

Effect of Chemical Treatment on the Mechanical Properties of Luffa Fiber Reinforced Epoxy Composite

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ABSTRACT

Novel luffa fiber reinforced epoxy composites are prepared and their mechanical properties are investigated before and after chemical treatment. The unique natural knitting structure of luffa provides an excellent reinforcement to the epoxy matrix. Knowing that the fiber-matrix bond gets stronger and imparts more strength to the composite when chemical treatment is done on fibers, composites are manufactured by untreated and treated luffa fiber using epoxy as a matrix. Luffa fiber is treated using benzoyl chloride and NaOH. Tensile and flexural tests are conducted on composites to investigate the effect of chemical treatment. Test results have shown that the chemical treatment on fibers improved the tensile strength, tensile modulus, flexural strength and flexural modulus by 27.21%, 49.37%, 41.84% and 6.44% respectively. Tensile modulus of luffa fiber composite is found to be higher compared with commonly used natural fiber composites. The experimental investigation suggests that, chemically treated luffa fiber reinforced epoxy composites could be a potential lightweight material in various applications.

Keywords: Luffa Fiber; Benzoyl Chloride Treatment; Mechanical Properties; Natural Fiber Composite



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1. Introduction

In the recent time, composite materials have gained huge attention to the researchers due to its superior mechanical properties like strength to weight proportion, crack durability, better physical, chemical and electrical properties etc. [1]-[3]. In composite materials, fibers are used as reinforcement while the matrix conforms the shape of the material which also transfers the load between fibers. Fibers could be synthetic (glass, carbon, nylon etc.) or natural (jute, bamboo, luffa etc.). Although, synthetic fibers have better strength, natural fiber are comparatively cheaper, abundant in nature and renewable sources of fiber [4]. Despite the fact that, the strength of the natural fiber is lower than the synthetic fiber, natural fibers are used in automobile industries and many other products like ball point pen, fishing hook, tennis racket, bicycle etc. [5]-[6].

Previous researchers have studied mechanical properties of different natural fiber reinforced composites with or without fiber surface treatment. Akil et al. studied the water absorption of jute fiber reinforced polyester composites [7]. A.V.R. Prasad and K.M. Rao studied mechanical properties of jowar, sisal and bamboo fiber reinforced composites [8]. A lot of research has been carried out on bamboo fiber reinforced composites by different researchers [9]-[13]. Moisture absorption characteristics of sisal and roselle fiber reinforced hybrid composites were studied by Athijayamani et al. [14]. Dhakal et al. [15] studied the effect of water absorption on the mechanical properties of hemp fiber reinforced composites. Palm and coir fiber reinforced composites were studied by Haque et al. [16].

Luffa cylindrica is a natural fiber of less weight, low cost and useful mechanical property but also has an uncommon

woven form which is exceptional in other natural fibers. Although a lot of research about mechanical properties of natural fiber reinforced composites were found in the literature. However, mechanical properties of luffa fiber reinforced composites are scarce in literature. Different mechanical properties of luffa fiber reinforced composites were studied by N. Mohanta and S.K. Acharya [17]-[18]. In this paper, the tensile and flexural properties of natural Luffa fiber are reported. The effect of NaOH and benzoyl chloride treatment on fiber surface to enhance the mechanical properties of Luffa fiber reinforced polymer composite with four layers of fiber interface is analyzed.

2. Experimental Details

2.1 Materials

Luffa fiber is used as reinforcement and epoxy (LY 556/HY 951 hardener) is used as matrix material. The Luffa cylindrica is collected from local agricultural market of Bangladesh and later, this luffa cylindrica is used to extract luffa fiber as described in section 2.2. The hardener is mixed with resin at a ratio of 1:10 as suggested by the manufacturer. NaOH and Benzoyl chloride are used to treat the fiber surface.

