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An Experimental and Numerical Approach of Polymer Composites Based on Jute-Bamboo Natural Fiber

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KEYWORDS

Composites;
Polymer adhesives;
Mechanical properties;
Natural fiber;
Numerical approach.

ABSTRACT

Due to the excellent mechanical properties, availability, and low cost, natural fiber is considered as potential reinforcement to make composite for many applications. In this study, the mechanical properties of jute-bamboo natural fiber based polymer composites are investigated both experimentally and numerically. Another attempt has been made to fabricate sports and safety equipment such as skateboards and helmets and investigated its mechanical performances. The materials were chosen epoxy resin as the matrix and woven jute and bamboo fiber as reinforcement. Hand layup techniques were used to fabricate the composites. The composites thus made were tested for their mechanical properties like the tensile test, flexural test, and impact test. Experimental results indicated that by incorporating the optimum amount of jute and bamboo fibers, the overall strength of the composite can be increased. Tensile strength; flexural strength and impact strength of composite sample JB31 are found to be higher 49.89 MPa, 45.43 MPa, and 132 J/m^2 respectively. Based on the test results and cost analysis, these composites can be used as the replacement of traditional material for making skateboards and safety helmets. A numerical procedure based on 3D modeling was carried out to evaluate the overall behavior of these composites. Modeling is carried out in Solid works and imported to ANSYS software. The analysis results were found to be closer to the experimental results.

1. Introduction

Over the last several years, there has been a growing interest in the use of natural fibers as reinforcement of polymer based on composites due to their excellent mechanical properties, low weight and low cost, easy availability, easy processing, being environmentally friendly, flexibility, high strength, and stiffness [1-3]. The main component of natural fiber is cellulose and the common source is plant kingdom including cotton, flax, hemp, bamboo, sisal, jute, banana, pineapple, etc. Bamboo fiber is cellulose fiber and is found to have excellent properties like high tensile strength, high specific strength, low cost when compared with synthetic fiber [4]. Jute is a long and soft vegetable fiber and this fiber is in great demand due to its cheapness, softness, color, high cash value, versatile nature, luster, uniformity, and length [5]. Due to environmental concerns, the high cost of synthetic materials, the focus of research on natural fibers like bamboo and jute as an alternative reinforcement in polymer composites have created an enormous interest of many researchers and scientists. Shin et al [6] and Okubo et al [7] found that due to reasonably good mechanical properties comparable to ordinary glass fiber composites, bamboo fiber reinforced composites can be used as a structural material in many applications. Rafiquzzaman et al. [8] investigated the mechanical performance of jute-glass fiber based on polymer composite. They found that jute fiber can be a very potential candidate for partial replacement of high-cost glass fibers for low load bearing applications. The use of a hybrid system was effective in increasing the tensile and dynamic mechanical properties of the oil palm-

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epoxy composite because of enhanced fiber/matrix interface bonding [9]. Verma et al. [10] examined the mechanical properties of glass/jute hybrid composites. It has been found that titanate treatment of jute fabric results in enhanced performance characteristics and mechanical properties of hybrid composites. Toshihiko et al. [11] investigated the tensile properties of jute, bamboo, and kenaf fiber based on polymer composites. They found that due to high stiffness and strong interfacial bonding kenaf fiber based on composite has higher tensile properties followed by jute and bamboo fiber based on composites. Another study showed that the impact behavior of bamboo-jute hybrid polymer composite is superior when compared with the single bamboo fiber based on composite [12]. Reza et al. [13] investigated the effect of three variables such as fiber orientation, CNT, and nano clay as fillers on the buckling strength of hybrid nano-composite and found that fiber orientation is the most effective parameter in concern of strength. Ahmed et al. [14] studied the elastic properties and notch sensitivity of untreated woven jute and jute-glass fabric reinforced polyester hybrid composites, analytically and experimentally. The jute composites exhibited higher notch sensitivity than jute–glass hybrid composites. Dixit et al. [15] reported a remarkable improvement in the tensile and flexural properties of hybrid composites compared to the un-hybrid composites. Krishnaprasad et al. [16] investigated the Mechanical and Thermal Properties of Bamboo Micro fibril Reinforced Polyhydroxybutyrate Bio-composites. They found that 10 wt% fibers loading has superior tensile strength. Whereas, impact strength of 20 wt.% fiber loading shows better impact strength. An experimental investigation of short carbon fiber based nano-composites reinforced with nano-silica and nano-clay is carried out by Janhgiri et al. [17]. They found, by increasing short fiber, the overall strength of the composite increases. Furthermore, by using nanoparticles the porosity can be reduced as a result the strength of the composite increases. The effect of stacking sequence on mechanical properties of woven jute and glass fabric reinforced polyester hybrid composites has been investigated by Ahmed et al. [18]. The stacking sequence has a larger effect on the flexural and inter-laminar shear properties than tensile properties. Thwe et al. [19] reported that mechanical properties of bamboo/glass fiber reinforced hybrid composites depend on fiber length, fiber weight ratio, and adhesion characteristics between the matrix and the fiber. The experimental investigation carried out by Mishra et al. [20] depicts that the addition of quite a small amount of glass fiber to the pineapple leaf fiber and sisal fiber-reinforced polyester matrix improves the mechanical properties of the resulting composites. The study also reported that the water absorption tendency of composites decreased because of hybridization and treatment of bio fibers. Velmurugan et al. [21] studied the tensile, shear, impact, and flexural properties of the palmyra/glass fiber hybrid composites. Fracture behavior and mechanical strength of the epoxy based on composite were investigated experimentally by Rostamiyan et al. [22]. They reported the presence of nano zirconia particles had a significant effect on the enhancement of mechanical strength and fracture toughness of epoxy composites. Pothan et al. [23] studied the banana-glass hybrid composites and found layering pattern or the geometry of the composites has a profound effect on the dynamic behavior of the composites. Zhong et al. [24] informed that the surface micro fibrillation of sisal fiber improves the compression strength, stability, tensile strength, internal bonding strength and wear resistance of the sisal/aramid fiber hybrid composites. Sanjeevamurthy et al. [25] studied the effect of moisture absorption on the mechanical properties of the coconut coir and sisal fiber hybrid composites and compared them with the composites with dry fires. It was found that the tensile and the flexural strength increased with an increase in fiber loading of composites at dry conditions.

