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Development and Evaluation of Hybrid Biocomposites from Luffa and Banana Fibres for Below the Knee Prosthetic Leg Socket

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Reinforced Epoxy Composites.

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Abstract: **The research work, "Development and Evaluation of Hybrid Biocomposites from Luffa and Banana fibres for below the knee prosthetic leg socket" was successfully carried out. Hybrid composites are one of the emerging fields in polymer science that are gaining attention for application in various sectors, such as health, building, aeronautic and automotive. In this study, Luffa and banana fibres were extracted and evaluated. Their characteristics were reported as potential alternative for harmful synthetic fibres (glass/carbon fibres) for below the knee prosthetic leg socket. Luffa and banana fibres were manually extracted and treated using 0.1mol solution of NaOH for 2 hours at room temperature. After the preliminary characterization, the treated and dried luffa/banana fibres were used to develop composites of woven banana fibre mat (WBF) and hybrid biocomposites of luffa particles (LP) and woven banana fibres (WBF) mat reinforced epoxy resin composites in predetermined proportions using the simple hand lay-up method. The composites were prepared according to America Society of Testing Materials (ASTM) standards and investigated for some mechanical properties. The treated and dried luffa/banana fibres were characterized using fourier transform infrared (FTIR) spectroscopy, x-ray diffraction (XRD), energy dispersive x-ray fluorescence (EDXRF), and tensile strength. From the characterization tests, it was observed that (FTIR) analysis confirmed the presence of the different functional groups of cellulose, hemicellulose and lignin absorbed on the structures of the fibres. X-ray diffraction and chemical composition characterization of treated banana fibre (TBF) showed two main diffraction peaks at angles approximately 16.12 and 23.14^0 corresponding to (100) and (170) lattice respectively. Crystallite size (1.45nm) of TBF minimizes water absorption. EDX spectrum of treated luffa fibre (TLF) showed a higher amount of iron intensity (90.66%) and calcium (80.13%) as the two main components in the chemical chain structure of cellulose. The maximum tensile strength was obtained at 38.5MPa for treated banana fibre. Entirely the aforementioned outcomes ensured that the WBF is the expected reinforcement to the fiber-reinforced composite materials in the application of prosthetic leg socket.**

Keywords: **Characterization tests, Mechanical properties, Luffa fibre, Banana fibre, Hybrid composites, Epoxy.**

1. INTRODUCTION

In today's modern world, hybrid composites are one of the emerging fields in polymer science that are gaining attention for application in various sectors, such as health, building, aeronautic and automotive. Due to environmental concerns by industrialists, researchers, and academicians, they are developing sustainable composite materials for most engineering applications. Natural fibres show attractive properties over synthetic fibres for instance low weight and cost, biodegradable, and availability in the environment (Sanjay *et al*., 2019 and Vinod, *et al*., 2019). Natural fibre-based manufacturing plants can control the emission of hazardous chemical and non-degradable waste generation during the manufacturing of synthetic fibres-based manufacturing plant (Vijay, *et al*., 2021).

Natural fibre-reinforced composites have distinctive advantages compared to synthetic materials including high specific strength, better stiffness, lightweight, biodegradability, thermal insulation, abundance, low cost, nonabrasive nature, nontoxicity, and so forth (Manimaran, *et al*., 2018).

Natural based fibres are becoming more important alternative to the traditional glass/carbon fibres due to their high specific strength, lighter weight, low density, non-toxicity, biodegradability, renewability and environmentally friendliness (Rosalem, e*t al*., 2012).

When natural fibres are closely compared to inorganic fibres, it presents some well-known advantages such as lower density and cost; are less abrasive to the processing equipment, harmless, biodegradable, renewable, and their mechanical properties can be comparable to those of inorganic fibres, furthermore, they are recyclable, easily available in most countries, easy fibre surface modification, and its relative non-abrasiveness.etc (Li *et al*., 2008; George *et al*., 2001)

Campbell *et al*., (2012), compared plant-based natural fibres such as banana, ramie, seashell, flax, soya, cotton, bamboo and corn with traditional synthetic fibres (glass and carbon). Results of mechanical properties of the natural based composites compared favorably with those of carbon-based fibres, affirming that natural based composites have great potentials for use as alternative for production of prosthetic leg sockets.

The history of Man can be as well linked to the use of fibres; traditionally as a rope, canvas, and sacking. Very high interests in banana cultivation in recent years have been achieved for two main reasons; one is banana's ability to provide huge commercial earnings for producing nations and the other is that banana's ability to accumulate carbon dioxide at a clearly high rate (Amaducci *et al*., 2000). The merits of using natural lignocellulosic fibres as reinforcements of the matrix can't be overemphasized. Banana is clearly known as a cellulosic source with economic and ecological advantages.