2.2 Fiber Extraction

Luffa fiber is collected out of ripe Luffa (**Fig. 1(a)**). When Luffa is ripe the xylem fiber network is opened consisting of lignin and cellulose. The natural lignin-cellulose bond is weaker. To form a stronger bond lignin needs to separate out which acts as matrix here. The fiber is separated from lignin-cellulose bond by fermenting in fermented water for 15 days (**Fig. 1(b)**). The extracted fiber is then dried in atmospheric air (**Fig. 1(c)**).

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Fig. 1 (a) Raw luffa, (b) Fermenting in water and (c) Drying in atmospheric air.

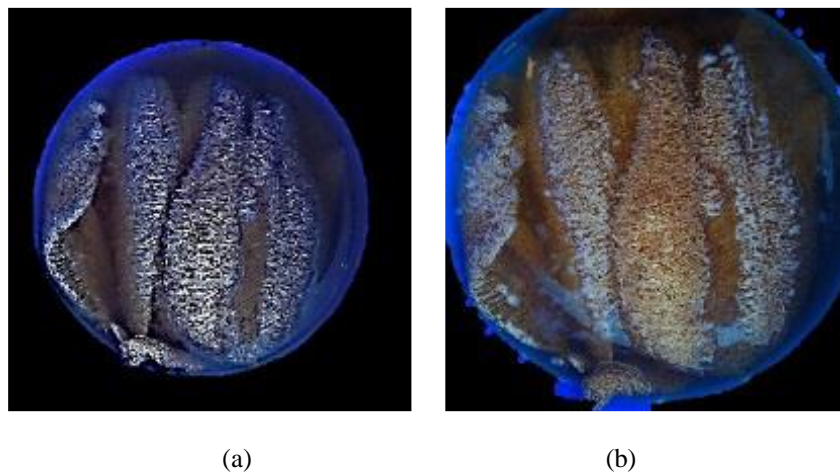


Fig. 2 (a) Fiber mixing with NaOH solution and (b) After 1h the NaOH and fiber mixture

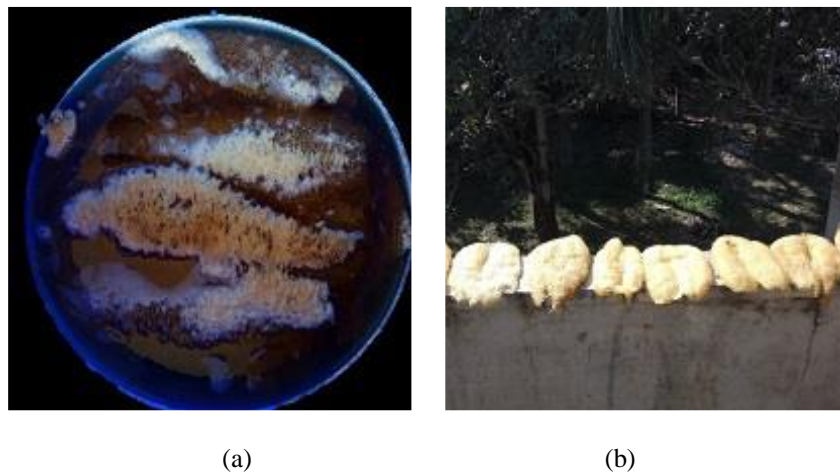


Fig. 3 (a) After 15 minutes continuous stirring the benzoyl chloride and fiber mix and (b) Drying in atmospheric air.

2.3 Chemical Treatment

To enact the hydroxyl bond of the cellulose and lignin, the strands are treated with 10% NaOH for 1 hour as shown in [Fig. 2](#). After that, the strands are kept in benzoyl chloride for 15 minutes with continuous stirring ([Fig. 3](#)). Benzoyl chloride removes the cellulose and lignin bond by creating cellulose and benzoyl chloride bond. The strands are then soaked in ethanol which weakens the benzoyl chloride-cellulose bond. It is necessary to weaken this benzoyl chloride-cellulose bond

because it reduces the fiber matrix interfacial strength. The strands are then washed properly using distilled water to remove any additional ethanol. Finally, the strands are dried in atmospheric air followed by oven drying at 70 °C for 6 hours [\[17\]](#).