From the above literature review, it can be seen that up to now many researchers have been investigated the hybrid effect of different natural and synthetic fiber based on composites. However, investigation of jute/bamboo based on hybrid composite is rare. The authors believed that knowledge of mechanical behaviors of the bamboo-jute fiber reinforced hybrid polymer composites would have an essential role for many applications, e.g. automobiles, sports, constructions, etc. Therefore, in the present study, mechanical behaviors of jute-bamboo natural fiber based on polymer composites are investigated. A numerical approach based on 3D modeling is carried out to correlate the experimental results with the simulation

2. Materials and Method

2.1. Materials Collection

In this study, woven jute and bamboo fiber were used as reinforcement and the epoxy resin (ADR 246 TX) was used as the matrix shown in Fig. 1 Hardener ADH 160 and Methyl Ethyl Ketone Peroxide (MEPOXE) were used to improve the interfacial adhesion and impart strength to the composites. The hardener and resin were purchased from a chemical company. The woven jute and bamboo fiber are collected from the local market. A resin and hardener mixture of 3:1 was used to obtain optimum matrix composition. Mechanical properties of jute fiber, bamboo fiber, and epoxy resin are shown in Table 1.

(a) (b) (c)

Fig. 1. (a) Woven Bamboo fiber (b) Woven Jute fiber (c) Epoxy Resin

Table 1. Mechanical Properties of fiber and matrix [8]

Properties	Jute fiber	Bamboo fiber	Epoxy resin
Density (g/cm^3)	1.3	0.8	1.2
Young modulus (GPa)	26.5	18	2.7
Specific Gravity (gm/cc)	1.3	0.8	—
Poisson's ratio	—	—	0.4

Table 2. Name and compositions of the tested sample

Sample	Compositions		
	Jute fiber (Wt. %)	Bamboo fiber (Wt. %)	Epoxy (Wt. %)
J1	40	-	60
B1	-	40	60
JB11	20	20	60
JB13	10	30	60
JB31	30	10	60

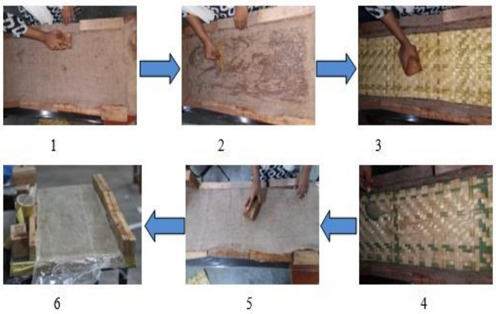

Fig. 2. Complete sequential processes for fabrication of bamboo-jute composites

Fig. 3. Photographic view of Test specimens

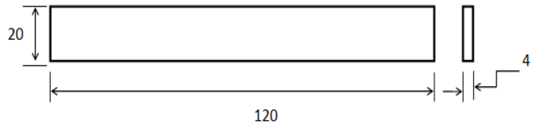

Fig. 4. The schematic diagram of test specimens (Unit: mm)

2.2. Fabrication Procedure

The fabrication of composite material was carried out by the conventional hand layup technique. First, a releasing agent and resin were applied to the mold surface. Then a layer of the woven jute fiber/woven bamboo fiber was laid down, followed by a quantity of liquid resin epoxy poured onto it. Brushes and hand rollers were used to remove any void in the fiber structure and to spread the resin evenly throughout the fibers. The process was repeated until the required number of layers was built up. Finally, these specimens are taken to the hydraulic press to force the air gap to remove any excess air present in between the fibers and resin and then kept for several hours to get the perfect samples.

