EFFECT OF CARBON NANOPARTICLES ON THE MECHANICAL PROPERTIES OF BANANA FIBER REINFORCED POLYMER

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***Abstract*—Natural fiber-reinforced composites, at present, are having a significant role to meet the challenge of developing materials of high strength to weight ratio for the application in the field of automotive and aerospace. In this research, the effect of carbon nanotube (CNT) as filler material in banana fiber reinforced polymer has been studied by incorporating carbon nanotube and banana fiber with epoxy resin in different weight ratios. The materials were prepared by the hand layup process. Two cases were considered for the study where the sum of weight percentage of fiber and filler in the composite were kept 8% for the first case and 16% for the second one. The experimental results showed remarkable improvement in the tensile and flexural properties of the composite due to the addition of carbon nanotubes. The tensile strength increased by 11.33% for the addition of 1.5% of CNT in the first case and 13.29% for the addition of 2.5% of CNT in the second case. On the other hand, flexural strength increased by 71.5% and 123% respectively for adding CNT of stated weight percentage.**

Index: Natural fiber, composites, Carbon Nanotubes, Hand Layup

I. INTRODUCTION

At present, composite materials have a wide range of engineering applications in the field of automobile and aerospace industries due to their specialized characteristics. A composite material is a combination of two or more materials that have different physical and chemical properties. When they are combined, it is possible to achieve the combinations of distinct properties of several materials to create unique characteristics. Usually, a composite material has two parts, one is the matrix and the other one is fiber. Additionally, fillers or other components may be applied to enhance its properties. The matrix can be categorized into three types, they are polymer, metal and ceramic matrix. The aerospace or automobile industry's ultimate goal is to develop products that are lighter in weight and overall more efficient than the existing designs. In recent, many research works are being undertaken to meet this goal. Fiber Reinforced Polymer (FRP) materials are having a great role in this sector for developing cost-efficient, high stiffness to weight ratio and high strength to weight ratio materials [1].

Natural fibers are now getting priority in today's research field in materials science due to their unlimited resources, availability, light weight and low cost [2][3]. In the present research, the composite material has been developed by the inclusion of banana fiber in a polymer matrix with the addition of carbon nanotubes. Carbon nanotubes are the allotropes of carbon having molecules of cylindrical shape and hexagonal structure. Their diameter can be from 1 to 100 nm [4]. These nanoparticles have motivated research on their various engineering applications and using them as filler materials for composites [5]. These nanoparticles have ultra-high-strength, excellent mechanical and thermal properties.

Kumar and Choudhary [6] conducted their research on the mechanical properties of banana and glass fiber reinforced hybrid composites. In their experiment, it has been found that the tensile strength of Hybrid Fiber Reinforced (HFREC) increased by 1.24% than Glass Fiber Reinforced Epoxy Composites. Moharaj and Gangadharan [7] studied the mechanical properties of banana fiber/ glass fiber hybrid composites. They developed a number of plates of different mixing ratios. They found that the plate number four (30(F):70(R)) with reinforcement resin mixture Vajram (Gum Arabic) 80% and Epoxy (20%) possess shows the highest Tensile strength, Flexural strength, Impact strength, and Hardness compare to other five plates. Thomas Mathew et.al. [8] determined the tensile strength of 1000N for only banana fiber reinforced polymer and 1250 for banana fiber and hair reinforced polymer. Adde and Elias [9] investigated the effect of increasing the weight percentage of banana fiber in epoxy resin. The tensile and flexural strength increase with the addition of banana fiber up to 60%. Santhosh et.al. [10] had done comparative analysis of the mechanical properties of Sodium Hydroxide treated and untreated banana fiber reinforced composite. Salahi et.al. [4] worked on the fabrication and characterization of hydroxyapatite-carbon nanotubes composite. They used hydroxyapatite with the matrix component and carbon nanotubes were added with the composites at various weight percentages. They have observed that the bending strength of the material decreased a bit at first, but eventually increases with the increase of carbon nanotubes percentage. Saravanan et.al. [11] studied the influence of modified multi-walled carbon nanotubes on mechanical and thermal properties of carbon fiber reinforced epoxy resin hybrid nanocomposites. They experimented by reinforcing the carbon fiber/epoxy resin composite with the different weight percentages of carbon nanotubes that is 0.3%, 0.6%, 0.9%, 1.2% and 1.9%. Their experimental results showed that the tensile strength and flexural strength of the material improves along with the hardness. Ahmadvand, Ali Rohani [12] studied the physical and mechanical properties of polypropylene nanocomposites with the addition of carbon nanotubes (MWCNT). They experimented with different percentages of carbon nanotubes. For their study, they have concluded that the tensile and flexural strength increased considerably with the addition of CNTs.