2.4 Manufacturing Process

Hand lay-up method is used which is a very effective way to manufacture composite [\[19\]-\[20\]](#). Rectangular aluminum plate with a size of (300 mm × 300 mm) is used as mold plate.

Fig. 4 shows the schematic diagram of the lay-up. At first, the mold release is applied to the mold plate which facilitate the easy removal of composite after curing. The resin hardener mixer is then applied to the mold plate with a soft roller and brush. The first layer of fiber is then placed on the mold plate and applied resin hardener mixer with the brush and roller. The roller ensures uniform distribution of resin hardener mixer on the fiber layer and removes any air bubbles that formed. The next layer of fiber is then placed on top of the first layer and the procedure repeated. Top mold plate is placed on top of the top layer of fiber and a pressure of 100 MPa is applied which ensures the uniform thickness of the manufactured composite. At this stage, the composite is cured at room temperature for 24 hours. In this way, composites are manufactured by using both treated and untreated fiber. Untreated fiber is used as a baseline for the comparison of mechanical properties.

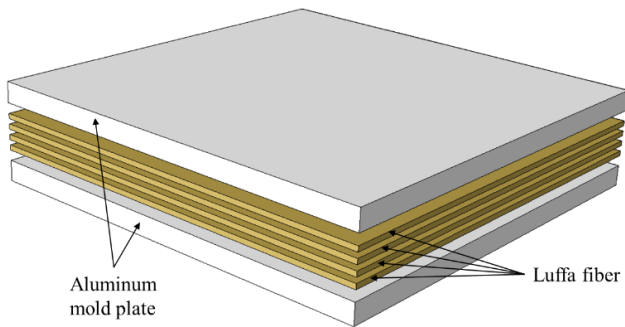


Fig. 4 Schematic diagram of lay-up.

2.5 Tensile Test

Tensile test on both type of composite (treated and untreated) are performed. Total 10 samples are tested among 5 are from untreated fiber and the remaining are from treated fiber composite. The specimens are cut from the composite plate manufactured following the standard ASTM D3039 [21] and the specimen size is 147 mm \times 20 mm \times 4.5 mm as shown in **Fig. 5**. During the test, the specimens are placed inside the hydraulic grip of universal testing machine at a loading rate of 2 mm/min. The load-displacement response are recorded and later these data are used to calculate stress and strain along with specimen width, thickness and a gauge length of 25 mm.

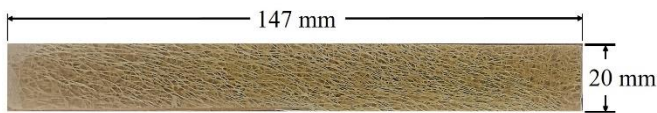


Fig. 5 Tensile test specimen.

2.6 Flexural Test

Three-point bending test is performed on the manufactured specimen to evaluate the flexural properties. Five specimen from the untreated and five specimen from the treated fiber are tested following the standard ASTM D7264 [22] and the specimen dimension is 133 mm \times 28 mm \times 4.5 mm as shown in **Fig. 6**. Three-point bending tests are carried out on the same universal testing machine with a loading rate of 1 mm/min. A constant span length to thickness of 32:1 is maintained during the test and for calculating the flexural chord modulus of

elasticity, 0.001 to 0.003 strain range is selected as suggested by ASTM D7264.