The complete sequential fabrication process is shown in Fig. 2 After the composite material get hardened completely, the composite material is taken out from the hydraulic press and rough edges are neatly cut and removed as per the required dimensions. The composite laminate samples were cured by exposure to normal atmospheric conditions.

The fabricated composites were cut for mechanical testing as per the ASTM D3039, ASTM D790 and ASTM D256standards. The photographic view and the schematic diagram of the test specimens are shown in Fig. 3 and Fig. 4 respectively.

Five types of composites with different fiber wt.% were used to analyze the mechanical performances. The name and compositions of the tested sample are summarized in Table 2.

2.3. Experimental Procedure

The tensile test of the specimen was performed using an electro-mechanical testing machine as per ASTM D3039 standards.

The strength was calculated from the maximum load at failure of the tensile stress. Flexural testing commonly known as three-point bending testing was also carried out as per ASTMD790 standards by using (Universal testing machine).

Impact testing of the specimen was carried out on the Tinius Olsen machine as per the procedure mentioned in ASTM D256.

The specimen is placed in the impact machine and impact force is applied to the specimen at the other side of the V-notch by releasing the hammer to make an impact on specimens from a certain height.

After impact, the height of the hammer from the ground is noted.

All experimental tests were repeated four times to generate the data and the average value is taken for results analysis.

3. Experimental Results and Discussions

3.1. Tensile Test

The different composite specimen samples are tested in the universal testing machine (UTM) and the samples are left to break till the ultimate tensile strength occurs. The tensile stress vs displacement curves of various composites are shown in Fig. 5 Results show that composite JB31 gives better tensile strength compared to others composites.

The comparison result of various composites with different weight fractions of reinforcement is shown in table 3 and Fig. 6. Results indicate that, by incorporating jute fiber with bamboo fiber, the overall tensile strength is increased when compared with other single jute (J1) and bamboo (B1) fiber reinforced composite.

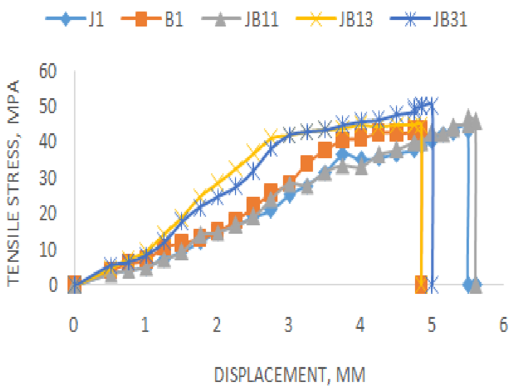

Fig. 5. Tensile stress vs displacement curves

Table 3. Average tensile, flexural, and impact strength of different samples

Sample	Tensile Strength (MPa)	Flexural strength (MPa)	Impact Strength (J/m^2)
J1	43.22	39.87	103.56
B1	42.53	36.67	94.13
JB11	46.65	37.76	101.89
JB13	44.56	39.89	117.87
JB31	49.89	45.78	132.03

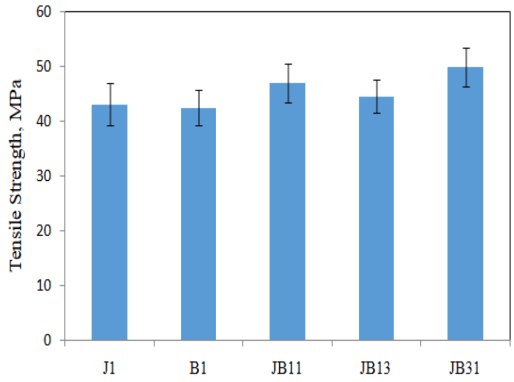

Fig. 6. Comparison results of the tensile strength (Error bar shows the standard deviation of four experiments)

When compared to the composites of single jute fiber composite (J1) and single bamboo fiber composite (B1), bamboo fiber composite (B1) exhibits lower strength (42.53 MPa) which is probably due to their poor interfacial bonding property between fibers and matrix. Similar behavior of single fiber based on composites is observed by Toshihiko et al. [11]. Furthermore, when 50% of bamboo fiber is added to support the jute fiber (JB11), the tensile strength is increased by 13% compared to the other composites. However, when jute fiber content was added in the range of 70% to 75% (JB31), the best overall strength is obtained. These results indicated that by incorporating the optimum amount of jute and bamboo fibers, the overall tensile strength of the composite can be increased, which is probably due to the hybridization effect of the composites.