The main objective of the prosthesis is to provide the possibility of restoring functional capabilities to people with amputations and they are an extension of the user's limb (Irawan, *et al.*, 2011). The extension may be the upper or the lower limb. The upper limb extension (upper limb prosthesis) is designed to replace the upper lost limb of the body whereas the lower limb extension is designed for replacing the lower lost limb of the body. However, this study focuses on the development and evaluation of hybrid biocomposites from luffa/banana fibres for application in below the knee prosthetic leg socket.

2. MATERIALS AND METHOD

The materials and equipment used for this research work are: Epoxy resin (Araldite LY-556), Hardener (Araldite HY 951), Luffa fibres, Banana fibres, Sodium hydroxide (NaOH), Distilled water, Mould releasing agent, Wax, Hand gloves.

2.1 Preparation of the raw materials

Bundles of luffa aerial root stalks were collected around Efekwo-Otukpa in Ogbadibo Local Government Area of Benue State. Luffa fibre preparation was through water retting (Begum and Islam, 2013). The bundles of luffa aerial root stalks were submerged in water for 24 hours to allow decay-causing bacterial to be absorbed. Thereafter, the fibre strands were freely extracted and left for 48 hours under room temperature. The extracted fibres were soaked in distilled water for 24 hours and then removed and room dried for 72 hours. The dried luffa fibres were treated using 0.1 mol of sodium hydroxide (NaOH) solution and allowed to dry under room temperature for another 24 hours (Bar and Almeida, 2013). The fibres were then pounded gently into particulates and sieved using standard test sieve into 300μm.

Plates 1a - 1c present photographs of untreated luffa fibres, treated and dried luffa fibres, grinded and sieved luffa particles respectively.

(a) **(b)** **(c)**

Plate 1: **(a) Untreated Luffa Fibre, (b) Treated and dried Luffa Fibre, (c) Grinded and sieved Luffa Particles**

Banana stem was cut from the plant harvested from a plantation in Makurdi, Benue State. The fibres were extracted by removing the bark from the stem, followed by manually peeling off the fibres from the bark using the hand stripping method (Paramasivam, *et al*., 2020).

The extracted fibres were sun dried for 72 hours until all the moisture was removed from the fibre and then treated with 0.1 mol of NaOH solution for 2 hours. Bar and Almeida, (2013) reported that surface chemical treatment has a significant role in determining the crystallinity of the banana fibre.

Distilled water was used in neutralization procedure to remove the alkali from the surface of the fibres. After being neutralized, the fibres were air dried for 24 hours to remove all moisture prior to weaving and lamination (Begum and Islam, 2013). The fibres were then woven into bidirectional 0/90^{o} fibre mat. Plates 2a-2d present photographs of banana stem, strips from banana stem, extracted banana fibre and hand-woven banana fibre.

(a) (b) (c) (d)

Plate 2: **(a) Banana Stem, (b) Strips from Banana Stem, (c) Extracted Banana Fibre and (d) Hand Woven Banana Fibre.**

3. PREPARATION OF THE COMPOSITE

The composites were fabricated by hand lay-up process. The fibre mat was hand woven from banana fibres. The mould used for fabricating the composites was made from aluminum material with a debonding agent applied on the inner side. The inner cavity dimension of the mould is 180mm x 130mm x 8mm thick. For the single composite, the fibre mat was neatly cut into the mould size, mounted on the base plate of the mould which was placed on the table, and then it was completely filled with the epoxy resin. Epoxy hardener was the catalyst mixed with epoxy resin to give effective binding. The epoxy resin applied was distributed to the entire surface by means of a roller and the air gaps formed during fabrication were removed by gently squeezing using a roller until the matrix was set properly under the pressure of 6MPa. The setup was left to cure for 24 hours at room temperature. The same process was repeated for the 2 layers woven banana fibre mat (2LWBF) and 3 layers woven banana fibre (3LWBF) mat.

Hybrid biocomposites of luffa particle (LP) and woven banana fibre (WBF) mat was fabricated using the same hand lay-up process. The epoxy resin was mixed with the hardener in the weight ratio of 2:1. The fibre mat was neatly cut into the mould size, mounted on the base plate of the mould. The luffa particle of predetermined W% was impregnated with epoxy resin and distributed to the entire surface of the mat by means of a roller and the air gaps formed during fabrication were removed by gently squeezing using a roller until the matrix was set properly under the pressure of 6MPa. The specimen was allowed to cure for 24 hours at room temperature. The process was repeated for LP/2LWBF and LP/3LWBF mat. Now the prepared composites were cut for testing conforming to the dimensions of America Society of Testing Materials (ASTM) standards.

