NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Evaluating the Engineering Properties of Conductive Bio-Composite for Mechanical and Computer Installations Design

[1*]Idama, O., [2]Edafiadhe, E.D, [3]Ighologe, O., [1]Ighofiomoni, O.M., [4]Ekruyota, G.O.

[1]Department of Computer Engineering, Delta State University of Science and Technology, Ozoro, Nigeria
[2]Department of Mechanical Engineering, Delta State University of Science & Technology, Ozoro, Nigeria
[3]Department of Electrical Engineering, Delta State University of Science & Technology, Ozoro, Nigeria
[4]Department of Computer Science, Delta State University of Science & Technology, Ozoro, Nigeria
*Corresponding author: engrkings20@gmail.com

Article Info

Keywords: *Aerospace components, computer devices, mechanical properties, potential applications, sustainable materials*

Received 3 March 2024
Revised 16 April 2024
Accepted 21 April 2024
Available online 29 April 2024

https://doi.org/10.5281/zenodo.11095087

ISSN-2682-5821/© 2024 NIPES Pub. All rights reserved.

Abstract

This research focused on the production of conductive composite (CC) by using recycled agricultural residues and carbon-based materials. Five CC samples were created by combining carbonized periwinkle shells ash (PSA) and recovered graphite (SGr) from battery products using the hand lay-up method, with epoxy serving as the matrix. The mechanical and electrical properties of the CC were assessed following approved procedures outlined by ASTM International. It was noted that the laboratory test results indicated that both PSA and SGr, considerably influenced the tensile strength and electrical conductivity (EC) of the composite samples. The tensile strength increased from 89 to 110 MPa was the PSA volume increased from 10 to 16% (by % mass of the matrix). Similarly, the EC of the composites showed a tendency to increase from 0.0065 to 0.074 s/cm, as the PSA integrated into the composite the composite rose from 10% to 16%. Results obtained from this experiment indicated that recycled agricultural waste materials and recovered graphite can be effectively utilized to produce conductive composites. These composites hold promise for applications in manufacturing sensitive electronic devices and aircraft components.

1. Introduction

Composite is a material created by integration of two or more reinforcement materials into a matrix. The matrix acts as the binding agent, bonding the reinforcement materials together; while the reinforcement materials provide the necessary structural integrity to the composite created [1,2]. The lower density of composites compared to traditional materials is a significant advantage, which directly impacts the overall structural weight of products manufactured from them. This property has led to the widespread use of composites in the production of lightweight automobile, aerospace and marine vessel parts. Modern advancement in composite revealed the suitability of composites in infrastructural development, mostly in bridges, dams and buildings construction due to their appreciable mechanical strengths and resistance to harsh environmental factors [3-6]. Composites are widely utilized in various engineering and non-engineering applications, as they have numerous advantages over most traditional materials. Most composites have high resistivity to corrosion and tensile failure. This makes them ideal materials for the production of engineering products, which are exposed to harsh environment conditions [7]. Apart from engineering applications, composite units are widely applied in the medical, sports, furniture and textile sectors, to produce sustainable materials and equipment. In the medical field composites are utilized to manufacture laboratory tools, prosthetics, and implants. To enhance environmentally friendliness, composites are now tailored to reduce reliance on traditional (synthetic) materials [8, 9].

Conductive composite (CC) is a subset of composite materials, which is produced through the incorporation of conductive reinforcement materials (fillers or fibers) into a non-conductive matrix [10]. Conductive composites are employed in computer installations to minimize the occurrence of electric power surge and mitigating icing problems. Some sensitive electronic components developed with conductive composites include circuit boards, sensors, Faraday cages, and heat sinks [11]. Conductive composites have the ability of dissipating static electricity and averting electric charge accumulation; therefore, minimizing those hazards associated with electric power surges and electrostatic discharges (ESD). These scenarios help to protect the sensitive electronic accessories from failures; hence ensuring the reliability of computer systems operations [12]. Some conductive composites tend to have elevated electromagnetic shielding which is advantageous in reducing the electromagnetic interference (EMI) challenge, by captivating the reflecting electromagnetic radiation and enhancing the performance of the electronic devices [13, 14]. Several conductive composites display good thermal conductivity properties, which are necessary for thermal management (dissipating heat) in electrical and electronic components. This attribute assists in enhancing the performance of the device, by preventing overheating of the electronic systems [15. 16].