3.2. Flexural Test

The flexural stress and displacement curves measured by the three point bending test are shown in Fig. 7. Results exhibit a significant difference in the strength of different samples. Flexural strength (45.78 MPa) is found to be higher for the sample JB31 followed by JB13, JB11, J1, B1 respectively. Flexural results of various composites with different weight fractions of reinforcement are presented in Table 3 and the comparison results are presented in Fig. 8. It can be seen that the flexural strength of bamboo composite (36.67 MPa) is lower than that of jute fiber composites (39.87 MPa) which is perhaps attributed to their low stiffness and poor interfacial bonding between fibers and matrix. Similar mechanical behavior of single fiber based on composites is observed by Toshihiko et al. [11]. Furthermore, with the addition of jute fiber with bamboo fiber (JB11), the composite gives better flexural strength compared with single reinforced composites. However, when jute fiber content was added in the range of 70% to 75% (JB31), the best overall strength is obtained.

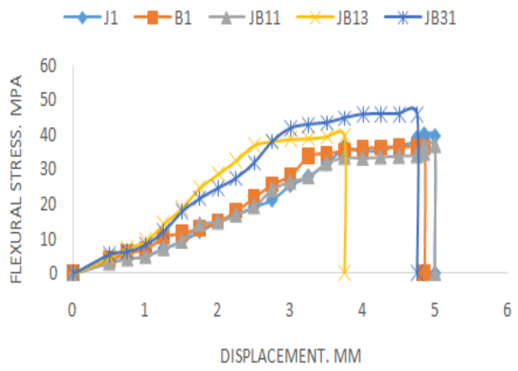

Fig. 7. Flexural stress vs displacement curves

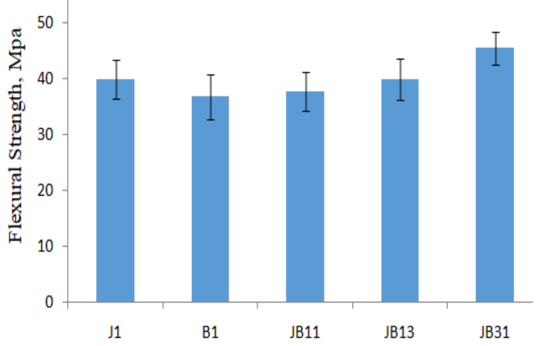

Fig. 8. Comparison results of flexural strength (error bar shows the standard deviation of four experiments)

These results indicated that by incorporating the optimum amount of jute and bamboo fibers, the overall flexural strength of the composite can be increased, which is probably due to the hybridization effect of the composites.

3.3. Impact Test

Experimental results of impact testing of various composites with different weight fractions of reinforcement are presented in Table 3 and the comparison results are presented in Fig 9. It can be seen that the impact strength of the single bamboo composite, B1 (94.13 J/m^2) is lower than that of single jute fiber composites, J1 (103.56 J/m^2) which is perhaps attributed to their low stiffness and poor interfacial bonding between natural fibers and matrix. Furthermore, the addition of jute fiber with bamboo fiber, the composite (JB11, JB13, and JB31) gives better impact strength compared with single reinforced composites. However, when jute fiber content was added in the range of 70% to 75% (JB31), the best overall strength is obtained. This is probably due to increasing the amount of jute content which is less brittle than bamboo fiber, the overall brittleness of material decreases, and impact strength increases. Similar impact behavior of jute-bamboo based hybrid composites is observed by Pramod et al. [12]. They found that the addition of jute fiber with bamboo fiber increased the overall impact strength of composites.

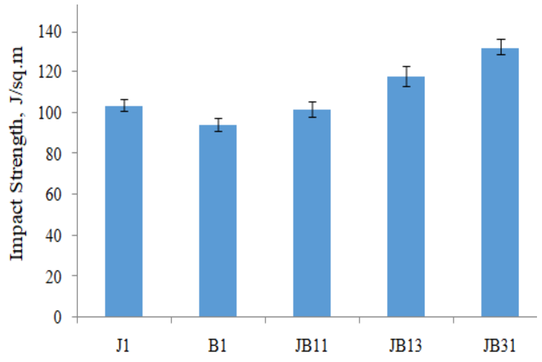

Fig. 9. Comparison results of impact strength (error bar shows the standard deviation of four experiments)

4. Skateboard and Safety Helmet

4.1. Fabrication and Performances Test

In the present study, another attempt has been made to fabricate sports and safety equipment such as skateboards and helmets by using epoxy resin with jute-bamboo reinforcement. The combination of Jute-bamboo-epoxy ratio which exhibits superior mechanical performances (JB31= jute 30%+ Bamboo 10% + epoxy 60%) were chosen and the same fabrication procedure was used to fabricate of skateboard and helmet as described in the sample fabrication section. The photograph of the fabricated skateboard and helmet is shown in Fig. 10. The skateboard and helmet thus made were tested for their mechanical properties.