Table 1: Composition of WBF Mat and Epoxy Composite

WBF Mat No. of Layers	Epoxy resin (g)	Epoxy hardener (g)
1	193.2	96.6
2	186.4	93.2
3	179.8	89.9

Table 2.Composition of LP/WBF Mat and Epoxy Composite

WBF Mat No. of Layers	Luffa particles (g)	Epoxy resin (g)	Epoxy hardener (g)
1	6.1g	186.4g	93.2g
2	12.2g	172.6g	86.3g
3	18.3g	159g	79.5g

Characterization Study

3.1 Spectroscopic characterization (FTIR). The functional compound of the fibres was measured by using the Fourier Transform Infrared (FTIR) Spectrophotometer (FT-IR 8400S, Shimadzu Corporation, Japan). To measure the infrared of treated and dried luffa/banana fibres, the fibres were crushed and blended with potassium bromide (KBr) due to the transparent nature of KBr. The scan rate of FTIR spectrometer was 32 per min and resolution of 2 per cm in the wave number region range of 400–4000 cm−1 at a room temperature of 30 °C and RH of 65% was documented in absorbance mode as a function of the wave. The process was used for the identification of functional groups present in treated and dried luffa/banana fibres.

3.2 X-ray diffraction (XRD). The crystallinity index of the treated and dried luffa/banana fibres specimen was studied using XRD. The degree of structural arrangement is determined through the crystallinity index whose amount is paramount important because it influences the alkali treatment and mechanical properties of natural cellulosic fibres. XRD diffractometer (Malvern Panalytical Aeris, Malvern, United Kingdom) with PIXcel detector and fixed slits with Fe filtered Co-Kα radiation was used to study the crystallographic properties of treated and dried luffa/banana fibres.

Morphology study

3.3 Energy dispersive X-ray spectroscopy (EDX). EDX is a common method used to identify elements (for instant Carbon, Oxygen, and Nitrogen, etc.) of natural fibres. The elemental presence of treated and dried luffa/banana fibres was determined by EDX (TEAM™ EDS), which is equipped with the scanning electron microscopy (SEM).

Physical Characterization

3.4 Density Testing

In this present study, the density of the composites was carried out using Archimedes principle and each pre-weighed sample size of 4cm by 4cm was immersed in a beaker containing a known level of water and the difference between the initial and final level of water in the beaker was calculated as the volume of the sample. The densities of the samples were evaluated using equation (1). (Tewari et al, 2012).

$$\rho = \frac{M}{V} \quad (g/cm^3) \qquad (1)$$

Where p is the density of the sample, M represents the mass of each sample and V is the volume of the sample.

Mechanical Properties

3.5 Tensile Testing

The tensile strength of the produced composites was measured with a Monsento Tensometer Type W with S/No. 9875 in accordance with the ASTM D638 procedure. The dimensions of the sample were 60mm x 6.24mm x 0.06mm thick for each sample with gauge length of 40mm. The Test was conducted by gripping each end of a reduced section specimen and slowly pulling it until catastrophic failure occurs. The Figure 1 present the tensile testing equipment.

The tensile strength, elastic modulus and per cent elongation at fracture can be expressed as: (Vishu, 2013).

$$\text{Tensile strength (MPa)} = \frac{p}{bh} \qquad (2)$$

Where; p is the pulling force (N), b is the specimen width (mm), h is the specimen thickness (mm).

Figure 1: Tensile testing equipment

3.6 Impact Testing

The impact strength test of the sample was done using the Charpy impact testing machine with capacities of 15J and 25J and model no. cat. Nr. 412 and in accordance with ASTM standard D-256. In this method, the specimen was supported horizontally as a simple beam and fractured by a blow delivered in the middle by the pendulum. The impact test specimen dimensions were 75mm x 8mm x 7 mm. Five samples were tested and the average of the values of the energy required for fracture in joules was recorded. Impact is a single point test that measures a materials resistance to impact from a swinging pendulum. Impact is defined as the kinetic energy needed to initiate fracture and continue the fracture until the specimen is broken. The Figures 2 and 3 present the impact testing specimen and equipment respectively.

