Journal of Physical Science, Vol. 29(3), 23–35, 2018

Effect of High-frequency Microwave Radiation on the Mechanical Properties of Plantain (*Musa paradisiaca*) Fibre/Epoxy Biocomposite

Patrick Imoisili Ehi,[1,2*] Dagogo Ibiye Tonye,[3] Popoola Adeola Victor[1] and Okoronkwo Afemefuna Elvis[1]

[1]Chemistry Department, Federal University of Technology, P.M.B. 704, Akure, Ondo State, Nigeria
[2]Research and Development Department, Engineering Materials Development Institute, P.M.B. 611, KM 4, Ondo Road, Akure, Nigeria
[3]Chemistry Department, University of Capetown, Rondebosch, Cape Town, 7700, South Africa

[*]Corresponding author: patrickehis2002@yahoo.com

Published online: 25 November 2018

To cite this article: Ehi, I. P. et al. (2018). Effect of high-frequency microwave radiation on the mechanical properties of plantain (*Musa paradisiaca*) fibre/epoxy biocomposite. *J. Phys. Sci.*, 29(3), 23–35, https://doi.org/10.21315/jps2018.29.3.3

To link to this article: https://doi.org/10.21315/jps2018.29.3.3

ABSTRACT: *Natural fibres were extracted from plantain (Musa paradisiaca) pseudostem and modified using high-frequency microwave irradiation under different conditions in terms of power and time. First, the mechanical and morphology of treated and untreated fibre were investigated. Mechanical (tensile) properties test results reveal that microwave radiation at 550 W power was able to improve the tensile strength and modulus of the fibre. Scanning electron microscope (SEM) analysis shows surface roughness of the fibre has increased and uniform surface roughness was achieved. However, higher power and time of microwave irradiation causes a decrease in the mechanical properties the fibre as SEM image reveals the serious damaging effect on the surface of the fibre, due to degradation and rupturing of fibre cells by the exposure of inner central lumen of the fibre. In the second part, fibre-polymer biocomposite was fabricated using epoxy as the polymer matrix. Tensile and flexural test results reveal an increase in strength at optimised microwave power and time. A decrease in mechanical properties was observed at prolong and higher power radiation. Water absorption of fibre-polymer biocomposite was found to decrease after treatment at lower irradiation, interfacial adhesion of fibre-matrix was shown to increase with surface modification as reveals by SEM micrograph.*

Keywords: Plantain fibre, microwave radiation, mechanical properties, biocomposite, *Musa paradisiaca*

1. INTRODUCTION

Natural fibre reinforced composites consist of naturally occurring plant fibre as reinforcement and thermoplastic or thermosetting polymers as the matrix. The resulting fibre polymer composite is not only renewable, less abrasive, recyclable but have nonabrasive properties, high specific strength and stiffness.[1–3] Over the years, different natural occurring fibres such as hemp, jute, flax, kenaf, coconuts and banana fibre have been studied and used as reinforcement for plant fibre composites production with thermoplastic and thermosetting polymers as matrices.[4–13]

The major disadvantages of using natural fibre in a fibre polymer composite in comparison with synthetic fibres are high moisture absorption, poor wettability, incompatibility with some polymeric matrices, etc.[14] To overcome these challenges, researchers have over the years suggested the use of physical and chemical treatments for surface modification as a way of overcoming these challenges and improving the properties of natural fibres.[14–16] The use of chemical and physical methods has been found to reduce the inherent hydrophobicity of natural fibre.[17] However, the issues of environment and health are major concerns on the use of hazardous chemicals for modifying the fibre and its disposal. Thus, the use of non-hazardous chemical and physical modification of natural fibres are becoming an attractive area of research.

Microwaves are electromagnetic waves that lie between radio and infrared frequency regions in the electromagnetic spectrum. Their interaction with materials is generally via reflection, transmission or absorption. The majority of the microwave frequencies are dedicated for communications and radar purposes, while 915 MHz, 2.45 GHz, 5.8 GHz and 20.2–21.1 GHz frequencies are designated for scientific, medical and industrial uses.[18,19] The ability of some materials to convert microwaves into heat makes them suitable for microwave processing.[20] Conventional heating processes involve the heat been concentrated along the materials surface rather than the interior, microwave energy is, however, absorbed by the material and converted to heat.[21]

