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Optimization of the Tensile Behavior of Natural Fibre Reinforced Composite for Hockey Stick Application with Taguchi method

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ABSTRACT: *This paper experimentally investigated the tensile behaviors of hybrid composite structures containing different concentrations of Banana and Sponge Gourd fibres (BF and SGF) for Hockey stick application. The weight percent of 5, 10, 20 and fibre size of 150µm, 300µm and 600µm were used in this research. The design of the experiment was done via Taguchi robust design. `The effects of hybrid concentrations on the tensile behaviors were also investigated. The structural analysis of the developed natural hybrid composite was done using scanning electron microscopy (SEM). The natural hybrid composites demonstrated excellent tensile behaviors at different concentrations of the reinforcements with maximum ultimate tensile strength of 79 MPa obtained by 10%wt Ba, 10%wt Sg natural hybrid composite at 150um fibre size. The natural hybrid composite recorded higher strength than the epoxy resin matrix. The improvements of mechanical properties are guaranteed by the distribution of BF and SGF in the epoxy resin matrix as evidenced in the microstructural analysis.*

KEYWORDS: *Epoxy resin, Banana Fibre, Sponge Gourd Fibre, Tensile behaviors.*

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I. INTRODUCTION

The invention of composite material has dated back to the nineties and since then has provided man with a wider range of materials to select from (Mueller and Krobjilowski, 2017). The use of natural organic materials which are abundant in our environment to form a composite of continuous or discontinuous fibrous or particulate materials embedded in matrix which will serve as glue, will yield a composite with better mechanical properties (Nwambu et al. 2022, Ekwedigwe et al., 2023). However, natural fibres reinforced polymer composites (NFRPC) do not offer superior mechanical properties than synthetic fibres reinforced polymer composites (FRPC). Some researchers (Venkateshwaran et al. 2011, Ekwedigwe et al., 2023; Okoye et al., 2023) found that to enhance the properties of composites reinforced with natural fibres; they can be mixed with other conventional fibres to produce hybrid composites with superior properties. Weed et al. 2014 reported that banana fibre-reinforced composites had comparatively weak bonding between fibre and matrix. Likewise, Jacob et al. 2005 observed that banana fibres had a hydrophilic nature, and there was weak bonding between the matrix and fibre when the banana fibre was combined with the hydrophobic matrix. Therefore, there are standard methods for the improvement of fibre and matrix bonding as described by Paul et al. 2008 and Li et al., 2007. The first method was to make the fibre surface rough so that the polymer can anchor at the mechanical anchoring sites. The second procedure was a chemical treatment that could be used to modify the fibre surface for the reduction in its hydrophilicity, to improve its bonding with the matrix. Consequently, better bonding between the matrix and the fibre was achieved, and the material was improved mechanically courtesy of the presence of additional reinforcing material (Singh et al., 2017; Nwambu et al., 2023). In the recent times, the use of natural fibres for reinforcement in polymer composites has increased (Singleton, 2003; Nwambu et al., 2022; Ekwedigwe et al., 2023). Sumaila et al. 2013 investigated the influence of fibre length on the mechanical and physical properties of nonwoven short banana, random oriented fibre and epoxy composite and they observed that the tensile properties and percentage elongation of the composite achieved an improved properties in composite fabricated with 15 mm fibre length. Based on the literature, several authors have investigated the mechanical behaviors of the hybrid composite using different natural fibres (Ekwedigwe et al., 2023, Achebe et al., 2020). However, there is no research that relates to the influence of hybrids composite of banana and sponge gourd fibre on the structure and tensile behaviors of hybrid composite, hence this recent study was initiated to close the gap.

II. MATERIALS AND METHODS

A. Material Sourcing

The banana fibre and the sponge gourd were sourced locally from Okonkwo's Farm in Aguata, Anambra State, Nigeria. Waterborne transparent epoxy resin (LY556), hardener (HY-951), and sodium hydroxide (NaOH) solution used in this study were procured from Victor Chemicals located in Lagos state, Nigeria.