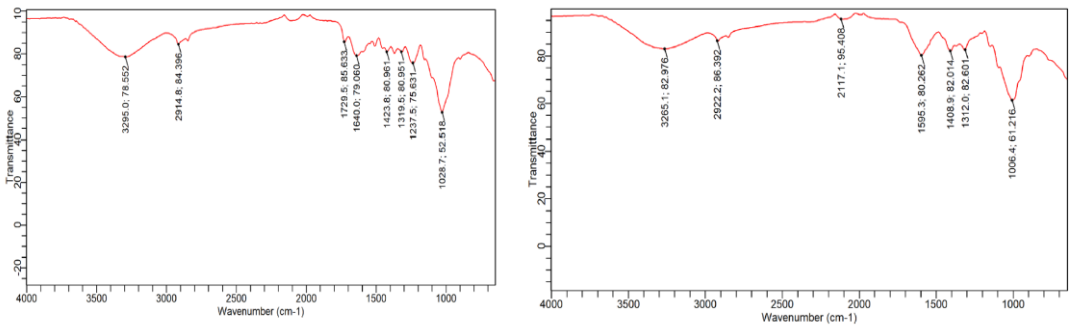
Figure 2: Impact testing specimen

Figure 3: Impact testing equipment

4. RESULTS AND DISCUSSIONS

The results of various characterization tests are reported here. These include evaluation of FTIR, XRD, EDX, density test, tensile and impact strength that have been studied and discussed.

4.1 Spectroscopic Characterization (FTIR) Result

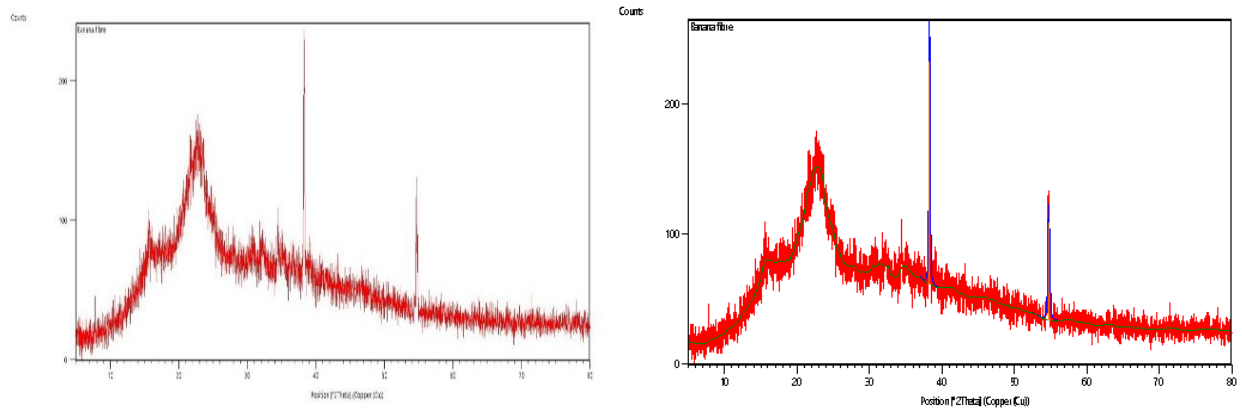


(A) **(B)**

Figure 4: (A) Graphs of FTIR Spectra of Treated Luffa Fibre and (B) FTIR Spectra of Treated Banana Fibre.

The FTIR tests for both treated and dried luffa/banana fibres were conducted to determine the various percentages of cellulose, hemicellulose and lignin contents. The respective FTIR graphs showed similar ranges of spectra wavenumbers of between 4000-600 cm^{-1} and well suppressed ripples at various points. However, according to Taslima *et al.*, (2021) report on natural fibres chemical properties, banana stem fibre amongst others was observed to show high percentage components of holocellulose (65.2%) and cellulose content (63.9wt %) which is in agreement with experimental result that high cellulose in natural fibres is considered as the principal component which contributes to increase in tensile strength, stability, stiffness, and resistance to hydrolysis as well as economic production of fibres for several applications. Similarly, the spectra of the treated banana fibre in the current research has revealed equally high percentage components of the functional contents that greatly enhances the tensile strength of the fibre.