In this regard, the use of microwave irradiation on natural fibre is gaining substantial attention and has been reported by researchers. Xue and Xin reported in their study of microwave irradiated wool fabric, that microwave heating is more efficient than conventional heating.[22] Annapurna et al. reported that microwave irradiation could affect the macromolecular parameters, crystallographic structures and morphology of sisal fibre.[23] Mahmoodi et al. found potential production of new environment-friendly textile fibres in their study of silk degumming using microwave irradiation.[24] Meanwhile, Singh et al. studied the suitability of microwave irradiation on joining of a green composite.[25] Moharram and Mahmoud completed transformation of cellulose lattice type I into cellulose lattice type II without any heating using a microwave.[26] These research findings indicated that microwave radiation is an effective treatment method for natural fibre as well as fibre polymer composite due to their beneficial effects on processing time and mechanical properties.

Researcher such as Chimekwene et al., Okafor et al., Alvarez-López et al., Edith et al. and Imoisili et al. have studied plantain fibres as a source of natural fibre and their various applications.[27–31] However, there is no report on the effect of high-frequency microwave radiation treatment on the properties of plantain (*Musa paradisiaca*) fibre. This work is aimed at evaluating the effect of the physical modification on plantain fibre surface by applying microwave radiation treatments on the fibres. These actions are intended primarily to evaluate the effect of these modifications on pristine plantain fibre, whether the resulting fibres would obtain improve strength and stiffness thus improving the properties of the fibre reinforced polymer biocomposite.

Figure 1: Samples at different interval days.

2. EXPERIMENTAL

2.1 Extraction of Fibre

Plantain pseudostem were collected from a local farm in the south-west Nigeria state of Ondo after the harvest season and the fibre was extracted using water retting methods as reported by Tahur et al., in which plantain fibres were extracted for 35 days at 7 days intervals as shown in Figure 1.[32]

2.2 Fibre Modification

The microwave radiation treatment of the fibres was carried out in a microwave oven Sanyo Electronics Model EM 51052 having adjustable power of 550–750 W with a microwave frequency of 2.45 GHz. The extracted fibres were treated with microwave irradiation at power setting of 550 W and 750 W for different treatment period (2 min and 4 min). The fibres were removed from the oven and cooled under vacuum for 24 h.[24] The microwave treated (MV) fibres were designated as 550W2, 550W4, 750W2 and 750W4. The prefix W denotes the power setting whereas the suffixes of it represent the microwave irradiation time on the fibres in minute as reported in Table 1.

Table 1: Microwave treatment applied on plantain fibre.

Category	Treatment
UT	Untreated plantain fibres
550W2	550 W power treated fibre for 2 min
550W4	550 W power treated fibre for 4 min
750W2	750 W power treated fibre for 2 min
750W4	750 W power treated fibre for 4 min

2.3 Fibre Reinforced Polymer Biocomposite

Epoxy resin 3554A, a bisphenol class of epoxy resin and 3554B an amine class hardener was used as the polymer matrix. The weight ratio of resin to hardener used was 5:1. The fibres are cut into 10 mm length and distributed uniformly at the bottom of a steel mould, previously coated with a mould releasing agent. After being thoroughly mixed, the matrix was poured over the fibres evenly, then pressed and pushed down with the iron roller to avoid and eliminate air bubbles. Finally, a load is given to it to remove excess matrix and left for curing at room temperature for 24 h. Biocomposites with 15% constant amount of plantain fibre were manufactured for both treated and untreated fibres.

2.4 Mechanical Properties

Tensile tests were carried out on both untreated and microwave radiation treated plantain fibres according to ASTM D 3822 at room temperature on a Universal Instron testing machine model 3369, with 25 N as load cell full range. Fibres were tested in the as-received state at a gauge length of 10 mm in displacement control and at a crosshead speed of 1 mm min^{-1}. Tensile and flexural tests were carried out on the composite using a Universal Instron testing machine model 3369, in accordance with ASTM Test Method D638 and D790. The reported data is the average of five successful tests.

2.5 Morphology of Fibre

The fracture surface of composite and fibres was examined under a Zeiss Ultra Plus emission scanning electron microscope (SEM) to see the effect of microwave modification on their surface properties.

2.6 Water Absorption Properties of Biocomposite

Water absorption studies were performed following the ASTM D570-98 method. Test samples of untreated and microwave treated plantain fibres biocomposite were weighed and then soaked in a bath of distilled water at room temperature. At several times, the fibre samples were removed from the water, dried by a cotton cloth and weighed again. The percentage of water absorbed in the fibre was calculated by the weight difference between the samples exposed to water and the dried sample.