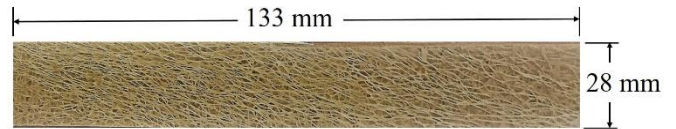
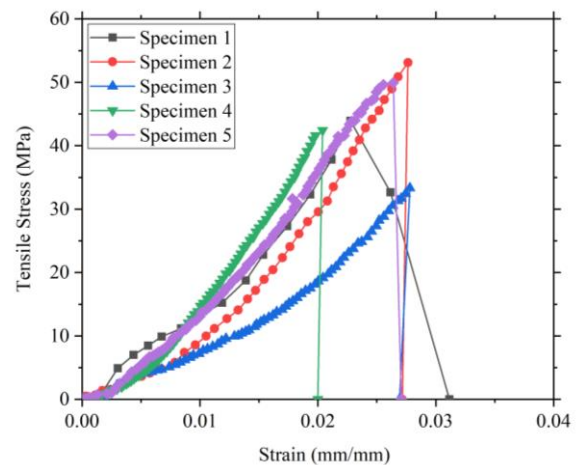


Fig. 6 Flexural test specimen.

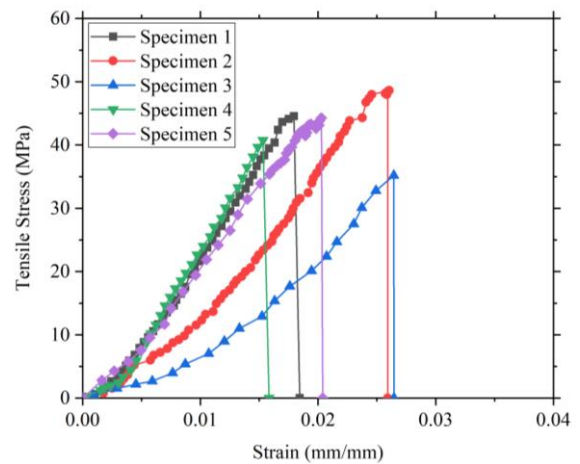
3. Results and Discussion

3.1 Tensile Test Results

As mentioned in section 2.5, tensile test is performed on luffa fiber reinforced epoxy composite for both untreated and treated fiber. **Fig. 7(a)** shows the stress-strain response for untreated fiber while **Fig. 7(b)** shows the same for the treated fiber. By comparing **Fig. 7(a)** and **Fig. 7(b)** it is observed that the maximum stress for treated fiber is higher compared to the untreated fiber which indicates that the strength of the composite manufactured from the treated fiber increases with fiber treatment. **Fig. 8(a)** confirms this statement, which is a bar chart showing the strength of untreated and treated fiber composite. The average tensile strength of untreated and treated fiber are 11.43 MPa and 14.54 MPa respectively, which suggests a 27.21% increase in the tensile strength as shown in **Table 1**.



(a)

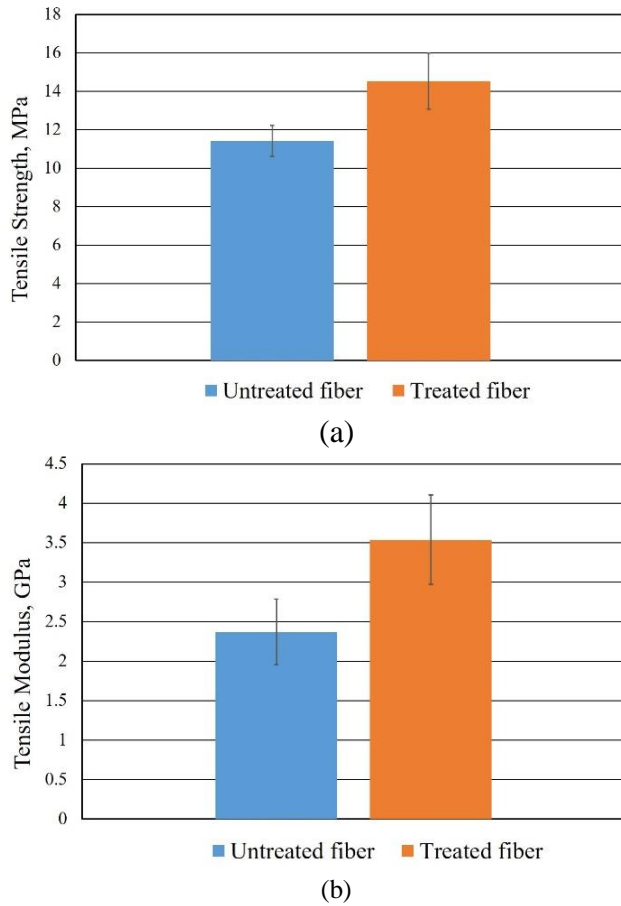


(b)

Fig. 7 Stress-strain diagram for the tensile test of (a) bamboo strip and (b) hybrid composite

Table 1 Tensile test results with standard deviation.