Visual analysis of the skateboard shows that the hand layup process provides a reliable process to make parts, especially ones without acute angles or small radii of curvature. The impact test on the skateboard was performed by a drop test where the skateboard a player on it was placed on a platform about 1ft height from the ground. Then the player jumped from that height. This activity has been repeated from a height of 2ft and 3ft also. Then the skateboard was observed and quantified for any defect. The heights were chosen like that because while skating the player have to make a stunt from this height. The results indicate that there is no significant damage or crack observed after the player jumped from the maximum 3 ft height. Drop test results are summarized in Table 4.

(a) (b)

Fig. 10. Fabricated sports and safety equipment (a) Skateboard (b) Helmet

Table 4 Skateboard Drop Test Results

Dropped Height	Photograph after drop test	Visual observation Remarks
1ft		No significant damage or crack observed
2ft		No significant damage or crack observed
3ft		No significant damage or crack observed

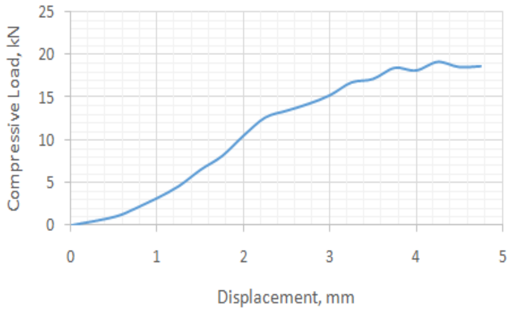

Fig. 11. Applied load vs. displacement curve during the helmet compression test.

Visual analysis of the helmets shows that the hand layup process provides a reliable process to make parts, especially ones without acute angles or small radii of curvature. The impact test on the helmet was performed by a drop test. In this test, the helmet was placed on a platform and a 3.4 Kg weight was dropped on it from a height, traveling at 9.9 m/s on impact. The test is run such that the impact occurs at different positions and the resulting damage is observed and quantified. A weight of 3.4 kg was chosen because it approximates the weight of a brick that is used for construction purposes. There was no visible damage to the helmet and no dents were seen. Under compression test, the helmet was placed with its base on a platform and compressed under constant displacement of 0.2mm/sec. The applied load vs displacement curve during the compression test is shown in Fig. 11. The maximum load applied was 18.2 kN with deformation of about 5mm.

4.2. Applicability and Cost Analysis

For the applicability test of these composites, mechanical properties (strength) of maple wood and ABS plastic were taken as a benchmark that traditionally used materials for making skateboard and safety helmets respectively. The comparison mechanical properties of jute-bamboo composite with other materials are shown in Table 5. From these results, it is observed that natural fiber based on hybrid composites exhibit superior mechanical properties compared with numerous engineering plastics and maple wood used for making safety helmets and skateboards [28-29]. These results indicate that these hybrid composites can meet the necessary criteria for a skateboard and safety helmet application. Results also indicate that jute fiber is more effective than bamboo fiber for enhancing the mechanical properties of polymer composites [8, 11, and 16]. This is probably due to the strong fiber/matrix interface bonding and higher stiffness of jute fiber based on composites compared to the bamboo fiber. Furthermore, by incorporating the optimum amount of synthetic fiber with natural fibers, the overall strength of the hybrid composite can be increased [8]. The cost analysis of composite helmets and skateboards is shown in Table 6. The cost analysis results show that by incorporating the optimum amount of jute and bamboo fibers, the overall strength of the composite can be increased and cost saving of more than 30% to 35% can be achieved. Finally, it can be concluded that in the concern of cost and environment, these composites can be used as the replacement of traditional material for making skateboard and safety helmets.