3. RESULTS AND DISCUSSION

3.1 Mechanical Properties

The mechanical properties of microwave radiation treated and untreated plantain fibres are reported in Figures 1(a) and 1(b), and fibre reinforced composite are reported in Figure 2. Plantain fibres exhibit the single linear elastic deformation until failure with no plastic deformation, which is typical of vegetable fibres.[33] Test results as shown in Figure 1 reveal that microwave radiation at 550 W was able to improve the tensile strength of fibre from 389 MPa to 499 MPa, while modulus of fibre was increased also from 7051 MPa to 8212 MPa. Tensile and flexural test results show an increase of both properties at a moderate radiation power of 550 W, which may be due to the moderate microwave power of 550 W been able to rearrange of the fibre structure and effectively releasing the residual stress in the fibre.[34] However, at high energy radiation of 750 W, decrease in the mechanical properties of the fibre and fibre polymer composite was observed. This may be due to degradation of the strength-providing cellulose and rupturing of fibre cells cause by high power microwave radiation.[24]

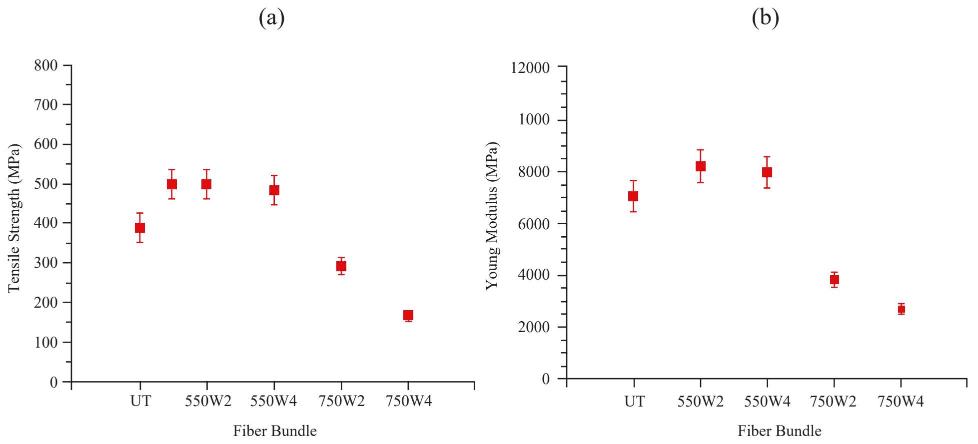

Figure 2: Plots of (a) tensile strength of untreated and microwave treated plantain fibre, and (b) modulus of untreated and microwave treated plantain fibre.

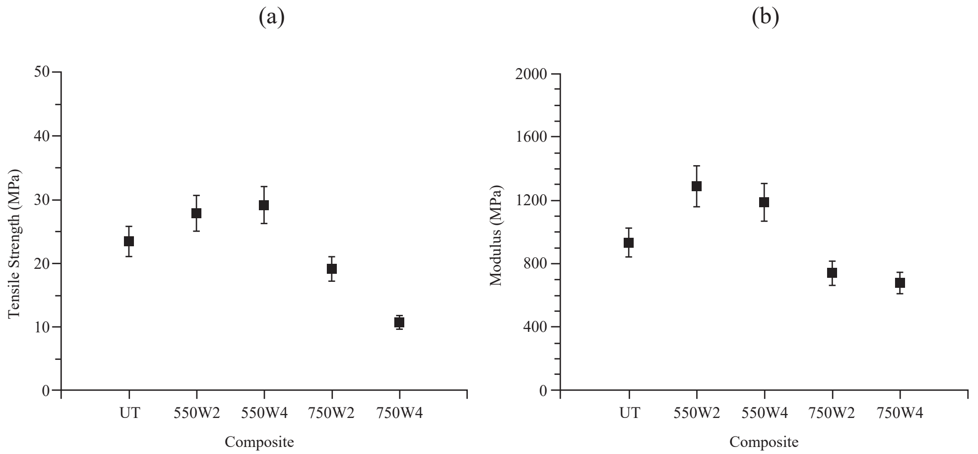

Figure 3: Plots of (a) tensile strength of untreated and microwave treated plantain fibre-epoxy biocomposite, and (b) modulus of untreated and microwave treated plantain fibre-epoxy biocomposite.