4.2 X-Ray Diffraction (XRD) Result

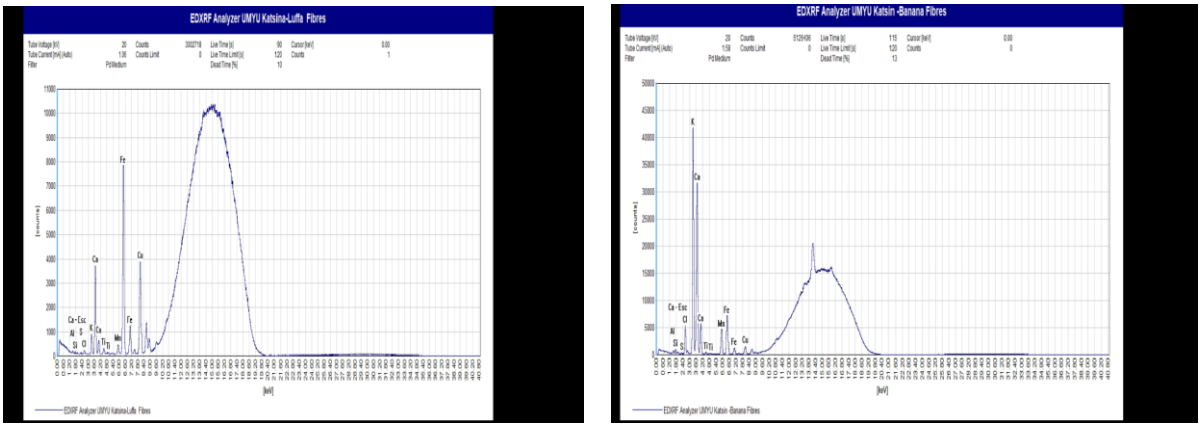


(A) **(B)**

Figure 5: **(A) Graphs of XRD for Treated Luffa Fibre (TLF) and (B) Treated Banana Fibre (TBF).**

X-Ray diffractogram of the TLF and TBF as represented in Figure 5 are showing respective diffraction peaks. According to Manimaran *et al*., (2018), the presence of amorphous constituents mainly hemicellulose, pectin, lignin, wax and amorphous cellulose is confirmed by the small intensity peaks and whereas, crystalline constituents of the treated fibres are confirmed by the high intensity peaks respectively. The peaks are typical of natural fibres and showing the presence of cellulose type I and IV (Senthamaraikannan *et al*., 2016). TBF as reported by Segal method has a good crystallite packing and strong structural arrangement for developing durable bio-composites. This is in agreement with the XRD analysis of this study. Crystallite size of banana fibre (1.45 nm) minimizes water absorption and chemical reactivity when reinforced in a matrix medium (Garette, *et al*., 2019). Therefore, this implies that banana fibre can be used in areas where water is present without deteriorating and as such validating banana fibre suitable for the production of prosthetic leg socket.

4.3 Energy Dispersive X-Ray Spectroscopy (EDXRF) Result



(A) **(B)**

Figure 6: **(A) Graphs of EDXRF Spectrum of Treated Luffa Fibre and (B) Treated Banana Fibre**

From the elemental analysis results, TBF compared to TLF, have relatively higher potassium content (1.9300%) as against calcium (1.2030%) with other trace elements. This confirms the presence of less amount of amorphous or non-cellulosic constituents on the surface of TBF. Composition of non-cellulosic elements of TBF is less (32.94%) compared to cellulose (58.45%). High extractives are considered as the important parameters in preventing the formation of micro-organisms as found in TBF while the low extractives increase hygroscopic property that minimizes impact on chemical and mechanization of composite materials. Also, the high values exhibited by TBF are similar to the values reported by Taslima, et al. (2021) which confirms TBF as a suitable sustainable material for prosthetic leg socket application.