Table 5. Comparison mechanical properties of fiber based on hybrid polymer composites

	Fiber Content (Wt %)	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (J/m^2)
This study	Jute 30%+ bamboo 10% (JB31)	49.89	45.78	132.03
Rafiquzzaman et al. [8]	Jute 30%+ glass 10%	64.89	76.78	189.65
Thwe et al. [19]	Bamboo 10% + Glass 20%	16.00	28.50	-
	Bamboo 20% + Glass 100%	17.50	27.30	-
Diuxit et al. [15]	Jute + Sisal	98.5	71.43	-
Krishnaprasad, et al. [16]	Bamboo 10%	11.05	-	99
	Bamboo 20%	12.05	-	75
	Bamboo 30%	11.17	-	52J
Comparable material (Maple Wood) [26]	-	5.31	34.50	-

Comparable material (ABS plastic) [27]	-	52.30	42.00	-

Table 6 Cost analysis of skateboard and helmet

Materials	Cost (Skateboard), $	Cost (Helmet), $
Jute 30% + Bamboo 10% Composite	17.5	6.5
Maple wood	25 -150	-
ABS Plastics	-	10-12

5. Numerical Analysis

In this study, commercial finite element analysis software was employed to correlate the experimental results with simulation. For the simulation, 3D modeling was used to design the original dimension of the fabricated skateboard and helmet. Modeling is carried out in Solid works and imported to ANSYS mechanical software. Boundary conditions are applied for uniaxial tensile test conditions. Contact between fiber and matrix is assigned as bonded conditions. Material properties, obtained from the Table 1 are assigned to respective models. Various layers are created by mating one layer to another in Solid works 2013 and these layers are uniform. By incorporating this cad model in ANSYS, a3D model mesh is done. The geometry of the model is shown in Fig. 12 and the finite element mesh of the model is shown in Fig. 13. In this analysis, mesh size is selected moderately coarse. A 20 nodes quadratic brick element was used in this model. The jute and bamboo fiber volume fraction was modeled as a real microstructure of the skateboard and helmet. The material data used in FEA (finite element analysis) were obtained from monotonic experimental values, based on differentiation of the composite structure. The models were assigned as homogeneous sections in dynamic conditions with explicit elements. The line on the bottom of the shell was constrained in the y-direction.

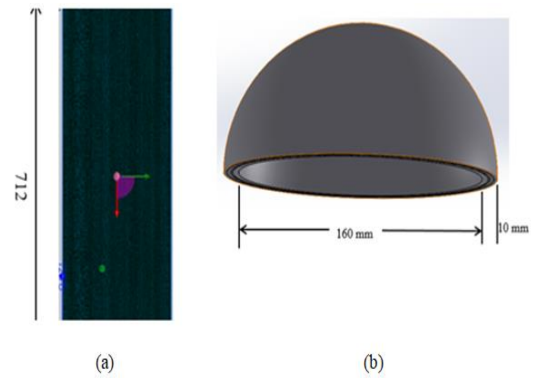

Fig. 12. Geometry with dimensions (a) Skateboard (b) Helmet (unit: mm)

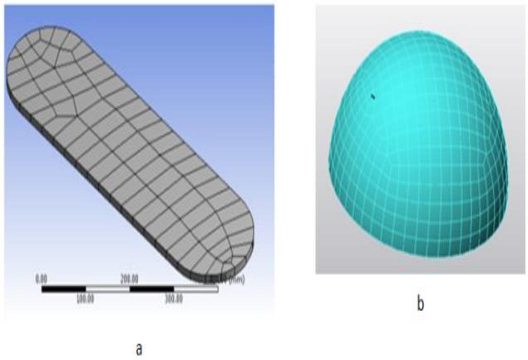

Fig.13. Mesh of the FEA model(a) Skateboard (b) Helmet

5.1. Boundary Conditions for Skateboard

For applying force on the geometry first of all two fixed support is applied on the two ends of the board in the lower portion. This helps to fix all degrees of freedom of the two ends. Next, the force is applied to the upper portion of the board. Here Lasso Volume Selection of the mesh is used to select the nodal areas where the force is to be applied. The correct face and force of the appropriate magnitude and direction is applied to the geometry

5.2. Boundary Conditions for Helmet

For applying force on the geometry first of all fixed support is applied on the lower portion of the helmet. This helps to fix all degrees of freedom of the lower ends. Next, the force is applied to the upper portion of the helmet. Here mesh is used to select the nodal areas where the force is to be applied. The correct face and force of the appropriate magnitude and direction are applied to the geometry.

6. Numerical Results and Discussions

The Von misses stress distributions under bending load conditions of the skateboard and helmet are shown in Fig. 14. This figure shows the high stress developed, where the force is applied and the equivalent stress is 55.21MPa. This result is found closer to experimental results where the flexural stress is 48.9 MPa.