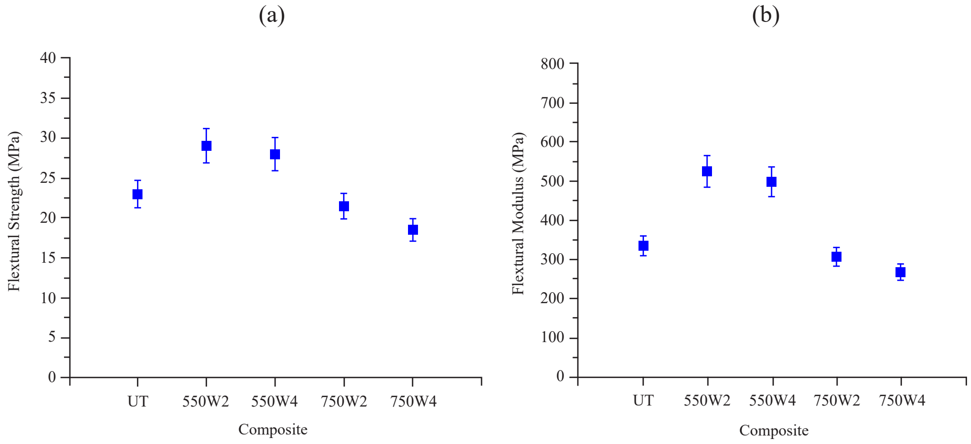

Figure 4: Plots of (a) flexural strength of untreated and microwave treated plantain fibre epoxy composite, and (b) flexural modulus of untreated and microwave treated plantain fibre-epoxy biocomposite.

3.2 SEM Analysis

SEM micrographs of untreated plantain fibres (UTs), 550W2, 550W4, 750W2 and 750W4 fibres are shown in Figure 5(a–e) and fracture surface of fibre reinforced composite are reported in Figure 6(a–c). It was observed that with the increase in irradiation period from 2 min to 4 min keeping the power constant at 550 W, the surface roughness of the fibre has increased, and uniform surface roughness was achieved. This suggests that with 550 W power microwave treated plantain fibre, a better adhesion with hydrophobic polymer resins could be achieved. Serious damaging effect on the surface of the fibre was observed at 750 W power microwave irradiation. The severity of damage can be estimated from the exposure of inner central lumen of the fibre irradiated for 4 min as shown in Figure 5(e); this has led to the heavy damage to the fibre surface along with the damage to the strength proving cellulose.[23]

Figure 6 shows fracture surfaces of treated and untreated fibre composite subjected to tensile stress. It was observed from Figure 6(a) that the surface of untreated fibre was completely devoid of matrix materials, this was an indication of fibre-matrix failure followed by fibre pull-out. The micrograph of 550W2 treated fibre composite (Figure 4(b)) shows that small fibre pull-out occurred with the existence of crack at the broken fibre end/sites, thus indicating strong bonding between fibre and polymer matrix. 750W4 treated fibre bio-composite as in Figure 6(c) shows multiples fibre pull-out, while the fibre shows splitting and tearing on the fibre surfaces indicating poor interfacial bonding of fibre-matrix and damage fibre surface.