Rezanezhad [17] manufactured CC by employing carbon nanoparticles. They noted that the incorporation of carbon material into the matrix resulted in an enhancement of both the mechanical strength and electrical conductivity of the composite. Tschannen [18] produced CC from the combination of wood and carbon fibers. They observed that the resulting products exhibited enhanced electrical and mechanical properties. These improvements render the composites well-suited for use in the design of smart applications. Obukoeroro [19] developed CC by incorporating carbon black and carbonized snail shell powder in epoxy resin. Their findings indicated that the filler materials exerted a notable influence on both the electrical conductivity and tensile properties of the produced specimens.

Recently, there are massive researches on the development of more environmental tolerant green composites also known as bio-composites [20, 21]. Through several green conductive composites have been created by integrating agricultural residues in non-metallic matrix [22-24], information on the utilization of periwinkle shells is still lacking. Therefore, the main aim of this research is to produce high quality environmentally friendly CC through substitution of spent graphite with periwinkle shells ash. Information obtained from this work will provide valuable insights into repurposing waste materials, thereby transforming them into valuable resources. This approach not only helps in reducing waste but also promotes environmental sustainability by decreasing reliance on non-renewable resources.

2.0 Materials and methods

2.1 Materials

Epoxy resin

The epoxy resin (LY556) or an analytical grade, obtained from a certified chemical supplier, was the non-metallic matrix employed for conductive composite production.

Periwinkle shells ash (PSA)

The periwinkle shells underwent carbonization following AOAC procedures. Subsequently, they were pulverized and sieved with a 150 µm sieve to attain the carbonized periwinkle shells ash (PSA).

Spent (recovered) graphite (SGr)

The recovered graphite was sourced from spent lithium-ion batteries as well as other battery types that feature graphite anodes.

2.2 Methods

Conductive composite (CC) production

Table 1 presents the experimental plan used to create the various CC specimens. The matrix used to prepare the CC was formulated by mixing the hardener and epoxy resin in a proportion of 3 parts hardener to 7 parts epoxy resin. All the constituents (PSA and SGr) of each CC unit were batched by weight (% mass of the matrix), to ensure consistency and precision in the final product. The quantities of reinforcement materials employed in CC production were deliberately chosen to deviate from the filler amounts utilized in prior research studies [10, 25, 26]. All the samples were fabricated by using the hand lay-up composite producing method outlined by Umurhurhu [27]. Thereafter, they were subjected to a consistent weight (10 kg) for 24 hours at room temperature (29±5^{o}C) to eliminate any trapped air.

Table 1: Composite samples composition

Sample Code	**Reinforcement materials (%)**		Matrix
	PSA	SGr	
SAM 1	12	12	76
SAM 2	14	10	76
SAM 3	16	8	76
SAM 4	18	6	76
SAM 5	20	4	76

2.3 laboratory analyses

2.3.1. Tensile strength

The tensile strength of each composite unit was determined in accordance with ASTM D3039 approved methods [34]. A sample measuring 0.3 m (Length “L”), 0.03 m (Width “W”), and 0.01 m (thickness “T), was secured between the jaws of a Universal Testing Machine “UTM” (Testometric model, manufacture in England). The specimen was then subjected to tensile force at a rate of 1 mm/min until it reached the breaking point, as shown in Figure 1. At the end of each test, the tensile strength was calculated through Equation 1 [4].

$$Tensile\ strength, \sigma = \frac{Force_{Max}}{Area} \qquad (1)$$

Figure 1: A composite sample undergoing tensile strength testing

2.3.2. Electrical conductivity determination

The electrical conductivity of each composite specimen was determined in accordance with ASTM D257-14 procedures [35], with the aid of a digit precision multimeter (model: Fluke 8845A 6.5, produced by Bench instruments, USA) as explained by Tien [25]. For each experimental unit, five samples were tested and the average value recorded.