Physical Characterization

4.4 Density Result

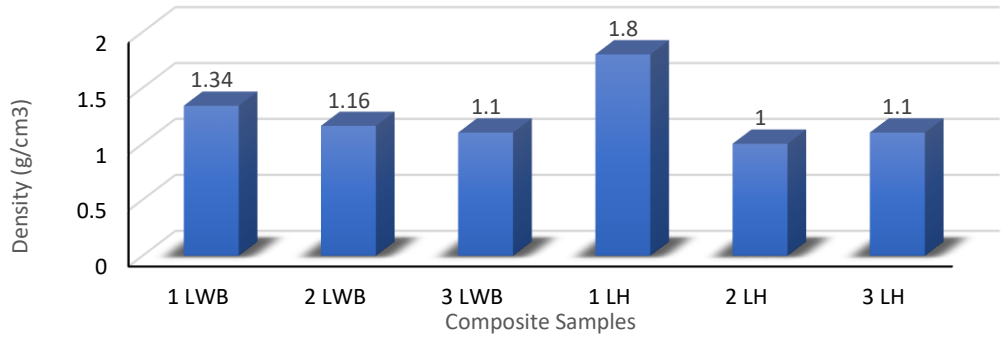


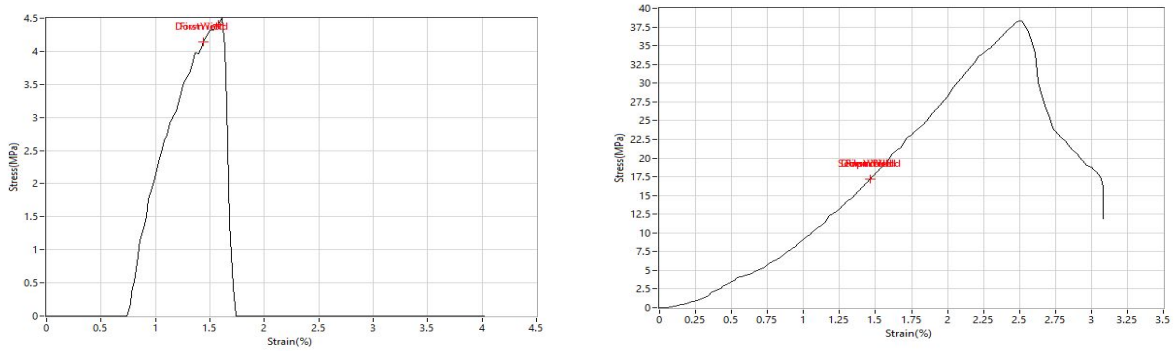
Figure 7: Variation of Density with Composite Samples

The variation of density for different laminate stacking sequences is shown in Figure 7. It was observed that with the WBF mat composite samples, the density varied from 1.1 – 1.34g/cm^3. However, with the hybrid of LP/WBF mat (1LH, 2LH, and 3LH), the density varied from 1.1 – 1.8 g/cm^3. It is interesting to note that both the single composite and hybrid showed similar trend of results whereby as the fibre contents were increased the density decreased. The reason for the drop in density could be the reason given by Nitin and Singh (2013) that the presence of porosity/voids decreased the density because there could have been enough pressure applied during compression. The low density values of 1 – 1.1g/cm^3 of this research work are significantly less than the synthetic fibres of carbon fibre (1.60 g/cm^3) and E-glass (2.56 g/cm^3) as reported by (Indran and Raj 2015).

Implication of this result is that, lower density values depict lower weight which is in conformity with one of the critical parameters needed for the production of prosthetic leg socket.

Mechanical Properties

4.5 Tensile Result



(A) **(B)**

Figure 8: **(A) Graphs showing Stress/Strain values for TLF and (B) Stress/Strain values for TBF**

It is well known that fibre strength is mainly responsible for strength properties of the composite. Therefore the stress/strain graph of the TLF as shown in Figure 8A varied from 0.7 – 4.5 MPa. The tensile strength was observed to increase in the fibre after treatment with NaOH solution. This confirmed that, the alkaline treatment was effective by the removal of the impurities which were responsible for the increase in tensile strength in the fibre. This result is in agreement with the observation of Das and Biswas (2016).

The tensile strength graph of TBF as shown in Figure 8B varied from 0.10 – 38.5MPa. The tensile strength was observed to increase with the application of chemical treatment on the fibre surface structure thereby removing all inherent impurities and improving the effectiveness of the functional contents in the fibre structure. This also revealed that the alkaline treatment

was significantly effective for the increase in the tensile strength. Also, it was observed that the TBF presented a tangible higher tensile strength of 38.5MPa than the TLF 4.5MPa thereby proving that TBF has superior properties than the TLF. This preliminary investigation led to the reason why the TBF was chosen to be used in woven mat form similar to the glass fibre in prosthetic leg socket application.

4.6 Impact Result

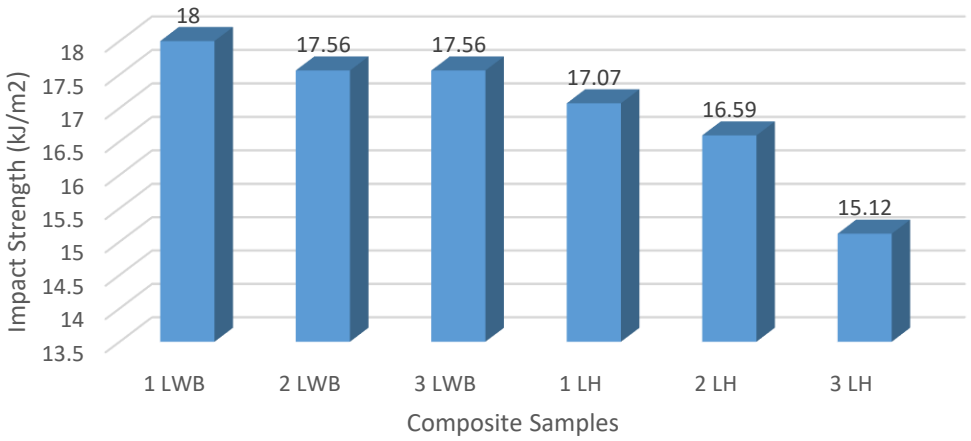


Figure 9: Variation of Impact Strength with Composite Samples under Investigation