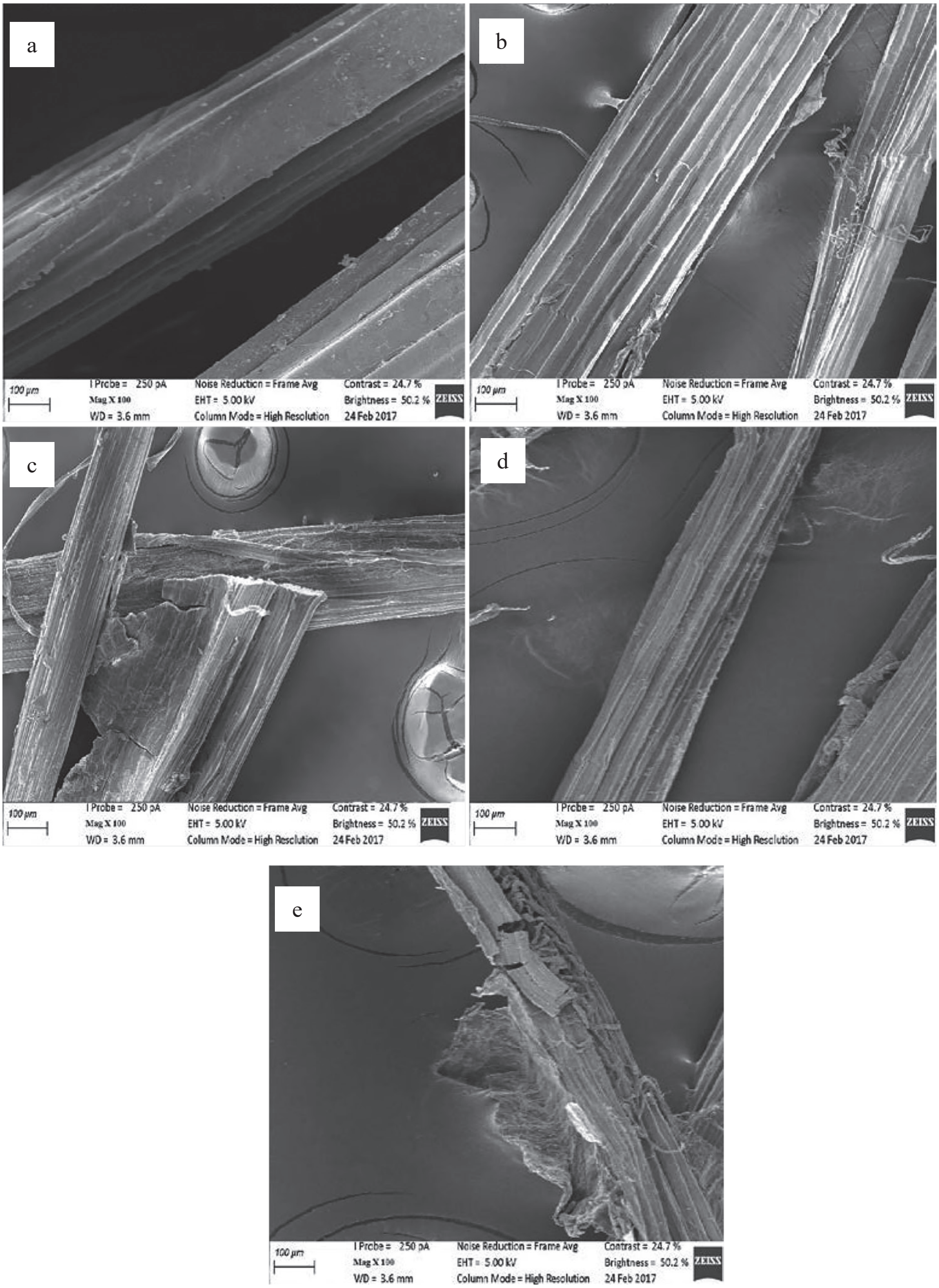

Figure 5: Longitudinal morphology of treated and untreated plantain fibres for (a) UT, (b) 550W2, (c) 550W4, (d) 750W2 and (e) 750W4.