3.0 Results and Discussion

3.1 Tensile strength

The results of the CC tensile strength are presented in Figure 2. The tensile strength of the SAM 1, SAM 2, SAM 3, SAM 4, and SAM 5 samples was observed to be 89 MPa, 101 MPa, 110 MPa, 99 MPa, and 92 MPa, respectively. This variation in tensile strength among the SAM samples indicates that the particulates have a substantial effect on the mechanical properties of the composite units. Although the inclusion of PSA has a beneficial impact on the TS of the CC, the study findings suggest that a large volume of PSA (greater than 16%) have detrimental effect on the composite, leading to a decrease in its tensile strength. Similar trends regarding the behavior of organic fillers in bio-composites were documented by Refs [28-30]. They found that lower percentages of reinforcement materials resulted in enhancements to the mechanical properties of composite panels, aligning them more closely with industrial requirements. Moreover, the TS values obtained from the experimental study were comparatively higher than those documented by Sadiq [45], yet lower when juxtaposed with the figures provided by Udo [46]. Udo [46] indicated that the TS of non-carbonized periwinkle shells particulates ranged from 180.7 to 214.3 MPa as the filler content increased from 10 to 50%. Conversely, Sadiq [45] reported that periwinkle shells particle epoxy polymer composite exhibited TS ranging from 42.85 to 100.94 MPa as the reinforcement content increased from 0.5 to 1.0%. Variations in the recorded TS values among the authors may be ascribed to potential human errors during experimental procedures, discrepancies in the types and ages of periwinkle shells utilized, as well as differences in shell preparation and preservation methods [21].

The decline in the mechanical property of the CC as the PSA fillers content exceed 16% could be attributed to weak bonding formation between the matrix and the excessive fillers. This creates reduction in the cohesion and adhesion within the material, ultimately resulting in poorer mechanical properties of the composite materials irrespective of the matrix used [31, 32]. The outcomes of this research are important in the field of material science because they confirm that strengthening the matrix with an appropriate quantity of fillers or fibers facilitates the production of composites with the desired mechanical properties. This has implications for a wide range of engineering and industrial applications, ensuring that the resulting materials meet specific performance requirements.