a. Materials preparation and chemical treatment

The banana and sponge gourd fibres were prepared separately. The banana fibre was soaked in water for 24hrs to remove any dirt or debris from the fibre and thereafter sun dried for 2 days. Afterward, degumming, removal of lignin, wax and optimum fibre roughness was achieved by soaking the dried banana fibre in 10% concentration of NaOH solution for 24hrs as reported by Cao et al., (2006) and Vidyashi *et al*. (2019). The alkaline treated fibre was thereafter continually rinsed with water until a pH value of 7 was obtained to a neutral solution of the fibre. The rinsed fibre is sun dried again for 2 days before subjecting to methanol treatment where the fibre was soaked in a dilute methanol solution (60 :40) for 3hrs which help in further increasing the fibre roughness and bonding properties of the fibre. The methanol treated fibre was subsequently sun dried for 2 days, after which the fibre is ready for pulverization. These procedures were also repeated during the preparation of sponge gourd fibre. The surface area of the fibres (banana and sponge gourd) was increased by pulverization technique, which converts the long grain fibres to a powdered form. The particle size analyses of the pulverized fibres were carried out in accordance with ASTM-60. 200g of the fibre particles were placed into a set of sieves arranged in descending order of fineness and electrically shaken for 15 minutes which is the recommended time to achieve complete classification. The weight retained on 150µm, 300µm and 600µm were used in this research. The wt% of the fibres (banana and sponge gourd), polymer was measured accordingly via an air tight electronic weighing balance from the data analysis obtained from the design of experiment using Taguchi.

b. Material fabrication

Heating of the paraffin wax to its melting point (50^0C) was done with the help of a Bunsen burner, afterward the liquid wax was immediately sprinkled on the metal mould before casting. This was done to enable easy removal of samples from the metal mould. After waxing the mould, the composite materials of different composition (5wt%, 10wt% and 20wt%) of banana and sponge gourd with hardener were mixed in a crucible plate and stirred continuously using a stirrer until a uniform mixture was obtained. The mixture was subsequently poured into a 300mm × 300mm waxed metal mould and allowed to set; the design formation was used in the production of the composite. Experiments were carried out under standard environmental conditions in the laboratory.

c. Characterization test

The tensile strength measurements were performed on a testometric testing machine at the University of Lagos, Nigeria. For the tensile test, the composite samples were 160mm×20mm× 4mm in dimension in accordance with ASTM 638-10 standard test method for tensile properties of polymer. The tests were performed at a constant strain rate of 0.5mm/min. the maximum tensile strength was calculated in accordance with the equation:

$$Rt = \frac{Pmax}{Bd} \quad (1.0)$$

Where, B = width of reduced cross section of the specimen measured in dry conditioning (mm), D = thickness of the specimen measured in dry condition, Pmax = maximum tensile load (N), R_t = maximum tensile stress (MPa). The microstructure was observed using JEOLJSM-6480LV type scanning electronic microscopy (SEM) at magnifications of X400 and X1500 respectively. The composite samples after the tests were cut to specific dimensions cleaned properly and mounted cross section wise on the SEM.

d. Taguchi experimental analysis

The design of the experiment was done via Taguchi robust design which involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Genichi Taguchi. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect the product quality with a minimum amount of experimentation, thus saving time and resources. Classical experimental design methods are too complex and are not easy to use. A large number of experiments have to be carried out when the number of process parameters increase. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments.

Signal to noise ratio for the higher the better =

$$-10log\sum\frac{y^{-2}}{n}$$

Where, n = No. of observations, R = Observed data for each response. Three superplastic forming parameters are considered as controlling factors. They are %wt of fibre 1 (banana), % wt of fibre 2(sponge gourd) and fibre particle size. Each parameter has three levels as shown in Table 1.0.