Condition	Tensile Strength (MPa)	% Increase	Tensile Modulus (GPa)	% Increase
Untreated	11.43 ± 0.81	-	2.37 ± 0.41	-
Treated	14.54 ± 1.43	27.21	3.54 ± 0.57	49.37

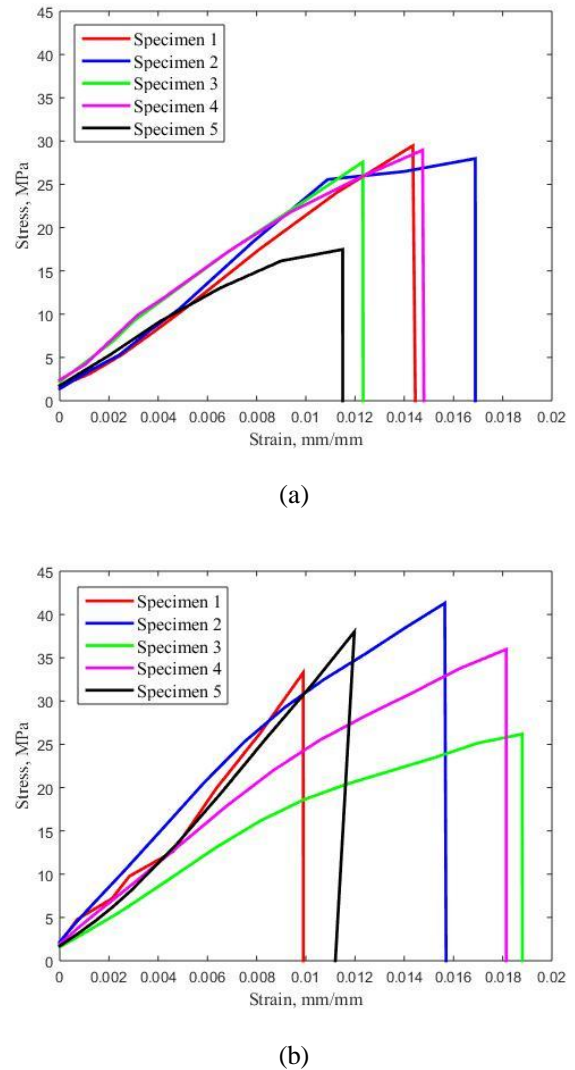
**Fig. 8** Effect of chemical treatment on (a) Tensile strength and (b) Tensile modulus.

It is also observed from Fig. 7 that the slope of the stress-strain curve for treated fiber composite is higher compared to untreated fiber. This suggests that the tensile modulus increases with the treatment of fiber and is represented by Fig. 8(b). Table 1 shows a comparative analysis of the tensile modulus for untreated and treated fiber. The average tensile modulus for untreated fiber is 2.37 GPa and for treated fiber is 3.54 GPa. So, the treatment of fiber increases the tensile modulus by 49.37%.