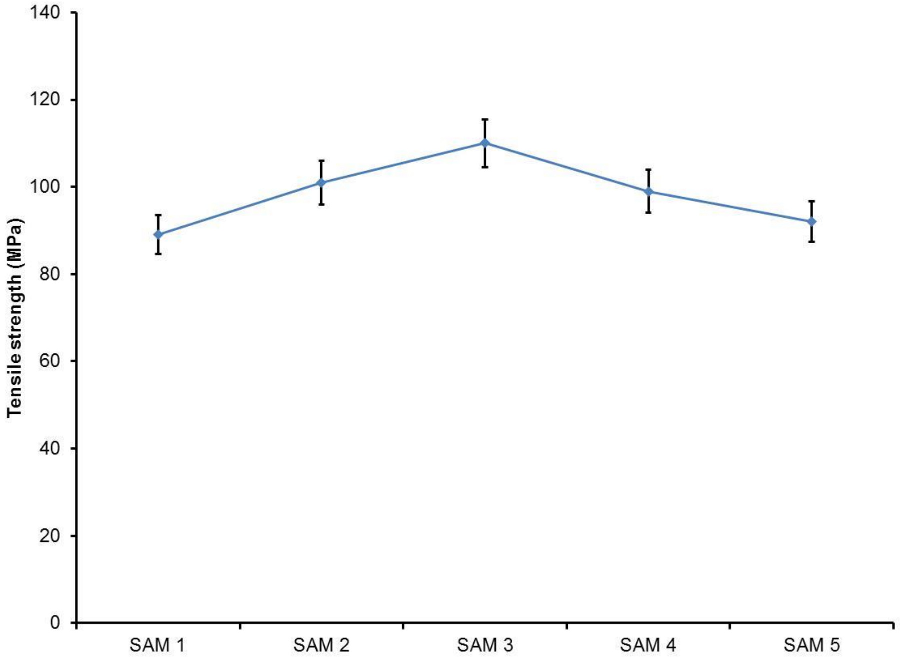

Figure 2: The CC tensile strength

3.2 Electrical conductivity (EC)

Figure 3 presents the EC values of the various composite specimens. Significantly, the PSA exerts substantial influence on the EC exhibited by the composites. As the quantity of PSA increased from 12% to 20%, the conductivity of the CC decreased non-linearly from 0.0065 to 0.0053 s/cm. The highest EC value of 0.074 s/cm was observed at a PSA content of 16%. As illustrated in Figure 3, the EC values of the samples labeled SAMs 1 to 5 were 0.0065, 0.0071, 0.0074, 0.0067, and 0.0053 S/cm, respectively. The decline in the EC values noted as the PSA increased from 14 to 20%, and the SGr decreased from 10 to 4% could be attributed to the lower volume of carbon ions present in the composite. This attribute aligns with the electrical properties of CC which are heavily influenced by the nature and quantity of conductive fillers integrated into the matrix [33]. Furthermore, the lower electrical conductivity (EC) values observed in samples with higher PSA content (greater than 16%) may be attributed to inadequate bonding between the fillers and the matrix. According to Eboibi [36], a higher ratio of fillers to matrix results in the formation of composites with voids and weak binding, which could impede the mobility of electric charges within the composites.

The results of this research are similar to those obtained by Feller [37] and Oxfall [38], whose findings indicated that carbon-based materials (fillers or fibers) notably enhance electron mobility within composite boards. According to Oxfall [38], the EC values of carbon black hybridized composite samples ranged between 1.0 x10^{-7} and 1.0 x10^{-2} s/cm. The differences in the EC recorded in this study, when compared to other authors [19, 39 - 40] results, could be attributed to the type of bio-fillers used for the composites production. The varied cellular structure and properties of agricultural materials directly impact their engineering characteristics, irrespective of the products derived from them [41, 42]. Likewise, the carbonization technique and hybridization pattern of filler materials play a pivot role in determining the electrical properties of the composites [43, 44].

The results of this study have demonstrated that agricultural residues and spent graphite can be repurposed and employed in the production of conductive composites with noteworthy electrical conductivity. Such composites hold potential for utilization in industries such as aerospace and computer production. The utilization of these waste materials in the production of valuable engineering products represents a positive initiative. Not only does it address the challenge of waste management that many countries face, but it also contributes to reducing greenhouse gas emissions and mitigating environmental hazards associated with the production of synthetic carbon-based filler materials. Furthermore, this research will offer new opportunities for manufacturing of sensitive electronic devices and aircraft components.