Table 1.0: Factors and levels

FACTOR	LEVEL
Wt% of banana (A)	3
Wt% of sponge gourd (B)	3
Fiber size (C)	3

III. RESULTS AND DISCUSSION

A. Tensile behavior of hybrid composite

Fig. 1.0 demonstrates the effect of different sample compositions (A to I) at each of three fiber sizes (150 µm, 300 µm, and 600 µm) on the tensile strength of composite materials. At 150 µm, samples A, B, and C contain varying percentages of banana (5%, 10%, 20%) while keeping the sponge gourd content constant at 5%. Tensile strength increases as the % weight of banana increases, indicating that a higher concentration of banana fiber improves tensile strength. Sample C with 20% banana content has the highest tensile strength at this fiber size (150 µm). Samples D, E, and F contain varying percentages of banana (5%, 10%, 20%) and sponge gourd (10%) together. The tensile strength remains relatively consistent or decreases slightly with increasing banana content. Sample F with 20% banana and 10% sponge gourd content has a lower tensile strength compared to sample D with 5% banana and 10% sponge gourd content. Samples G, H, and I contain varying percentages of banana (5%, 10%, 20%) while keeping the sponge gourd content constant at 20%. Tensile strength remains relatively consistent across these samples, indicating that the high sponge gourd content doesn't significantly affect tensile strength at this fiber size. At 300 µm, similar trends are observed at this fiber size, with samples A, B, and C showing higher tensile strength as the % weight of banana increases. Samples D, E, and F show that increasing banana content while keeping sponge gourd content constant at 10% leads to relatively consistent or slightly decreasing tensile strength. Samples G, H, and I with 20% sponge gourd content also have relatively consistent tensile strength values. The trends at 600 µm fiber size are somewhat different. Tensile strength remains relatively consistent for samples A, B, and C, suggesting that fiber size has a larger impact on tensile strength compared to banana content. Samples D, E, and F show a decrease in tensile strength with increasing banana content. Samples G, H, and I with 20% sponge gourd content also exhibit relatively consistent tensile strength values, but sample G (5% banana) stands out with a slightly higher tensile strength. In summary, the effect of % weight of banana and % weight of sponge gourd on tensile strength varies depending on the fiber size. Generally, increasing the % weight of banana tends to improve tensile strength, while the effect of sponge gourd content is less pronounced. Fiber size has a significant impact, with larger fibers generally resulting in lower tensile strength. The specific combination of these factors that optimizes tensile strength will depend on the intended application and desired mechanical properties of the composite materials.

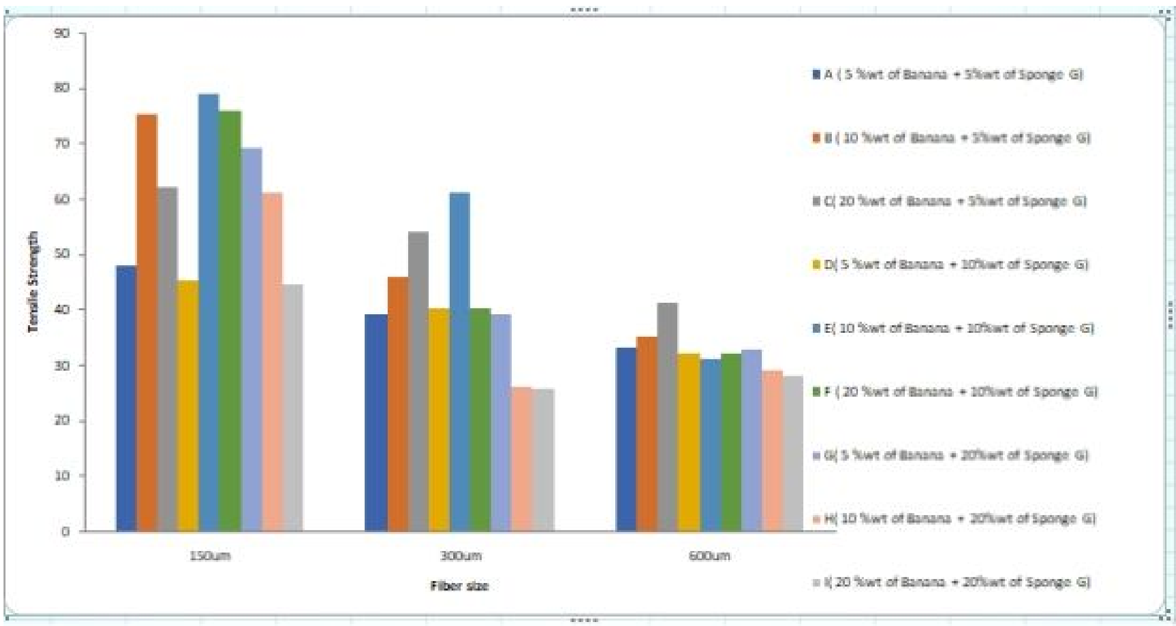

Fig. 1.0: Tensile strength properties of banana and sponge gourd particulates reinforced hybrid composite at different fibre size

Fig. 2.0 depicts the effect of the variables on the tensile strength of composite materials at different combinations of % weight of banana, % weight of sponge gourd, and fiber size. Let's analyze the effect of these variables on the tensile strength of the composite materials. As the % weight of banana increases (from 5% to 20%), the tensile strength generally decreases for all fiber sizes and samples. This suggests that an increase in the banana content tends to reduce the tensile strength of the composite materials. This reduction in tensile strength could be due to the inherent properties of banana fibers, such as lower stiffness and strength compared to some synthetic fibers. Similarly, as the % weight of sponge gourd increases (from 5% to 20%), the tensile strength generally decreases for most samples and fiber sizes. An increase in the sponge gourd content also appears to have a negative impact on tensile strength, likely due to the lower mechanical properties of sponge gourd fibers. The data is consistent in showing that, for each combination of % weight of banana and % weight of sponge gourd, the tensile strength is highest when the fiber size is 300 µm and lowest when the fiber size is

150 µm. This suggests that a larger fiber size contributes to higher tensile strength in the composite materials. Larger fibers can distribute stress more effectively and resist deformation. Overall, the data indicates that the % weights of banana and sponge gourd, as well as the fiber size, all play significant roles in determining the tensile strength of composite materials. To optimize the tensile strength of these composites, one would need to carefully balance the percentages of banana and sponge gourd while considering the fiber size to achieve the desired mechanical properties for a specific application.