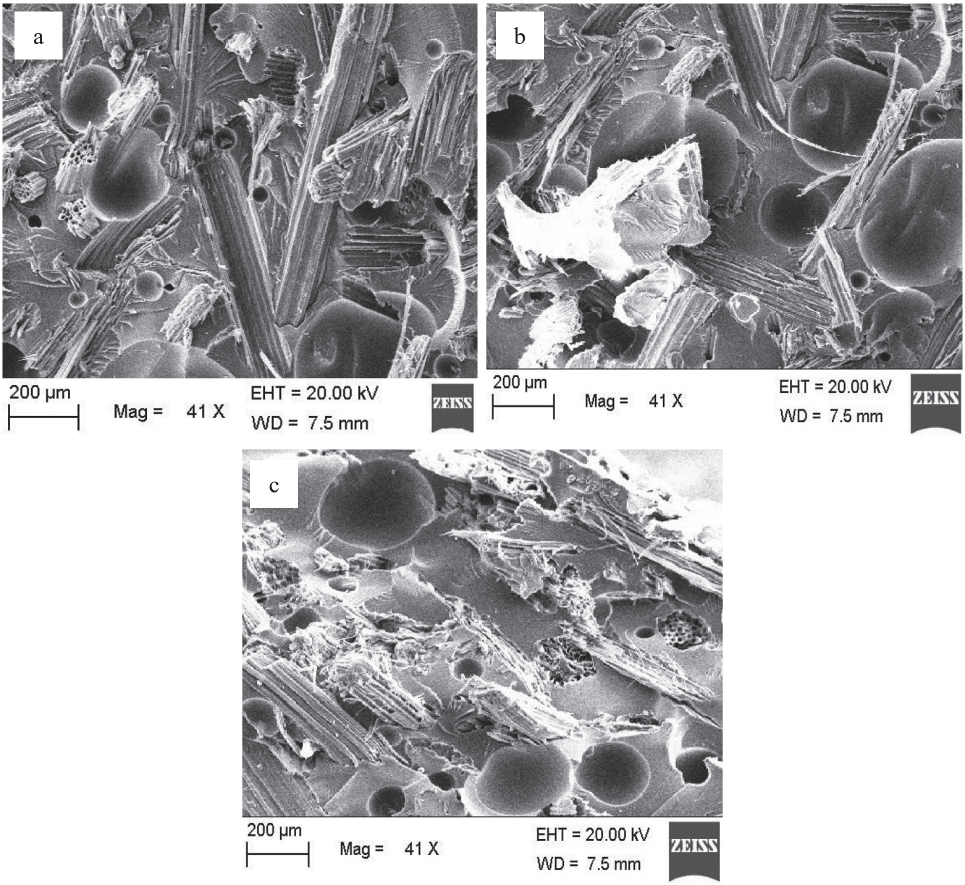

Figure 6: Fracture surface of treated and untreated fibre polymer composite of (a) UT, (b) 550W2 and (c) 750W4.

Figure 7 shows the water absorption curves of untreated and microwave radiation treated plantain fibre-epoxy biocomposite. All sample shows initial rapid absorption and later a saturated level without a further increase in sorption. The 550W2 treated fibre biocomposite shows lower absorption due to the effective reduction in the absorbed water and O-H group in the fibre and strong adhesion of fibre polymer matrix resulted in greater hydrophobicity and less moisture absorption.[24] Porosity content and fibre-matrix adhesion are known factors that are responsible for moisture behaviour of natural fibre composite, thus the high water absorption observed at 750 W may be due to the degradation of fibre resulting in a very porous, rupture cells which have resulted in an increase in the hydrophilic character of the composite.[35]

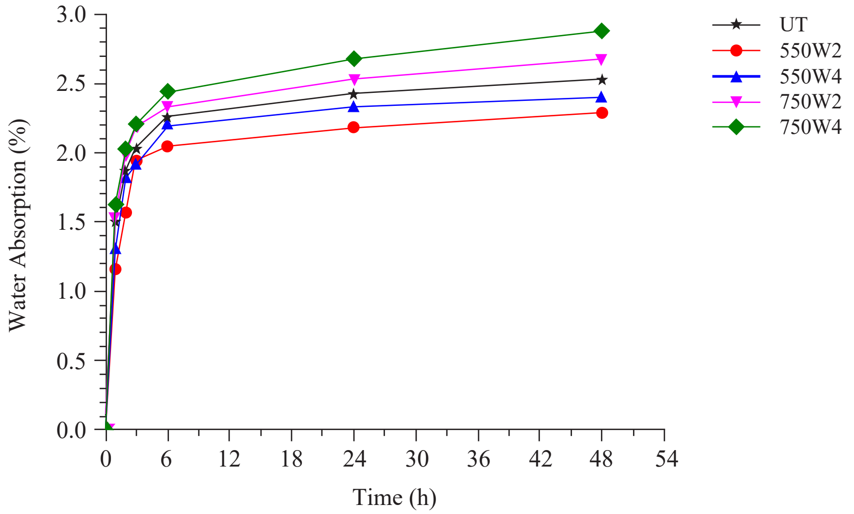

Figure 7: Water absorption of fibre-polymer biocomposite.

4. CONCLUSION

The applicability and suitability of high energy microwave radiation for the modification of plantain fibres and its effect on the mechanical, morphology and water absorption properties of fibre and fibre-polymer biocomposite has been investigated. The results obtained show that microwave irradiation at 550 W has improved the mechanical properties of both the fibres and fibre-polymer biocomposite as increases in mechanical properties and adequate surface roughness was achieved at optimised microwave power and time. Fibres irradiated at 750 W shows a serious damaging effect on the surface of the fibre with the increase in irradiation period from 2 min to 4 min. The severity of damage can be estimated from the SEM image, showing the exposure of inner central lumen of the fibre. As a general point, the longer period of high energy radiation of 750 W led to the heavy damage to the fibre surface along with the damage to the strength proving cellulose, thus resulting a decrease in mechanical properties and makes the fibre more permeable to moisture. Finally, it is concluded that microwave radiation of 550 W for 2 min period is the best to modify plantain fibre, which also gives an insight that microwave energy is a safer and cleaner modification of plantain fibre compare to conventional methods of drying nature fibre.