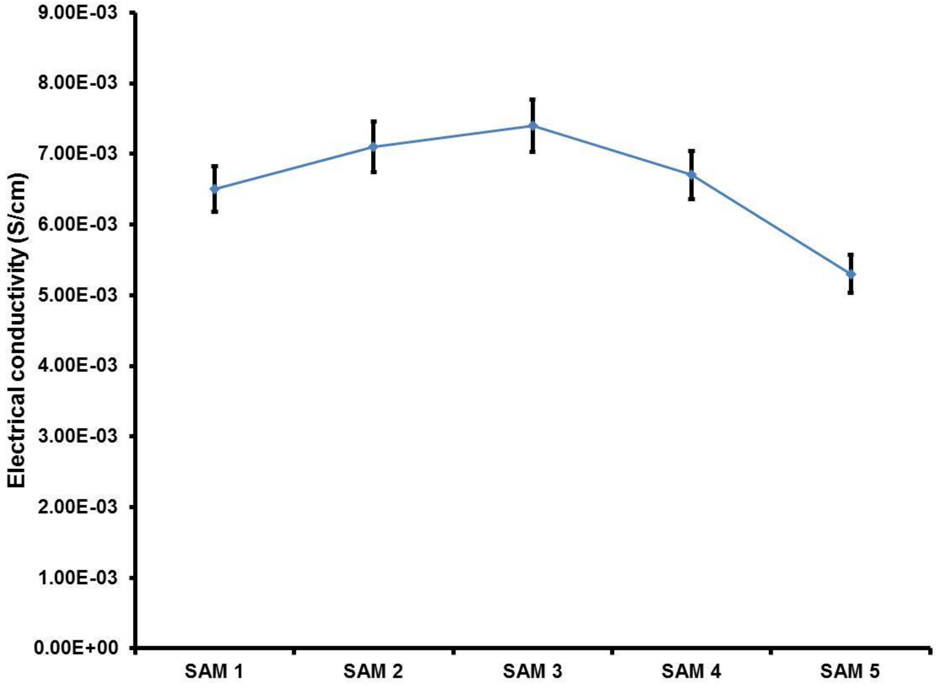

Figure 3: The CC electrical conductivity

4.0 Conclusion

This research was primarily embarked upon to development of a conductive composite (CC) material, through the utilization of recycled agricultural residues and carbon-based materials.
Various specimens of CC were manufactured by adjusting the volume of carbonized periwinkle shells (PSA) and spent graphite (SGr) incorporated into the composite material. Following production, the CC mechanical and electrical properties were measured in accordance with ASTM approved guidelines. The results depicted that the PSA caused substantial increment in both the tensile strength and electrical conductivity of the samples. This indicates the potential of these materials to serve as reliable alternatives in the manufacturing of automobile, electrical, aircraft, and computer components. Furthermore, this research had revealed the potential of utilizing recycled agricultural waste materials and recovered graphite to produce conductive composites.

References

[1] Huang, X., Su, S., Xu, Z., Miao, Q., Li, W., & Wang, L. (2023). Advanced Composite materials for structure strengthening and resilience improvement. Buildings, 13(10), 2406. https://doi.org/10.3390/buildings13102406

[2] Arpitha, G. R., Jain, N., Verma, A., & Madhusudhan, M. (2022). Corncob bio-waste and boron nitride particles reinforced epoxy-based composites for lightweight applications: fabrication and characterization. Biomass Conversion and Biorefinery. https://doi.org/10.1007/s13399-022-03717-1

[3] Agarwal, J., Sahoo, S., Mohanty, S., & Nayak, S. K. (2019). Progress of novel techniques for lightweight automobile applications through innovative eco-friendly composite materials: A review. Journal of Thermoplastic Composite Materials, 33(7), 978–1013. https://doi.org/10.1177/0892705718815530

[4] Edafeadhe, G.O.I., Agbi, G. G., & Uguru, H. (2020). Effect of calcium nitrate application on the structural behavour of okra (cv. Kirikou) fibre reinforced epoxy composite. Journal of Engineering and Information Technology, 7(2), 69-74.

[5] Ramawat, N., Sharma, N., Yamba, P., & Sanidhi, M. A. T. (2023). Recycling of polymer-matrix composites used in the aerospace industry-A comprehensive review. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.05.386

[6] Khan, F., Hossain, N., Mim, J. J., Rahman, S. M., Iqbal, Md. J., Billah, M., & Chowdhury, M. A. (2024). Advances of composite materials in automobile applications – A review. Journal of Engineering Research. https://doi.org/10.1016/j.jer.2024.02.017

[7] Sharma, A. K., Bhandari, R., Aherwar, A., & Rimašauskienė, R. (2020). Matrix materials used in composites: A comprehensive study. Materials Today: Proceedings, 21, 1559–1562. https://doi.org/10.1016/j.matpr.2019.11.086