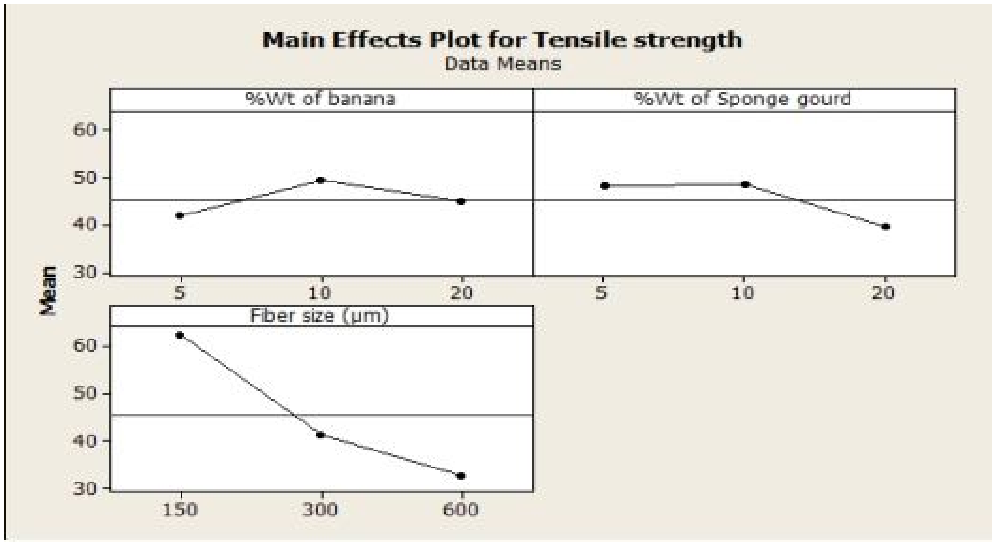

Fig. 2.0: Effect of process parameter on tensile strength og the hyrid composite.

B. Percentage elongation of the hybrid composite

Fig. 3.0 demonstrates the effect of different sample compositions (A to I) at each of three fiber sizes (150 µm, 300 µm, and 600 µm) on the % elongation of composite materials. At 150 µm fiber size, the % elongation values show variations depending on the composition. Sample B (10% banana + 5% sponge gourd) exhibits the highest % elongation, while sample D (5% banana + 10% sponge gourd) has the lowest % elongation. It is evident that increasing the percentage of banana generally results in higher % elongation values. Sample C (20% banana + 5% sponge gourd) shows higher % elongation than sample A (5% banana + 5% sponge gourd). Additionally, the presence of sponge gourd in the composite can influence % elongation. As seen in Fig. 1, sample H (10% banana + 20% sponge gourd) has a higher % elongation compared to sample B (10% banana + 5% sponge gourd), indicating that the combination of banana and sponge gourd affects the material's ductility. At 300 µm % elongation values at this fiber size also vary with different sample compositions. Sample E (10% banana + 10% sponge gourd) has the highest % elongation, while sample H (10% banana + 20% sponge gourd) exhibits the lowest % elongation. As in the case of 150 µm, increasing the percentage of banana tends to result in higher % elongation values. Sample B (10% banana + 5% sponge gourd) has a higher % elongation than sample A (5% banana + 5% sponge gourd). The presence of sponge gourd still influences % elongation, with samples containing sponge gourd generally showing higher ductility. For instance, sample D (5% banana + 10% sponge gourd) has higher % elongation than sample A (5% banana + 5% sponge gourd). At 600 µm fiber size, the % elongation values exhibit similar trends as at 150 µm and 300 µm. Sample E (10% banana + 10% sponge gourd) has the highest % elongation, while sample G (5% banana + 20% sponge gourd) exhibits the lowest % elongation. Consistently, increasing the percentage of banana tends to reduce % elongation values. Sample F (20% banana + 10% sponge gourd) has a lower % elongation compared to sample B (10% banana + 5% sponge gourd). The presence of sponge gourd continues to have a positive influence on % elongation, with samples containing sponge gourd displaying higher ductility. In summary, the % elongation of composite materials is influenced by the percentage of banana and sponge gourd as well as the fiber size. Generally, higher banana percentages tend to reduce ductility, while the presence of sponge gourd tends to increase % elongation. These trends are consistent across different fiber sizes, but the specific values vary depending on the sample composition.