Figure 9 presents the impact strength of the produced composite samples which demonstrated the capability of the reinforcements to withstand a suddenly applied load normally expressed in terms of energy. The impact strength of the 1LWBF -3LWBF mat reinforced epoxy resin was observed to decrease with increasing fibre contents and varied from 18 – 17.56 kJ/m^2. This drop may be attributed to the weak interfacial interaction between the composite samples and matrix material as reported by (Mani *et al*., 2014). However, the values of impact strength obtained by the produced composites of WBF mat are significantly better than the values of 0.002205, 0.002205 and 0.002701 J/cm^2 for 10% bagasse-based composite, 20% for bagasse-glass fibre composites and 30% for bagasse-glass fibre respectively (Tewari *et al*., 2012).

When comparing the results of 1LH - 3LH composite samples to 1LWBF -3LWBF, it showed that the WBF mat has better impact strength than the hybrid composite samples and therefore implies that the WBF mat composite samples of this research work have very high significant impact strength that can be used as alternative materials for the production of prosthetic leg socket.

5. CONCLUSIONS

In this work, development and evaluation of hybrid biocomposite of luffa and banana fibres for below the knee prosthetic leg socket was successfully carried out. The physical characterization, FTIR, XRD, EDX, tensile and impact strength of the composites as a function of fibre content were analyzed.

The preliminary characterization of the treated and dried luffa/banana fibres using FTIR spectroscopy revealed the concentration of functional contents such as cellulose, hemicellulose and lignin, XRD showed diffraction peaks respectively depicting the presence of crystalline constituents and EDXRF revealed both high and low extractive properties on the fibres surface structures. The comparatively high percentage of cellulose (55.1 wt%) in TBF can make higher strength and lower density (1g/cm^3) that would support relatively lightweight composite materials. The FTIR and EDX analysis of TLF and TBF demonstrated the functional groups and elements of chemicals. Overall, this investigation advances the facility of TLF/TBF to work for different applications.

The density test results showed significant low values of 1g/cm^3 and 1.1g/cm^3 for 2LHB and 3LWBF respectively, the TBF obtained the highest tensile strength of 38.5MPa and while 1LWBF had an optimum impact strength of 18kj/m^2.

Therefore, it is conclusive from the above results that the woven banana fibre mat exhibited better properties and can conveniently be a suitable sustainable replacement material for certain synthetic polymer composites applied in the manufacture of prosthetic leg socket and other applications.

SCOPE FOR FUTURE WORK

Similarly, various other natural reinforcing materials could be used to mix with banana fibre to form better hybrid composite which has better mechanical properties and as well as cost effectiveness.

Can also carry out scanning electron microscopy (SEM) analysis for this hybrid biocomposites.

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REFERENCES

[1] Alotaibi, M. D. *et al.* (2019). Characterization of natural fiber obtained from different parts of date palm tree. *Int. J. Biol. Macromol.* **135**, 69–76.

[2] Amaducci, S. Amaducci M.T. Benati R. and Venturi G., (2002). Crop yield and quality parameters of four annual fibre crops (hemp, kenaf, maize and sorghum) in the North of Italy. Industrial Crops & Products, 11(2-3), 179–186.

[3] Bar, E.K, Almeida, J. R. M. (2013). Aspects of alkali treatment of sponge gourd (luffa cylindrical) fibres on the flexural properties of polyester matrix composites, Journal of Applied Polymer Science; Vol. 87, No. 12, pp. 1927-1932.

[4] Begum, K. and Islam, M. A. (2013). Natural fibre as a substitute to synthetic fibre in polymer composites: A review, *Res. J. Eng. Sci.* pp 46–53.

[5] Boopathi, L., Sampath, P. S. & Mylsamy, K. (2012). Investigation of physical, chemical and mechanical properties of raw and alkali treated Borassus fruit fiber. *Compos. Part B* **43**, 3044–3052.

[6] Campbell AI, Sexton S, Schaschke CJ, Kinsman H, McLaughlin B, Boyle M.(2012). Prosthetic limb sockets from plant-based composite materials. *Prosthet Orthot Int*. 2012;36(2):181-9. http://doi.org/cv6d. [Links]

[7] Das, K.I. and Biswas, J.M. (2016). Effects of fibers and matrix adhesion on tensile properties of composites from natural fibers of luffa cylindrical fiber reinforced epoxy resin. *Journal of Material and Environmental Science*, 4(2), 120-132.