5. ACKNOWLEDGEMENTS

The authors are pleased to acknowledge the federal government of Nigeria, through the Federal University of Technology Akure (CHE/09/9420), for provision of materials and use of laboratory, and the kind assistance by Mrs. Oyedokun Opeyemi from the Research and Development Department, Engineering Materials Development Institute, Akure, Nigeria.

6. REFERENCES

1. Annapurna, P. et al. (2012). Electrical and mechanical properties of the potassium permanganate treated short sisal fibre reinforced epoxy composite in correlation to the macromolecular structure of the reinforced fibre. *J. App. Polym. Sci.*, https://doi.org/10.1002/app.38195.
2. Neus Anglès, M., Salvadó, J. & Dufresne, A. (1999). Steam-exploded residual softwood-filled polypropylene composites. *J. App. Polym. Sci.*, 74, 1962–1977, https://doi.org/10.1002/(SICI)1097-4628(19991121)74:8<1962::AID-APP10>3.0.CO;2-X.
3. Imoisili, P. E. et al. (2013). Mechanical properties of cocoa-pod/epoxy composite: Effect of filler fraction. *Amer. Chem. Sci. J.*, 3(4), 526–531, https:// doi.org/10.9734/ACSJ/2013/5526.
4. Placet, V. (2009). Characterization of the thermo-mechanical behaviour of Hemp fibres intended for the manufacture of high-performance composites. *Comp. A*, 40, 1111–1118, https://doi.org/10.1016/j.compositesa.2009.04.031.
5. Gowda, T. M., Naidu, A. C. B. & Chhaya, R. (1999). Some mechanical properties of untreated jute fabric-reinforced polyester composites. *Comp. A*, 30, 277–284.
6. Alix, A., Maris, S. & Lebrun, L. (2008). Bio-composite materials from flax plants: Preparation and properties. *Comp. A*, 39, 1793–1801, https://doi.org/10.1016/j.compositesa.2008.08.008.
7. John, M. J., Bellman, C. & Anadjiwala, R. D. (2010). Kenaf-polypropylene composite: Effect of amphiphilic coupling agent on surface properties of fibres and composites. *Carb. Polym.*, 82, 549–554. https://doi.org/10.1016/j.carbpol.2010.05.015.
8. Wei, W. & Gu, H. (2009). Characterization and utilisation of natural fibres composites. *Mat. Des.*, 30, 2741–2744, https://doi.org/10.1016/j.matdes.2008.11.002.
9. Imoisili, P. E., Ibegbulam, C. M. & Adejugbe T. I. (2012). Effect of concentration of coconut shell ash on the tensile properties of epoxy composites. *Pac. J. Sci. Tech.*, 13(1), 463–468.

10. Liu, H., Wu, Q. & Zhang, Q. (2009). Preparation and properties of banana-reinforced composites based on high-density polyethene (HDPE)/Nylon-6 blends. *Bioresour. Technol.*, 100, 6088–6097, https://doi.org/10.1016/j.biortech.2009.05.076.
11. Vigneswaran, C. et al. (2015). Banana fibre: Scope and value-added product development. *J. Tex. App. Technol. Manage.*, 9(2), 1–7.
12. De Rosa, I. M. et al. (2010). Effect of chemical treatments on the mechanical and thermal behaviour of Okra (*Abelmoschus esculentus*) fibres. *Comp. Sci. Techol.*, 70(1), 116–122, https://doi.org/10.1016/j.compscitech.2010.11.023.
13. Ku, H. et al. (2011). A review on the tensile properties of natural fibre reinforced polymer composites. *Comp. B*, 42(4), 856–873, https://doi.org/10.1016/j.compositesb.2011.01.010.
14. Bachtiar, D., Sapuan, S. M. & Hamdan, M. M. (2008). The effect of alkaline treatment on tensile properties of sugar palm fibre reinforced epoxy composites. *Mater. Des.*, 29, 1285–1290, https://doi.org/10.1016/j.matdes.2007.09.006.
15. Yousif, B. F. et al. (2012). Flexural properties of treated and untreated kenaf/epoxy composites. *Mater. Des.*, 40, 378–385, https://doi.org/10.1016/j.matdes.2012.04.017.
16. Rokbi, M. et al. (2011). Effect of chemical treatment on flexure properties of natural fibre-reinforced polyester composite. *Proced. Eng.*, 10, 2092–2097, https://doi.org/10.1016/j.proeng.2011.04.346.
17. Clark, D. E. & Sutton, W. H. (1996). Microwave processing of materials. *Ann. Rev. Mater. Sci.,* 26, 299–331, https://doi.org/10.1146/annurev.ms.26.080196.001503.
18. Katz, J. (1992). Microwave sintering of ceramics. *Ann. Rev. Mater. Sci.*, 22, 153–170. https://doi.org/10.1146/annurev.ms.22.080192.001101.
19. National Research Council. (1994). *Microwave processing of materials*. Washington: The National Academies Press, https://doi.org/10.17226/2266.
20. Murugan, R., Senthilkumar, M. & Ramachandran T. (2007). Study on the possibility in the reduction of dying time using micro oven dying technique. *Inst Eng. Ind. TX Text Eng. Div.*, 87, 23–27.
21. Li, J. P. et al. (2008). Instant modification of graphite nano sheets by the grafting of a styrene oligomer under microwave radiation. *J. App. Polym. Sci.*, 109, 1377–1380, https://doi.org/10.1002/app.28101.
22. Xue, Z. & Xin, H. J. (2011). Effect of microwave irradiation on the physical properties and structures of wool fabric. *J. Appl. Polym. Sci.*, 119, 944–952, https://doi.org/10.1002/app.32792