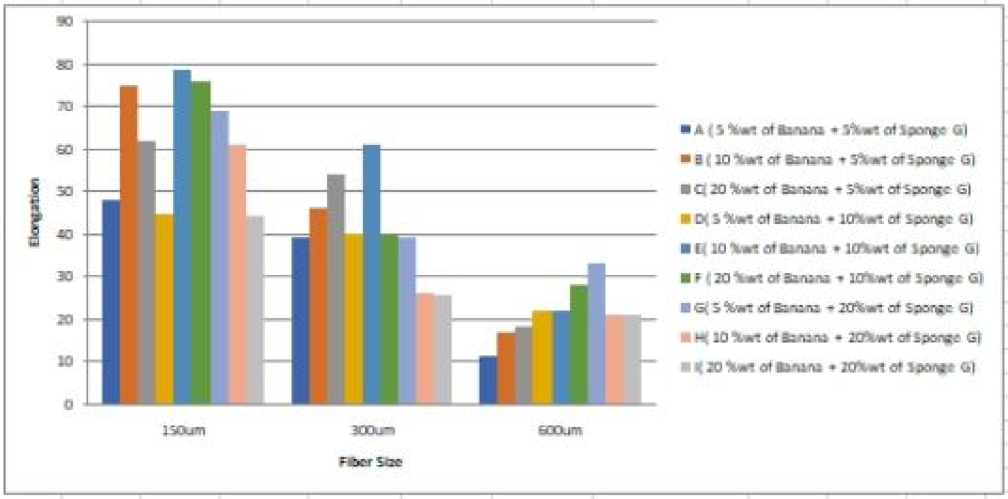

Fig. 3.0: % Elongation properties of banana and sponge gourd particulates reinforced hybrid composite at different fibre size

Fig. 4.0 illustrates the main effect of the process parameters on elongation of the hybrid composite, and the following were observed: The percentage of banana and sponge gourd in the composite materials has a noticeable effect on % elongation. Generally, increasing the % weight of banana tends to result in lower % elongation values. For instance, at a fiber size of 600 µm, sample C (10% banana + 5% sponge gourd) exhibits the lowest % elongation, while sample A (5% banana + 5% sponge gourd) has a slightly higher % elongation. The presence of sponge gourd in the composite can also influence % elongation. At the same fiber size, sample G (5% banana + 20% sponge gourd) shows a relatively high % elongation, indicating that the combination of banana and sponge gourd can affect the material's ductility. Fibre size plays a role in determining % elongation values. Smaller fiber sizes generally lead to higher % elongation values, indicating increased ductility of the composite material. For example, at 150 µm, sample A (5% banana + 5% sponge gourd) has a higher % elongation compared to the same composition at 600 µm, highlighting the positive influence of smaller fiber sizes on ductility. Additionally, as fiber size decreases, the differences in % elongation among samples with varying compositions tend to become less pronounced, suggesting that fiber size may play a dominant role in determining % elongation values in some cases. In summary, the % elongation of composite materials is influenced by the percentage of banana and sponge gourd as well as the fiber size. Generally, higher banana percentages and larger fiber sizes tend to reduce ductility, while the presence of sponge gourd can have varying effects on % elongation. Fiber size plays a significant role in determining the material's ductility, with smaller fiber sizes leading to higher % elongation values. However, complex interactions between these factors can result in unexpected trends in % elongation.