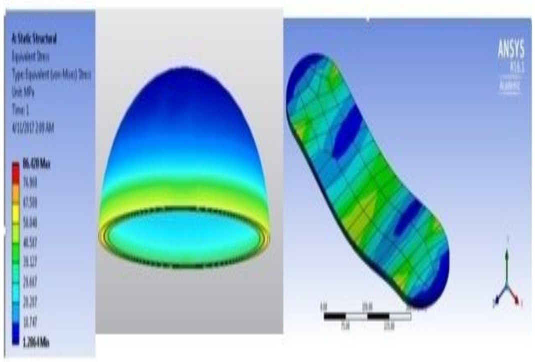

Fig. 14. Von misses stress

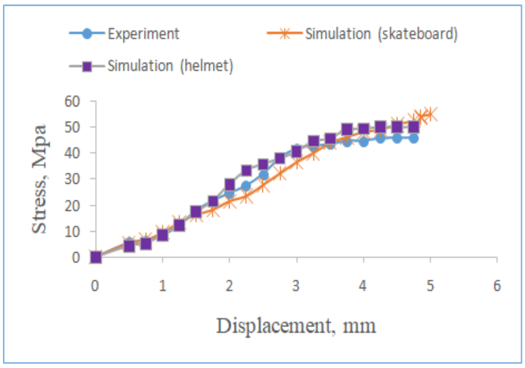

Fig. 15. Stress versus displacement relationship for jute–glass fiber reinforced composite.

The stress versus displacement curve measured by experiment and the FEM for jute–bamboo fiber reinforced composite is shown in Fig. 15. For the FEM analysis, the displacement was recorded as the input value and the load was recorded along the bending direction. The FEM results were found to be closer to the experimental results. However, FEM results showed about 10-15% higher stress compared to the experimental results. It is essential to note that in this simulation study, the composite plate had been assigned as an isotropic type of material in the input of FEA which has the same elastic properties in all directions. For the numerical analysis, the composite structure was considered as homogeneous materials. The inhomogeneous effect of the real microstructure of composite structure may be the cause of the difference in experimental and numerical results. This study is an initial work for simulation, to determine the suitability of the Ansys FEA software for verification and validation works.

7. Conclusions

In this present study, mechanical performances of jute-bamboo based polymer composites were tested and analyzed both experimentally and numerically. Another attempt has been made to fabricate sports and safety equipment such as skateboards and helmets and investigated its mechanical performances. It has been explored that the mechanical properties of the composites such as tensile strength, flexural strength, and impact strength are highly influenced by the wt% of the fibers used. The major findings are summarized below:

1. By incorporating the optimum amount of jute and bamboo fibers, the overall mechanical properties of the composite can be increased.
2. When compared with single fiber based on composites, hybrid composites exhibit superior mechanical properties.
3. The average tensile strength (49.89 MPa), flexural strength (45.78 MPa), and impact strength (132.03 $J/m^{2)}$ are found to be higher for the sample JB31 followed by JB13, JB11, J1, B1 respectively.
4. In the concern of cost and environment, these composites can be used as the replacement of traditional material for making skateboards and safety helmets. Furthermore, other potential applications of the jute-bamboo based hybrid composites can be in the automobiles and building industry.
5. Simulation results were found to be closer to the experimental results.

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References

[1] Chawla, K.K., 1998. *Composite materials: Science and Engineering.* 2ndedition. Springer, New York, pp. 13-87.

[2] Ashraf, M.A., Zwawi, M., Taqi Mehran, M., Kanthasamy, R. and Bahadar, A., 2019. Jute based bio and hybrid composites and their applications. *Fibers*, *7(9)*, p.77.

[3] Vignesh, V., Balaji, A.N., Rabi, B.R.M., Rajini, N., Ayrilmis, N., Karthikeyan, M.K.V., Mohammad, F., Ismail, S.O. and Al-Lohedan, H.A., 2021. Cellulosic fiber based hybrid composites: A comparative investigation into their structurally influencing mechanical properties. *Construction and Building Materials*, *271*, p.121587.

[4] Jain, S. and Kumar, R., 1994. Processing of bamboo fiber reinforced plastic composites. *Material and Manufacturing Process*, *9*(5), pp.813-828.

[5] Singh, H., Singh, J.I.P., Singh, S., Dhawan, V. and Tiwari, S.K., 2018. A brief review of jute fibre and its composites. *Materials Today: Proceedings*, *5*(14), pp.28427-28437.

[6] Shin, F.G., Xian, X.J., Zheng, W.P. and Yipp, M.W., 1989. Analyses of the mechanical properties and microstructure of bamboo-epoxy composites. *Journal of Materials Science*, *24*(10), pp.3483-3490.

[7] Okubo, K., Fujii, T. and Yamamoto, Y., 2004. Development of bamboo-based polymer composites and their mechanical properties. *Composites Part A: Applied science and manufacturing*, *35*(3), pp.377-383.