In this experiment, 8% wt banana fiber was reinforced in epoxy resin in first case. In the second case, banana fiber loading was kept 16%. Next 1.5% and 2.5% of carbon nanotubes were incorporated with banana fiber respectively for these two cases. The fibers were treated with 1% Sodium Hydroxide solution in order to remove moisture content, wax and impurities [13]. Chopped fibers of 15mm to 20mm length were used [14]. The composite samples were made by hand layup process. Tensile tests and flexural tests have been carried out for each sample and their comparative analysis has been presented.

II. METHODOLOGY AND APPROACH

In this experiment, banana fiber and carbon nanotubes were used as the reinforcing material and epoxy resin AW 106 and Hardener HV953 have been used as the matrix [7]. The composites were prepared by hand layup process.

. There were some steps to extract the fiber manually like as- a) selected the tree from which the fibers were to be extracted, was at the stage just before flowering; b) several layers of its skin had been peeled off from the stem; c) cut the layers of the stem into 1.5 feet pieces; d) the layers of thick skins were then pressed with a heavy roller. This process was continued for a couple of times to make the peels squeezed properly; e) the squeezed layers were kept in the water for 3 days. It had removed the dust, oil, wax etc. from the peels and it helped to soften the peels as it starts to rot; f) when the peels had started to rot, they were taken out of water and pressed once again to eject the absorbed water inside it. Next, with a sharp blade, the surfaces of the peels were rubbed thoroughly. This process was continued unless the fibers are fully extracted; g) once the fibers were completely extracted from the peels, they were washed thoroughly in water. While washing in water the fibers got more separated; h) then the fibers were dried in the sun for a couple of hours.

The extracted banana fibers were treated with 1% Sodium Hydroxide solution. Then they were washed thoroughly in water. Next, they were dried for 2 hours in sun. This had completely removed the remaining oil, wax and other impurities from the fibers. Sodium Hydroxide was collected from the chemistry laboratory of MIST.

Total of five types of samples were prepared at different weight ratios of fiber and fillers. Five Samples of each type were fabricated for tensile and flexural tests. The fibers and fillers portion were kept 8 and 16 percent in total.

A. *Preparation of Specimen*

Five mold cavities were prepared for five types of specimen. Wax was used for preventing the adhesiveness of the matrix to the surface of the mold cavity. The resin and hardener were mixed thoroughly in appropriate ratio. The fibers were chopped in 15 to 20mm pieces and arranged at random orientation in the matrix. The molds were pressed evenly with a wooden block to eliminate all the air bubbles created inside. These composites had been cured for 72 hours. The specimen sizes were kept according to the ASTM D-638-02 for tensile testing and ASTM D-790 for Flexural Test. To obtain the appropriate dimension, a grinding machine was used.

Figure 1. Banana fibers

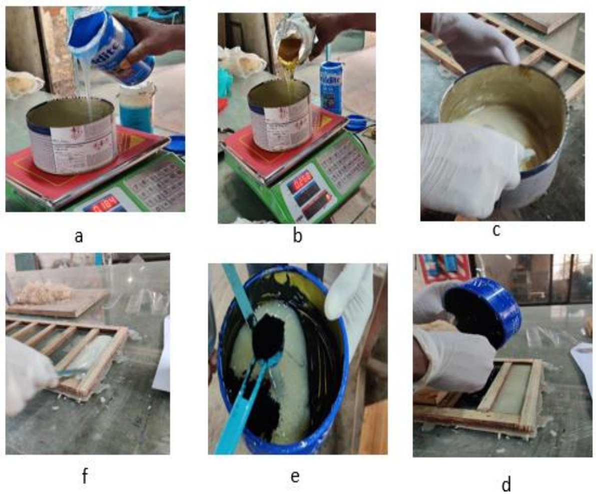

Figure 2. a) Weighting of Epoxy Resin b) weighting of hardener c) Mixing of resin and hardener d) Arrangement of fibers e) Mixing of CNT f) Placing in mold cavities.

Specimen 1, Specimen2, Specimen 3, Specimen 4 and Specimen 5 are referred as S1, S2, S3, S4 and S5 respectively in this experiment.

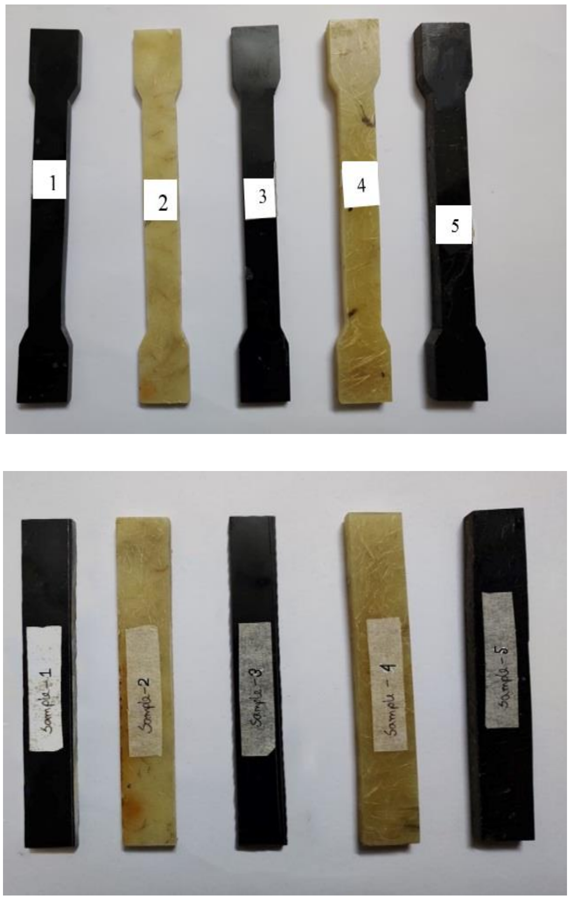

Figure 3. Specimen for Tensile (a) and Flexural test (b)

Table 1. Composition of the specimens

Specimen No	CNT	Banana fibre	Epoxy Resin + Hardener
(S1)	5%	0%	95%
(S2)	0	8%	92%
(S3)	1.5%	6.5%	92%
(S4)	0	16%	84%
(S5)	2.5%	13.5%	84%

B. Experimental Approach

The tensile test had been carried out according to the ASTM D-638-02. The test was done with the aid of Universal Testing Machine ‘Hounsfield’. The gage length was kept 50mm and grip to grip distance was approximately 115mm. The speed of testing was 5mm/min. It is the slope of the initial straight line portion of the stress-Strain curve. It can be calculated from the following equation,

$$E = \frac{PL}{\delta A}$$

$$E = \frac{\sigma L}{\delta} \dots\dots\dots\dots\dots\dots (1)$$

Here, δ = Deflection at the initial portion of curve

σ = Corresponding deflection

L = Gage length

E= Young’s Modulus

The flexural test had been conducted according to the ASTM Standard D-790. Here the span was taken 80mm. The test speed has been set to 2mm/min.

The tangent modulus of elasticity, also known as the “modulus of elasticity,” is the ratio that is within the elastic limit, of stress to corresponding strain. It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and using the following equation,

$$E = \frac{L^3 m}{4bd^3} \dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Here, L = Span of the test Specimen (mm) , m=Slope of the initial straight line portion of load-deflection curve, b= width, mm d= thickness, mm

Figure 4. Setup for Tensile Test

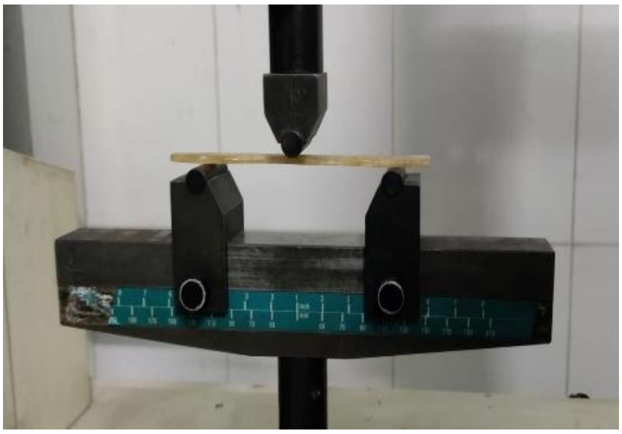

Figure 5. Setup for Flexural Test

III. Result & Discussion

A. *Tensile Test:*

From tensile testing tensile strength, young's modulus and maximum rate of strain were obtained. Young's modulus was calculated from equation (i).

Table 2. Tensile Test Findings

Specimen	Tensile Strength (MPa)	Young's Modulus (MPa)	Maximum Strain (%)
1	22	349.65	5.1
2	11.82	300.48	3.92
3	13.16	320	8.10
4	15.12	384.62	4.62
5	17.13	356	4.46

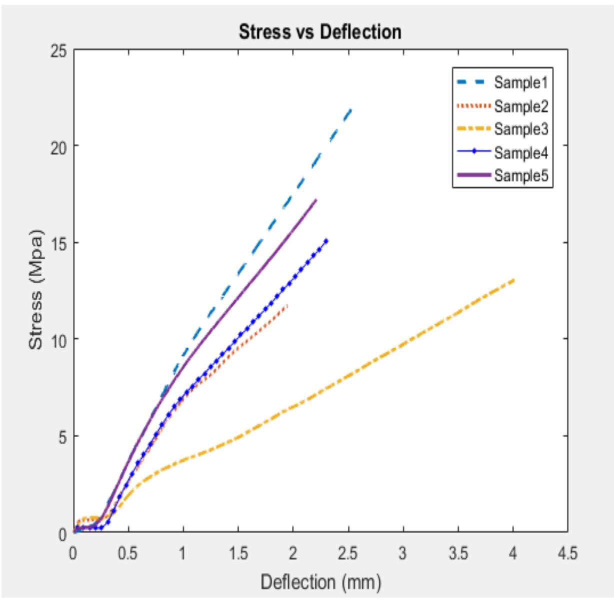

Figure 6. Stress vs Deflection Curve for tensile test

B. *Flexural Test Result*

From flexural testing, Flexural strength, Flexural modulus of Elasticity and maximum rate of strain were obtained. Flexural modulus of Elasticity was calculated from equation (ii).

Table 3. Findings of Flexural Test

Specimen	Flexural Strength(MPa)	Flexural Modulus of Elasticity(GPa)	Maximum Strain (%)
1	101.32	6.684	2.306
2	30.56	1.377	1.627
3	52.43	3.672	1.726
4	42.56	1.5208	2.869
5	95.32	5.5528	6.41

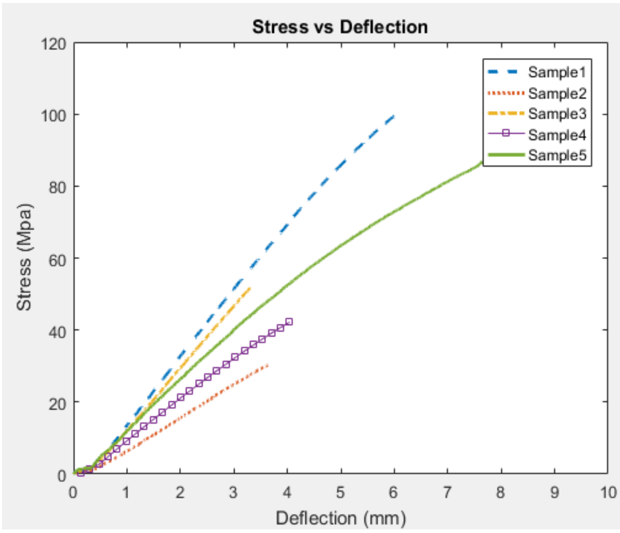

Figure 7. Stress vs Deflection Curve for flexural test

C. *Comparative analysis of Tensile Properties:*

Results showed that, among the composites containing banana fiber, Specimen 5 gives the maximum strength.

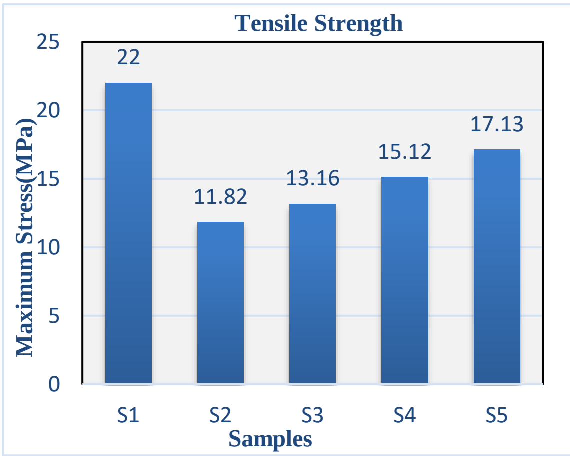

Figure 8. Tensile Strength Comparison

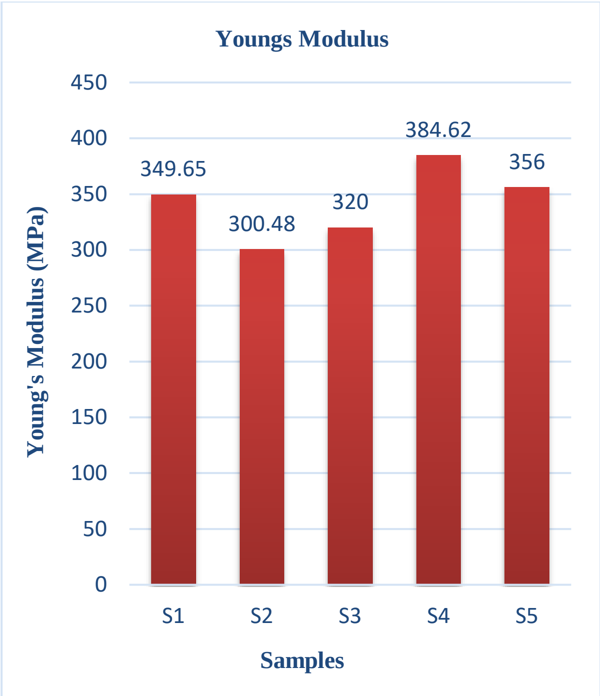

Figure 9. Young Modulus Comparison

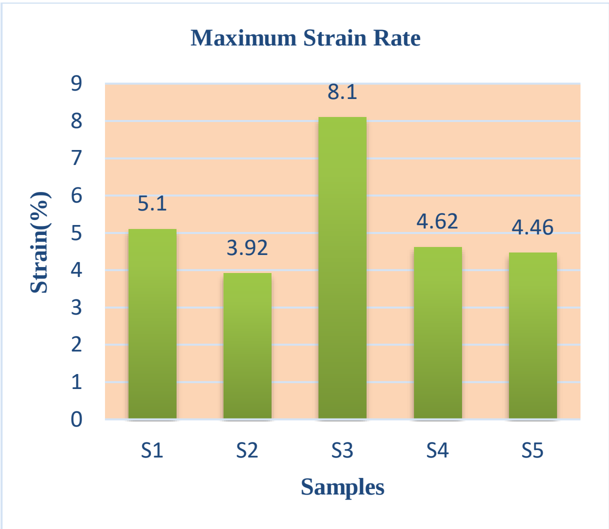

Figure 10. Maximum Strain Comparison

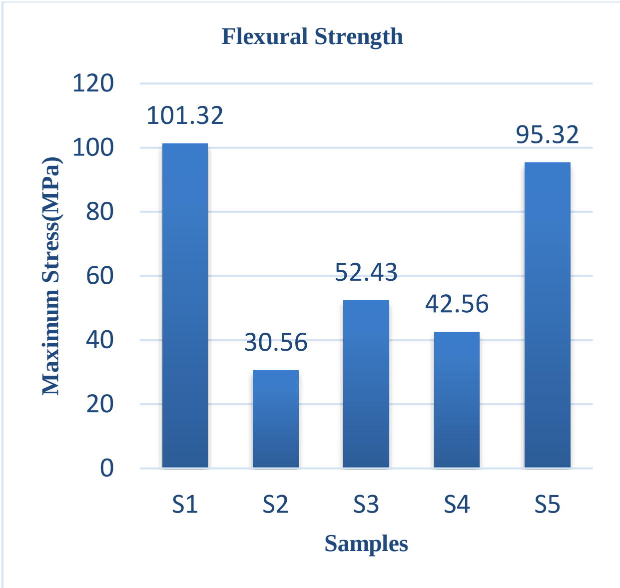

Figure 11. Flexural Strength Comparison

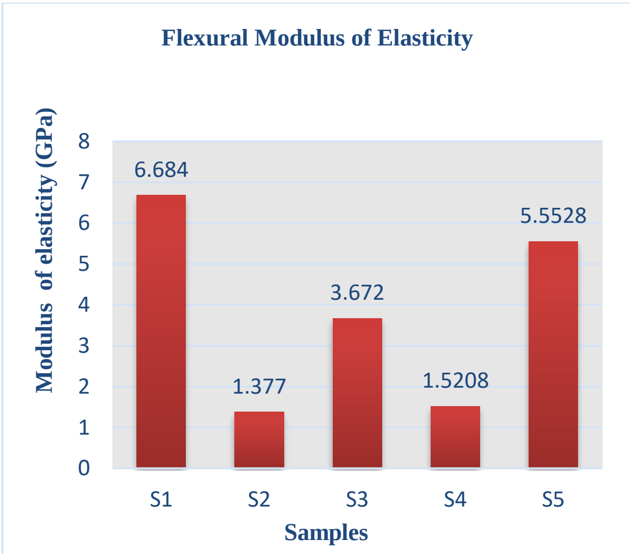

Figure 12. Flexural Modulus of elasticity Comparison

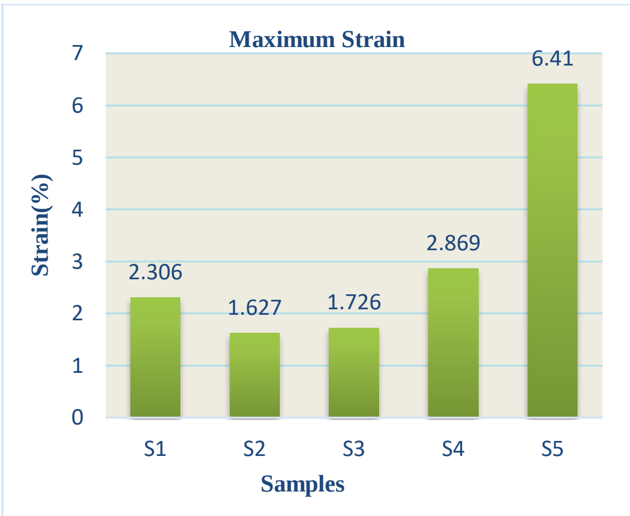

Figure 13. Flexural Strain Comparison

Young's modulus increased with the addition of CNT with 8% fiber loading but decreased when added with 16% fiber loading.

D. Comparative analysis of Flexural Properties:

From experimental analysis, it was found that, among the composites containing banana fiber, Specimen 5 gave both the maximum strength and Flexural Modulus of elasticity which was consisted of 13.5% banana fiber and 2.5% carbon nanotube.

IV. CONCLUSION

In this research, the influence of reinforcing carbon nanotube with banana fiber/epoxy composite at two different weight ratios has been investigated. In both weight ratios, the addition of carbon nanotube improved the mechanical properties of banana fiber/epoxy composite. The results showed that Sample 5 gave the most optimum result which was the composition of 2.5% carbon nanotube with 13.5 % of fiber loading in the epoxy composite.

From comparative analysis of tensile testing, we can see that the increase in the wt. % of carbon nanotube increases the maximum flexural and tensile strength. The comparative analysis of flexural test indicated that the enhancement of the wt% of carbon nanotube improves the Flexural Modulus of Elasticity. This also initially improves the Young's Modulus but further addition of CNT resulted in slight decrease in Young's Modulus of Elasticity.

Without filler, it was observed the composite with 16% fiber loading showed better properties. So, more investigation can be carried out with keeping the fiber loading 16% and varying the ratio of the carbon nanotube.

Further satisfying results can be obtained by mixing the nanoparticles by sonication or magnetic stirring so that the fillers will evenly be combined with the matrix and fill the air gaps.

In this study, CNTs were used without any surface modification. Surface modified CNTs may give a much more positive result than unmodified ones.

Other mechanical properties like the impact strength, hardness and thermal properties of this developed composite are remained to be studied.

V. REFERENCE

[1] M. H. Rafiquzzaman, A. Rahman, M. Sayeed, A. Nawazish, and M. H. Rahman, "Evaluation of Mechanical Behavior of Jute Fibre-Aluminum Powder Reinforced Hybrid Polymer Composites," *Int. J. Mech. Eng. Autom*, vol. 3, no. 5, pp. 202–207, 2016.

[2] M. Harikrishna, K. Ajeeth, and C. Thiagarajan, "Fabrication and mechanical properties of hybrid natural fiber composites (Jute / Banana / Glass)," vol. 119, no. 15, pp. 685–696, 2018.

[3] K. Murali Mohan Rao, K. Mohana Rao, and A. V. Ratna Prasad, "Fabrication and testing of natural fibre composites: Vakka, sisal, bamboo and banana," *Mater. Des.*, vol. 31, no. 1, pp. 508–513, 2010, doi: 10.1016/j.matdes.2009.06.023.

[4] E. Salahi and A. Rajabi, "Fabrication and Characterization of Hydroxyapatite-Carbon Nano Tubes Composites," *Am. J. Nanosci.*, vol. 2, no. 4, pp. 41–45, 2016,doi: 10.11648/j.ajn.20160204.11.

[5] M. R. Ayatollahi, S. Shadlou, M. M. Shokrieh, and M. Chitsazzadeh, "Effect of multi-walled carbon nanotube aspect ratio on mechanical and electrical properties of epoxy-based nanocomposites," *Polym. Test.*, vol. 30, no. 5, pp. 548–556, 2011, doi: 10.1016/j.polymertesting.2011.04.008.

[6] A. Kumar and D. Choudhary, "Development of Glass / Jute Fibers Reinforced Epoxy Composite," *Int. J. Eng. Res. Appl.*, vol. 3, no. 6, pp. 1230–1235, 2013.

[7] M. Mohanraj, "Experimental investigation of mechanical characteristics of natural resin reinforced glass / banana fiber composite," pp. 300–306, 2018.

[8] T. Mathew, V. S. K, P. Ak, S. Nr, P. Sh, and P. Sridharan, "Fabrication & Testing of Banana-Hair Reinforced Hybrid Composite," vol. 7, no. 4, pp. 6667–6670, 2017.

[9] K. Alemayehu, A. Yeshurun, and L. R. Elias, "Experimental Evaluation of Mechanical Properties of Banana Fiber Reinforced Polymer Composites," vol. 9, no. 6, pp. 724–733, 2018.

[10] P. Collart and M. Poitevin, "La Syphilis. Actualites Physio-Biologiques. Iv. Le Probleme De La Penicillinotherapie," *Sem. des Hop.*, vol. 57, no. 25–28, pp. 1161–1171, 1981.

[11] R. Saravanan, A. Sureshbabu And T. Maridurai, "influence of surface modified mwcnt on mechanical and thermal properties of carbon fiber/epoxy resin hybrid," *Digest Journal Of Nanomaterials And Biostructures*, vol. 11 no. 4 pp. 1303-1309, 2016.

[12] N. Ahmadvand, "Improvement of Mechanical and Physical Property of Polypropylene Nano Composites by the Addition of Multi-walled Carbon Nano Tube," *Nanosci. Nanometrology*, vol.3,no.1,p.20,2017,doi:10.11648/j.nsnm.20170301.14.

[13] N. Venkateshwaran, A. Elaya Perumal, and D. Arunsundaranayagam, "Fiber surface treatment and its effect on mechanical and visco-elastic behaviour of banana/epoxy composite," *Mater. Des.*, vol. 47, pp. 151–159, 2013, doi: 10.1016/j.matdes.2012.12.001.

[14] N. Venkateshwaran, A. Elayaperumal, and M. S. Jagatheeshwaran, "Effect of fiber length and fiber content on mechanical properties of banana fiber/epoxy composite," *J. Reinf. Plast. Compos.*, vol. 30, no. 19, pp. 1621–1627, 2011, doi: 10.1177/0731684411426810.