[8] Kamarudin, S. H., Mohd Basri, M. S., Rayung, M., Abu, F., Ahmad, S., Norizan, M. N., Osman, S., Sarifuddin, N., Desa, M. S. Z. M., Abdullah, U. H., Mohamed Amin Tawakkal, I. S., & Abdullah, L. C. (2022). A Review on Natural Fiber Reinforced Polymer Composites (NFRPC) for Sustainable Industrial Applications. Polymers, 14(17), 3698. https://doi.org/10.3390/polym14173698

[9] Elfaleh, I., Abbassi, F., Habibi, M., Ahmad, F., Guedri, M., Nasri, M., & Garnier, C. (2023). A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials. Results in Engineering, 19, 101271. https://doi.org/10.1016/j.rineng.2023.101271

[10] Alemour, B., Badran, O., & Hassan, M. R. (2019). A Review of Using Conductive Composite Materials in Solving Lightening Strike and Ice Accumulation Problems in Aviation. Journal of Aerospace Technology and Management. Internet Archive. https://doi.org/10.5028/jatm.v11.1022

[11] Ali, A., Baheti, V., Khan, M. Z., Ashraf, M., & Militky, J. (2019). Development of electrically conductive composites based on recycled resources. *The Journal of The Textile Institute*, 111(1), 16–25. https://doi.org/10.1080/00405000.2019.1644121

[12] Rosner, R. B. (2001). Conductive materials for ESD applications: an overview. IEEE *Transactions on Device and Materials Reliability*, 1(1), 9–16. https://doi.org/10.1109/7298.946455

[13] Kumar, R., Gupta, T. K., Dwivedi, N., & Mondal, D. P. (2022). Lightweight Carbon Composite Foams for Electromagnetic Interference Shielding Applications. Smart Materials Design for Electromagnetic Interference Shielding Applications, 59–108. https://doi.org/10.2174/9789815036428122010005

[14] Ji L., Ming-Yuan Y., Zhong-Zhen Y., Valeria N. (2023). Design and advanced manufacturing of electromagnetic interference shielding materials, *Materials Today*, 66, 245-272. https://doi.org/10.1016/j.mattod.2023.03.022.

[15] Li, M., Wang, M., Hou, X., Zhan, Z., Wang, H., Fu, H., Lin, C.-T., Fu, L., Jiang, N., & Yu, J. (2020). Highly thermal conductive and electrical insulating polymer composites with boron nitride. Composites Part B: Engineering, 184, 107746. https://doi.org/10.1016/j.compositesb.2020.107746

[16] Li, R., Yang, X., Li, J., Shen, Y., Zhang, L., Lu, R., Wang, C., Zheng, X., Chen, H., & Zhang, T. (2022b). Review on polymer composites with high thermal conductivity and low dielectric properties for electronic packaging. Materials Today Physics, 22, 100594. https://doi.org/10.1016/j.mtphys.2021.100594

[17] Rezanezhad, M., Shalbafan, A., & Thoemen, H. (2023). Development of electrically conductive wood-based composites using carbon nets. Polymer Composites, 45(3), 1985–1997. Portico. https://doi.org/10.1002/pc.27899

[18] Tschannen, C., Shalbafan, A., & Thoemen, H. (2023). Development of an Electrically Conductive MDF Panel-Evaluation of Carbon Content and Resin Type. Polymers, 15(4), 912. https://doi.org/10.3390/polym15040912

[19] Obukoeroro J. & Uguru, H. (2021). Evaluation of the mechanical and electrical properties of carbon black/carbonized snail shell powder hybridized conductive epoxy composite. *International Journal of Innovative Scientific & Engineering Technologies Research* 9(1), 39-49

[20] Phiri, R., Mavinkere Rangappa, S., Siengchin, S., Oladijo, O. P., & Dhakal, H. N. (2023). Development of sustainable biopolymer-based composites for lightweight applications from agricultural waste biomass: A

review. Advanced Industrial and Engineering Polymer Research, 6(4), 436–450. https://doi.org/10.1016/j.aiepr.2023.04.004

[21] Owamah, H. I., Uguru, H., Umukoro, L. O., Akpokodje, O. I., Helal, M., Sami, R., Alshehry, G., