhesion which in turn enhances the mechanical properties of the composite.

References

[1] Ahmed, M. and Kamke, F. A., "Analysis of Calcutta Bamboo for Structural Composite Materials: Physical and Mechanical properties", *Wood Science Technology*, 2008. 39 (6): 448-459.

[2] Baeurle, S. A., "Multiscale Modeling of Polymer Materials Using Field-Theoretic Methodologies": A Survey about Recent Developments. *Journal of Mathematical Chemistry*, 2009. 46 (2): 363–426, doi: 10.1007/s10910-008-9467-3.

[3] Bax, B. and Mussig, J., "Impact and Tensile Properties of PLA/Cordenka and PLA/flax Composites". *Composites Science and Technology*, 2008. 68 (4): 1601-1607.

[4] Biswas, S. and Satapathy, A. (2010). An Assessment of Erosion Wear Response of SiC Filled Epoxy Composites Reinforced with Glass and Bamboo Fibres. *International Polymer Processing*, 201. 3 (2): 205-222.

[5] Biswas, S., Satapathy, A. and Patnaik, A. (2010). Effect of Ceramic Fillers on Mechanical Properties of Bamboo Fibre Reinforced Epoxy Composites: A Comparative Study, *Journal of Advanced Materials Research*, 8 (4): 1031-1034.

[6] LuTingju, Man Jiang, Zhongguo Jiang, David Hui, Zeyong Wang, Zuowan Zhou, Effect of surface modification of bamboo cellulose fibers on mechanical properties of cellulose/epoxy composites, Composites Part B: Engineering, Volume 51, August 2013, Pages 28-34.

[7] Li Yanjun, Lanxing Du, Chi Kai, Runzhou Huang, Qinglin Wu, Bamboo and high density polyethylene composite with heat-treated bamboo fiber: Thermal decomposition properties, 2013. Volume 8, Issue 1.

[8] Mohan, R. K. and Ratana P. A. V. "Fabrication and Testing of natural fibre Composites: Vakka, sisal, bamboo and banana. Journal of Materials and Design, 2010. 31 (1): 508-513.

[9] Narayan, R., "Biomass (renewable) resources for production of materials, chemicals and fuels" – a paradigm shift, ACS Symp Ser 1992, 476.3.

[10] Netra, L., B. Thomas, S., K. and Rameshwar, A., "Analysis of morphological and mechanical behaviours of bamboo flour reinforced polypropylene composites, Nepal Journal of Science and Technology, 2012. 13 (1): 95-100.

[11] Prity Aniva Xess, "Erosion wear behaviour of bamboo fiber based hybrid composites, M. Tech. Thesis submitted to National Institute of Technology, Rourkela, 2012.

[12] Sahay, S. A study on the effect of chemical treatment on the mechanical behaviour of Bamboo-Glass Fiber Reinforced Epoxy based hybrid composites, National Institute of Technology, Rourkela, 2012.

[13] Sanjay, K., Chattopadhyay, R. K., Ramagopal, U., Aloke, K., "Bamboo fiber reinforced polypropylene composites and their mechanical, thermal, and morphological properties", Journal of Applied Polymer Science, Volume 119, Issue 3, Pages 1619-1626, 5 February 2011.

[14] Ratna, A. V., Prasad, K., R. "Mechanical properties of natural fiber reinforced polyster composites: Jowar, Sisal and Bamboo, Materials & Design", Volume 32, Issue 8-9, September 2011, Pages 4658-4663.

[15] Kumar, V., Pradeep, K., Kushwaha, R. K., "Impedance-spectroscopy analysis of oriented and mercerized bamboo fiber-reinforced epoxy composite", Journal of Materials Science, May 2011, Volume 46, Issue 10, pp 3445-3451.

[16] Kushwaha, K. P. and Kumar R., "Bamboo Fiber Reinforced Thermosetting Resin Composites": Effect of Graft Copolymerization of Fiber with Methacrylamide", Journal of Applied Polymer Science, Vol. 118, 1006-1013 (2010).

[17] Sahoo, A., K. Ogra, R., Sood, A., and Ahuja, S. P., "Nutritional evaluation of bamboo cultivars in sub-Himalayan region of India by chemical composition and in vitro ruminal fermentation", Japanese Society of Grassland Science, (Jan 2010) 56, pg 116-125.

[18] X.-J. Xian, Zheng, W.-P., Shin, F. G., "Analyses of the mechanical properties and microstructure of bamboo-epoxy composites". Journal of Materials Science 24 (1989), 3483-3490.

[19] Abhijit, J., M., Rao Bhaskar and Lakshmana, R. C., "Extraction of Bamboo Fibers and Their Use as Reinforcement in Polymeric Composites" Journal of Applied Polymer Science, 2000. Vol. 76, 83-92.

[20] Yong, C. and Yi-qiang, "Evaluation of statistical strength of bamboo fiber and mechanical properties of fiber reinforced green composites", J. Cent. South Univ. Technol. 2008. 15 (s1): 564-567.

[21] Lakkard, S. C. Patel, J. M. "Mechanical properties of bamboo, a natural composite". J Fibre Science Technology 1981; 14: 319-22.

[22] Amada, S. Ichikawa, Y. Munekata, T. and Nagase, Y. and Shimizu, H. "Fiber texture and mechanical graded structure of bamboo". Composites Part B 1997; 28B: 13-20.