23. Annapurna, P. et al. (2013). Effect of microwave radiation on the macromolecular, morphological and crystallographic structures of sisal fibre. *Appl. Phys. A*, 112, 1063–1071, https://doi.org/10.1007/s00339.012.7489.
24. Mahmoodi, N. M. et al. (2010). Silk degumming using microwave irradiation as an environmentally friendly surface modification method. *Fib. Polym.*, 11, 234–240. https://doi.org/10.1007/s12221-010-0234-2.
25. Singh, I. et al. (2011). Feasibility study on microwave joining of "green" composites. *Akadem*., 1–6.
26. Moharram, M. A. & Mahmoud, O. M. (2007). X-ray diffraction methods in the study of the effect of microwave heating on the transformation of cellulose I into cellulose II during mercerization. *J. Appl. Polym. Sci*., 105, 2978–2983. https://doi.org/10.1002/app.26580.
27. Chimekwene, C., Fagbemi E. & Ayeke P. (2012). Mechanical properties of plantain empty fruit bunch fibre reinforced epoxy composite. *Int. J. Res. Eng. IT. Soc. Sci.,* 2(6), 86–94.
28. Okafor, E., Ihueze C. & Nwigbo S. (2012). Optimisation of hardness strengths response of plantain fibres reinforced polyester matrix composites (PFRP) applying Taguchi robust design. *Int. J. Eng.-Trans. A Bas*., 26(1), 1–8.
29. Alvarez-López, C. et al. (2014). Development of self-bonded fiberboards from a fiber of leaf plantain: Effect of water and organic extractives removal. *Bioresour.*, 10(1), 672–683.
30. Edith, M. et al. (2017). Natural fibers from plantain pseudostem (*Musa paradisiaca*) for use in fiber-reinforced composites. *J. Nat. Fib*., https://doi.org/10.1080/15440478.2016.1266295.
31. Imoisili, P. E. et al. (2017). Effect of chemical treatment on the morphology and mechanical properties of plantain (*Musa paradisiaca*) fibre. *IOSR J. Appl. Chem*., 10(5), 70–73, https://doi.org/10.9790/5736-1005017073.
32. Tahur, P. M. D. et al. (2011). Retting process of some bast plant fibres and its effect on fibre quality: A review. *Bioresour.*, 6(4), 5260–5281.
33. De Rosa, I. M. et al. (2010). Morphological and thermal characterisation of okra (*Abelmoschus esculentus*) fibres as potential reinforcement in polymer composites. *Compos. Sci. Technol.*, 70(1), 116–122, https://doi.org/10.1016/j.compscitech.2009.09.013.
34. Tsukada, M. et al. (2005). Microwave irradiation technique to enhance protein fibre properties. *Autex Res. J.*, 5, 40–48.
35. Khan Arifuzzaman, G. M. et al. (2015) Effect of chemical treatment on the physical properties of non-woven jute/PLA biocomposite. *Bioresour.*, 10(4), 7386–7404.