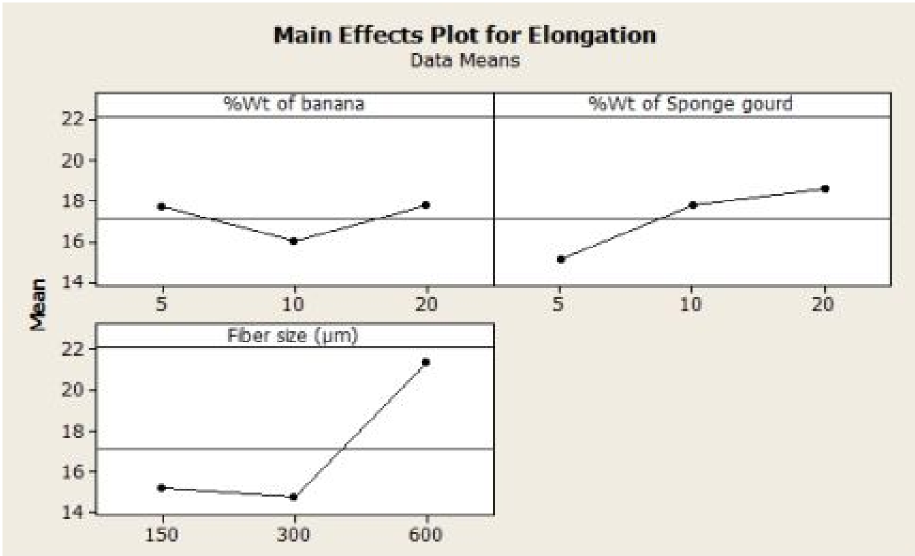

Fig. 4.0: Main effect plot of %Elongation versus the process parameter of the hyrid composite.

C. Scanning electron Microscope of hybrid composite (BF+SG)

SEM micrograph of the fractured surface of the sample presented in Fig. 5.1a shows that the failure of the specimen is mainly brittle failure. Fig. 5.1b shows that failure of the specimen is mainly by banana fibre fracture and sponge gourd fibres are being pulled out the matrix. Since the flexural strength of banana fibre is more, higher bending forces are required to fracture banana fibre and pulling them out from the matrix. The interfacial adhesion between banana fibre and matrix is much better when compared with that of sponge gourd fibre and matrix. The combined effect of fracture of most of the banana fibre and pulling out of sponge gourd fibre leads to higher tensile strength of the hybrid composite, Fig. 5.1c features the cross section of the fractured surface. The failure pattern such as fibre bundle pull out (dark pits) and fibre debonding can be seen easily, reflects the major characteristic of brittle fracture. Different fracture characteristics viz. debonding and micro crack propagation can be seen for sample in Fig. 5.1d. These are the characteristics of brittle fracture hence; it denotes that the mode of failure is brittle fracture. In this case, debonding of banana fibre can be seen easily due to major composition of banana fibre which gets debonded easily. It was observed that the morphology from fig 5.1d possess a finer grain and equiaxed structure when compared to other SEM samples, which attributes to their better tensile properties.

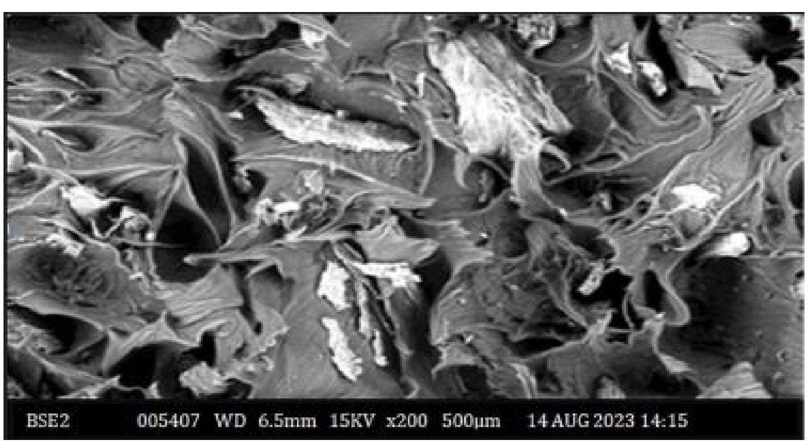

Fig 5.1a: SEM fracture surface for the 0%wt of Ba, 0%wt of Sg (control sample)

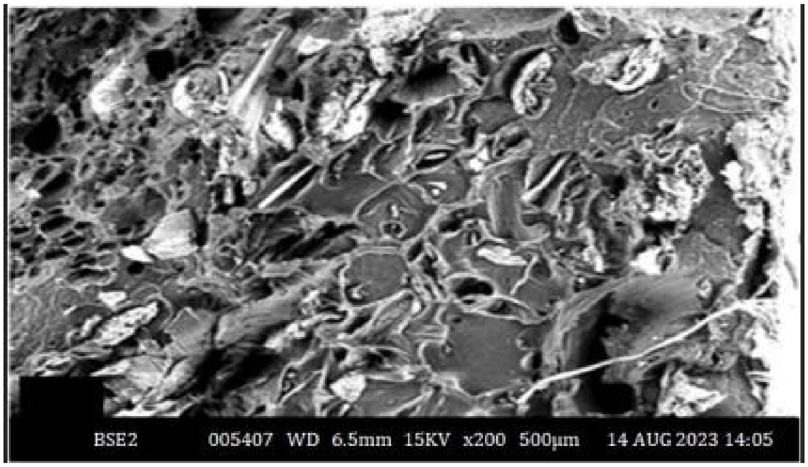

Fig5.1b: SEM fracture surface for the 20%wt of Ba, 10%wt of Sg at 600um fibre size