[8] Garette Jebadurai, S, Edwin Raj, R, Sreen, V.S. and Binoj, J.S. (2019). Comprehensive characterization of natural cellulosic fiber from coccinia grands stem. Carbohydr. Polym. 207-675-683

[9] George, J., Sreekala, M.S. & Thomas, S., 2001. A review on interface modification and characterization of natural fiber reinforced plastic composites. Polymer Engineering & Science, 41(9).

[10] Idran, A.S. and Raj, B.M. (2015). "Analysis Report on Synthetic Fibres". Indian Annual Publication. Vol. 21. (23-78).

[11] Irawan, A. P., T. P. Soemardi, K. Widjajalaksmi, and A. H. S. Reksoprodjo (2011). "Tensile and flexural strength of ramie fiber reinforced epoxy composites for socket prosthesis application", *International Journal of Mechanical and Material Engineering, vol. 6, no. 1. pp. 46-50.*

[12] Li, Y., Hu, C. & Yu, Y., 2008. Interfacial studies of sisal fiber reinforced high density polyethylene (HDPE) composites. Composites Part A, 39(4), 570–578.

[13] Manimaran, P., Senthamaraikannan, P., Muruganathan, K. & Sanjay, M. R. (2018). Physicochemical properties of new cellulosic fibers from *Azadirachta indica* plant. *J. Nat. Fibers* **15**(1), 29–38.

[14] Mani, G. T. and Miller, W. C. (2014). "The prevalence and risk factors of falling and fear of falling among lower extremity amputees," *Arch. Phys. Med. Rehabil.*, 82(8):1031–1037

[15] Nitin, S and Singh, V.K. (2013). Mechanical properties of Wallnut reinforced composite, J. Mater. Environ. Sci, 4(2),233.

[16] Paramasivam, S. K., D. Panneerselvam, D. Sundaram, K. N. Shiva, and U. Subbaraya. (2020). Extraction, characterization and enzymatic degumming of banana fiber. *Journal of Natural Fibers* 19:1–10. doi:10.1080/15440478.2020.1764456.

[17] Rahman, M. M., Rimu, S. H., Biswas, S., Rashid, T. U., Chisty, A. H., Ashiqur Rahman, M. D., Murad, S., & Haque, P. Preparation of poly(acrylic acid) exfoliated clay composite by in-situ polymerisation for decolouration of methylene blue from wastewater. *Int. J. Environ. Anal. Chem.* https:// doi. org/ 10. 1080/ 03067 319. 2020. 18137 32(2020).

[18] Rosalem, R.T, Danusa, K.P. (2012). Study on why Natural Based Fibres are Possible Alternatives for the Traditional Glass- Carbon Fibres. JRRD, 84(2):342-352,

[19] Sanjay, M. R., Jyotishkumar Parameswaranpillai, S. S., Jawaid, M., Pruncu, C. I. & Khan, A. (2019). A comprehensive review of techniques for natural fibers as reinforcement in composites: Preparation, processing and characterization. *Carbohydr. Polym.* **207**, 108–121.

[20] Senthamaraikaannan, M.N. Santar, B.M. and Ashitan, A.S. (2016). "Research work on X-Ray Diffractographic Lenses". Reported in UK Annual PUB. Revised edition.

[21] Senthamaraikannan, P. & Kathiresan, M. Characterization of raw and alkali treated new natural cellulosic fiber from *Coccinia grandis* L. *Carbohydr. Polym.* **186**, 332–343 (2018).

[22] Taslima, M.N. Santa, B.T. and Reeves, B.T (2021). "Review Study of the Composites Chemical Contents". Science Centre Pub Annually. Med.Eng. Conference Papers. (Rec.20134).

[23] Tewari, M. Singh, V.K Gope, P.C. nd Chaudhary, A.K (2012). Evaluation of mechanical properties bagasse-glass fibre reinforced composite. Journal of Mater Environ. Sci., 3(1),171-184.

[24] Vijay, R., Singaravelu, D. L., Vinod, A., Sanjay, M. R. & Siengchin, S. (2021). Characterization of alkali-treated and untreated natural fibers from the stem of parthenium hysterophorus. *J. Nat. Fibers* **18**(1), 80–90.

[25] Vinod, A. *et al.* (2019). Characterization of untreated and alkali treated natural fibers extracted from the stem of *Catharanthus roseus*. *Mater. Res. Express* **6**(8), 1–20.

[26] Vishu, S. (2013). Plastics Testing. In: Handbook of Materials Selection. Edited by Myer Kutz Copyright, NewYork, John Wiley and Sons. Inc.