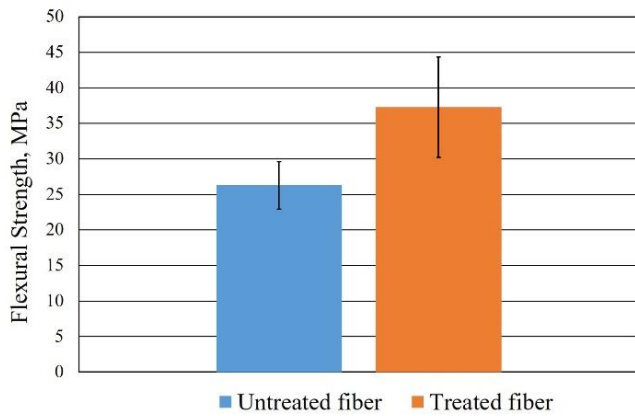
3.2 Flexural Test Results

Fig. 9 shows stress-strain response from the three point bending test for both untreated and treated fiber composites. It

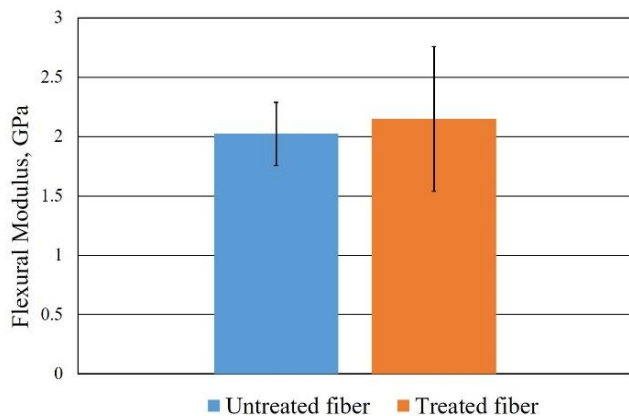
is observed from this figure that the maximum strength and slope of the curve of treated fiber (Fig. 9(b)) is higher compared to the untreated (Fig. 9(a)) one. This is represented in Fig. 10 and Table 2. Table 2 shows that the flexural strength and modulus of treated fiber is increased by 41.84% and 6.44% respectively compared to untreated fiber.

**Fig. 9** Stress-strain diagram of flexural test for (a) Untreated fibers and (b) Treated fibers.**Table 2** Flexural test results with standard deviation.

Condition	Flexural Strength (MPa)	% Increase	Flexural Modulus (GPa)	% Increase
Untreated	26.29 ± 3.36	-	2.02 ± 0.27	-
Treated	37.29 ± 7.09	41.84	2.15 ± 0.61	6.44



(a)



(b)

Fig. 10 Effect of chemical treatment on (a) Flexural strength and (b) Flexural modulus.

4. Conclusion

The mechanical properties of luffa fiber reinforced epoxy composite are investigated in this paper. Luffa fiber is treated with NaOH and benzoyl chloride and the mechanical properties are compared for untreated and treated fiber composites. It is found that the tensile strength and modulus for treated fiber are increased by 27.21 % and 49.37 % respectively. Flexural strength and modulus is increased by 41.84 % and 6.44 % respectively. It is found that the overall mechanical properties of the composites improved because of chemical treatment.

References

- [1] Islam, M.S., Melendez-Soto, E., Castellanos, A.G. and Prabhakar, P., 2015. Investigation of woven composites as potential cryogenic tank materials. *Cryogenics*, 72, pp.82-89.
- [2] Castellanos, A.G., Islam, M.S., Shuvo, M.A.I., Lin, Y. and Prabhakar, P., 2018. Nanowire reinforcement of woven composites for enhancing interlaminar fracture toughness. *Journal of Sandwich Structures & Materials*, 20(1), pp.70-85.
- [3] Islam, M.S. and Prabhakar, P., 2017. Interlaminar strengthening of multidirectional laminates using polymer additive manufacturing. *Materials & Design*, 133, pp.332-339.