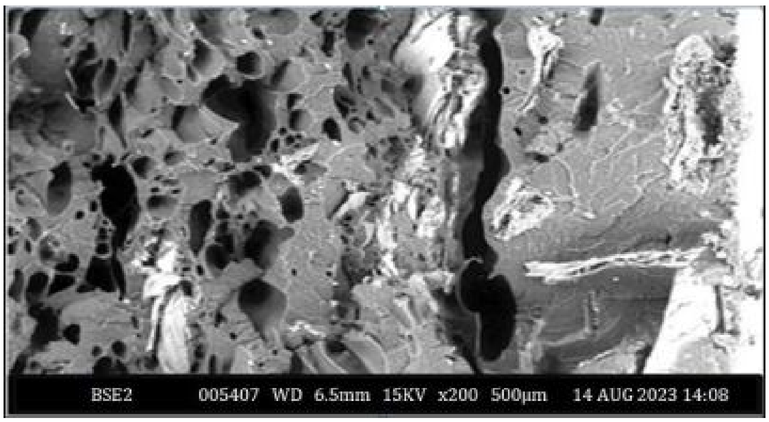

Fig5.1c: SEM fracture surface for the 20%wt of Ba, 10%wt of Sg at 300um fibre size

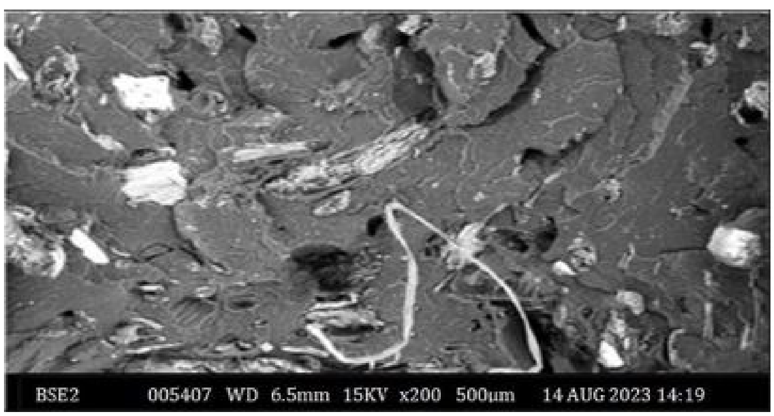

Fig5.1d: SEM fracture surface for the 10%wt of Ba, 10%wt of Sg at 150um fibre size

IV. CONCLUSION

In this experimental study, the effects of banana fibre and sponge gourd fibre concentrations on the percentage elongation, ultimate tensile strength of Banana Fibre (BF) and Sponge Gourd Fibre (SG) hybrid composite for hockey stick application were explored in detail. The effects of hybrid concentrations on the tested properties were also investigated. The results of the study indicated that the developed natural fibre reinforced hybrid composite recorded excellent tensile behaviors at different concentrations of the reinforcements.

The results of the study can be summarized thus:

- The Ultimate tensile strength increases with increase in different % of both banana fibre and sponge gourd fibre, but decreased significantly at 20 %wt, 600um (BF) and (SGF) respectively. 10%wt Ba, 10%wt Sg at 150um fiber size produced the best tensile strength result which is in accordance with the range of tensile strength requirement by a material before it can be considered for hockey stick application.
- Fibre size affects the % elongation, the % elongation values show variations depending on the composition, (10% banana + 5% sponge gourd) exhibits the highest % elongation at 150um fibre size, while at 300um fibre size (10% banana + 10% sponge gourd) has the highest % elongation, and (10% banana + 10% sponge gourd) has the highest % elongation at 600um fibre size.
- The study has established the optimum contribution of banana, sponge gourd fibre at specific fibre size that will produce a hybrid composite of better percentage elongation and tensile strength.
- The study also established the fact that the natural fibre-based hybrid composite can also be considered as material for Hockey stick fabrication.

REFERENCES

Haneefa A., Bindu P., Aravind I., Thomas S., Studies on Tensile and Flexural Properties of Short Banana/Glass Hybrid Fiber, Journal of Composite Materials, 42 (2008), pp. 1471-1489.