[8] Rafiquzzaman, M., Islam, M., Rahman, H., Talukdar, S. and Hasan, N., 2016. Mechanical property evaluation of glass–jute fiber reinforced polymer composites. *Polymers for*

Advanced Technologies, *27*(10), pp.1308-1316.

[9] Jawaid, M., Khalil, H.A., Hassan, A., Dungani, R. and Hadiyane, A., 2013. Effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm epoxy composites. *Composites Part B: Engineering*, *45*(1), pp.619-624.

[10] Varma, I.K., Krishnan, S.A. and Krishnamoorthy, S., 1989. Composites of glass/modified jute fabric and unsaturated polyester resin. *Composites*, *20*(4), pp.383-388.

[11] Toshihiko HOJO, Zhilan XU, Yuqiu YANG, Hiroyuki HAMADA., 2014. Tensile Properties of Bamboo, Jute and Kenaf Mat-reinforced Composite. *Energy Procedia*, 56, p. 72.

[12] Bansal, S., Ramachandran, M. and Raichurkar, P., 2017. Comparative analysis of bamboo using jute and coir fiber reinforced polymeric composites. *Materials Today: Proceedings*, *4*(2), pp.3182-3187.

[13] Azadi, R. and Rostamiyan, Y., 2015. Experimental and analytical study of buckling strength of new quaternary hybrid nanocomposite using Taguchi method for optimization. *Construction and Building Materials*, *88*, pp.212-224.

[14] Ahmed, K.S., Vijayarangan, S. and Naidu, A.C.B., 2007. Elastic properties, notched strength and fracture criterion in untreated woven jute–glass fabric reinforced polyester hybrid composites. *Materials & design*, *28*(8), pp.2287-2294.

[15] Dixit S. & Verma P., 2012. The effect of hybridization on mechanical behaviour of coir/sisal/jute fibres reinforced polyester composite material. *Research journal of Chemical Science*, 2, p.91.

[16] Krishnaprasad, R., Veena, N.R., Maria, H.J., Rajan, R., Skrifvars, M. and Joseph, K., 2009. Mechanical and thermal properties of bamboo microfibril reinforced polyhydroxybutyrate biocomposites. *Journal of Polymers and the Environment*, *17*(2), pp.109-114.

[17] Jahangiri, A.A. and Rostamiyan, Y., 2020. Mechanical properties of nano-silica and nano-clay composites of phenol formaldehyde short carbon fibers. *Journal of Composite Materials*, *54*(10), pp.1339-1352.

[18] Ahmed, K.S. and Vijayarangan, S., 2008. Tensile, flexural and interlaminar shear properties of woven jute and jute-glass fabric reinforced polyester composites. *Journal of materials processing technology*, *207*(1-3), pp.330-335.

[19] Thwe, M.M. and Liao, K., 2000. Characterization of bamboo-glass fiber reinforced polymer matrix hybrid composite. *Journal of materials science letters*, *19*(20), pp.1873-1876.

[20] Mishra, S., Mohanty, A.K., Drzal, L.T., Misra, M., Parija, S., Nayak, S.K. and Tripathy, S.S., 2003. Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. *Composites science and technology*, *63*(10), pp.1377-1385.

[21] Velmurugan, R. and Manikandan, V., 2007. Mechanical properties of palmyra/glass fiber hybrid composites. *Composites Part A: applied science and manufacturing*, *38*(10), pp.2216-2226.

[22] Rostamiyan, Y., Youseftabar, H. and Azadi, R., 2018. Experimental study on the effect of nano zirconia on mechanical strength and microstructure of damaged epoxy-nanocomposites. *Materials Research Express*, *6*(2), p.025046.

[23] Pothan, L.A., George, C.N., John, M.J. and Thomas, S., 2010. Dynamic mechanical and dielectric behavior of banana-glass hybrid fiber reinforced polyester composites. *Journal of Reinforced Plastics and Composites*, *29*(8), pp.1131-1145.

[24] Zhong, L.X., Fu, S.Y., Zhou, X.S. and Zhan, H.Y., 2011. Effect of surface microfibrillation of sisal fibre on the mechanical properties of sisal/aramid fibre hybrid composites. *Composites Part A: Applied Science and Manufacturing*, *42*(3), pp.244-252.

[25] Girisha, C., Sanjeevamurthy, G. and Srinivas, G.R., 2012. Sisal/coconut coir natural fibers-epoxy composites: Water absorption and mechanical properties. *Int J Eng Innov Technol*, *2*(3), pp.166-170.

[26] Skateboard Deck: *Mechanical Properties,* 2015. Available at: https://skateboardpropertiesblog.wordpress.com/mechanical-properties/ April 2022.

[27] Plastic International: *Material Property Matrix*. Available at: https://www.plasticsintl.com/material-property-matrix?materials=abs, April 2022.