- [4] Deshpande, A.P., Bhaskar Rao, M. and Lakshmana Rao, C., 2000. Extraction of bamboo fibers and their use as reinforcement in polymeric composites. *Journal of applied polymer science*, 76(1), pp.83-92.
- [5] Ochi, S., 2012. Tensile properties of bamboo fiber reinforced biodegradable plastics. *International Journal of Composite Materials*, 2(1), pp.1-4.
- [6] Ramesh, M., Palanikumar, K. and Reddy, K.H., 2013. Mechanical property evaluation of sisal-jute-glass fiber reinforced polyester composites. *Composites Part B: Engineering*, 48, pp.1-9.
- [7] Akil, H.M., Cheng, L.W., Ishak, Z.M., Bakar, A.A. and Rahman, M.A., 2009. Water absorption study on pultruded jute fibre reinforced unsaturated polyester composites. *Composites Science and Technology*, 69(11-12), pp.1942-1948.
- [8] Prasad, A.R. and Rao, K.M., 2011. Mechanical properties of natural fibre reinforced polyester composites: Jowar, sisal and bamboo. *Materials & Design*, 32(8-9), pp.4658-4663.
- [9] Mi, Y., Chen, X. and Guo, Q., 1997. Bamboo fiber-reinforced polypropylene composites: Crystallization and interfacial morphology. *Journal of applied polymer science*, 64(7), pp.1267-1273.
- [10] Tokoro, R., Vu, D.M., Okubo, K., Tanaka, T., Fujii, T. and Fujiura, T., 2008. How to improve mechanical properties of polylactic acid with bamboo fibers. *Journal of materials science*, 43(2), pp.775-787.
- [11] Chattopadhyay, S.K., Khandal, R.K., Uppaluri, R. and Ghoshal, A.K., 2011. Bamboo fiber reinforced polypropylene composites and their mechanical, thermal, and morphological properties. *Journal of applied polymer science*, 119(3), pp.1619-1626.
- [12] Chen, X., Guo, Q. and Mi, Y., 1998. Bamboo fiber-reinforced polypropylene composites: A study of the mechanical properties. *Journal of applied polymer science*, 69(10), pp.1891-1899.
- [13] Ismail, H., Shuhelmy, S. and Edyham, M.R., 2002. The effects of a silane coupling agent on curing characteristics and mechanical properties of bamboo fibre filled natural rubber composites. *European Polymer Journal*, 38(1), pp.39-47.
- [14] Athijayamani, A., Thiruchitrambalam, M., Natarajan, U. and Pazhanivel, B., 2009. Effect of moisture absorption on the mechanical properties of randomly oriented natural fibers/polyester hybrid composite. *Materials Science and Engineering: A*, 517(1-2), pp.344-353.
- [15] Dhakal, H.N., Zhang, Z.Y. and Richardson, M.O.W., 2007. Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites. *Composites science and technology*, 67(7-8), pp.1674-1683.
- [16] Haque, M.M., Hasan, M., Islam, M.S. and Ali, M.E., 2009. Physico-mechanical properties of chemically treated palm and coir fiber reinforced polypropylene composites. *Bioresource technology*, 100(20), pp.4903-4906.
- [17] Mohanta, N. and Acharya, S.K., 2016. Fiber surface treatment: Its effect on structural, thermal, and mechanical

- properties of Luffa cylindrica fiber and its composite. *Journal of composite materials*, 50(22), pp.3117-3131.
- [18] Mohanta, N. and Acharya, S.K., 2013. Tensile, flexural and interlaminar shear properties of Luffa cylindrica fibre reinforced epoxy composites. *Int. J. Macromol. Sci*, 3, pp.6-10.
- [19] Asif, M., Rahman, K.A., Faisal, M.O. and Islam, M.S., 2020. Comparative Study on Mechanical Properties of Bamboo Strip and Bamboo Strip-Glass Fiber Reinforced Hybrid Composites. *Journal of Engineering Advancements*, 01(01), pp.06-10.
- [20] Islam, M.S., Azmy, S. and Almamun, A., 2019. Comparative Study on Mechanical Properties of Banana and Rattan Fiber Reinforced Epoxy Composites. *American Journal of Engineering Research (AJER)*, 8(2), pp. 1-6.
- [21] Standard, A.S.T.M., 2008. Standard test method for tensile properties of polymer matrix composite materials. *ASTM D3039/D M*, 3039, p.2008.
- [22] ASTM D7264, 2007. Standard test method for flexural properties of polymer matrix composite materials. *American Society for Testing and Materials Annual Book of ASTM Standards*.