Jacob, M.; Joseph, S.; Pothan, L.A.; Thomas, S. A study of advances in characterization of interfaces and fiber surfaces in lignocellulosic fiber-reinforced composites. Compos. Interfaces 2005, 12, 95–124.

Li K, Fu S, Zhan H, Zhan Y. and Lucia L. (2010). Analysis of the chemical composition and morphological structure of banana pseudo-stem. BioResources.5:576-585.

Cao, Shibata S. and Fukumoto, (2006). Mechanical properties of biodegradable composites reinforced with bagasse fibre before and after alkali treatments. *Applied science and Manufacturing*, Volume 37p. 423-429.

Li W, Zhang Y, Li J, Zhou Y, Li R. and Zhou W. (2015). Characterization of cellulose from banana pseudo-stem by heterogeneous liquefaction. Carbohydate Polymers. 132, 513-519

Mueller D.H and Krobjilowski A,(2017). New Discovery in the Properties of Composites Reinforced with Natural Fibres. *Journal of Industrial Textiles* 33(2), pp.111-129.

Okafor E.C., Okafor E.J. and Ikebudu K.O. (2021). Evaluation of machine learning methods in predicting optimum tensilestrength of microwave post-cured composite tailored for weightsensitiveapplications. *An International Journal Engineering Science and Technology*.

Paul, S.A.; Pothan, L.A.; Thomas, S. Advances in the Characterization of Interfaces of Lignocellulosic Fiber Reinforced Composites. Charact. Lignocellul. Mater. 2008, 249–274.

Singh, J.I.P.; Dhawan, V.; Singh, S.; Jangid, K. Study of Effect of Surface Treatment on Mechanical Properties of Natural Fiber Reinforced Composites. Mater. Today Proc. 2017, 4, 2793–2799.

Singleton, A.C.N.; Baillie, C.A.; Beaumont, P.W.R.; Peijs, T. On the mechanical properties, deformation and fracture of a natural fibre/recycled polymer composite. Compos. Part B Eng. 2003, 34, 519–526.

Sumaila M., Amber I., Bawa M., Effect of Fiber Length on the Physical and Mechanical Properties of Random Oriented, Nonwoven Short banana (Musa Balbisiana) Fiber/Epoxy Composite, Asian Journal of Natural & Applied Sciences, 2 (2013), pp. 39-49.

Summerscales, J.; Virk, A.; Hall, W. A review of bast fibres and their composites: Part 3—Modelling. Compos. Part A Appl. Sci. Manuf. 2013, 44, 132–139.

Venkateshwaran N, Elayaperumal A. (2010). Banana fibre reinforced polymer composites—A review. *Journal Reinforced Plastics and Composites*.29, 2387-2396

Venkateshwaran N., Elayaperumal A., Banana Fiber Reinforced Polymer Composites - A Review, Journal of Reinforced Plastics and Composites, 29 (2010), pp. 2387-2396.

Vigneswaran C, Pavithra V, Gayathri V and Mythili K. (2015). Banana fibre: Scope and value-added product development. *Journal of Textile and Apparel, Technology and Management*.9, 1-7.

Nwambu, C. N., Robert, C., Alam, P., Tensile behavior of unaged and hygrothermally aged discontinuous Bouligand structured CFRP composites, *Oxford Open Materials Science,* 3 (1), 2023.

Ekwedigwe, C. M., Nwambu, C. N., Nnuka, E. E., Effects of rice straw fibre and walnut shell ash particulates on the mechanical behavior of epoxy composite. *Unizik Journal of Engineering and Applied Sciences,* 1(1), 69-77, 2023.

Okoye, C. N., Okolie, P. C., Azaka, O. A., Nwambu, C. N., Tensile Behaviors of Al-Si-Mg Alloy Reinforced with Periwinkle Shell and Manigera Indica Particulates. *International Journal of Novel Research in Civil Structural and Earth Sciences,* 10 (3), 15-24, 2023.

Ekwedigwe, C. M., Nnakwo, K., Nwambu, C. N., Viscoelastic properties of alkaline treated walnut shell/rice straw fiber/epoxy biocomposite. *Journal of Civil Engineering and Environmental Scences,* 9(1), 009-013, 2023.

Nwambu, C. N., Robert, C., Alam, P., Tensile behavior of unaged and hygrothermally aged asymmetric helicoidally stacked CFRP composites, *Journal of Composites Science* 6 (5), 137, 2023.

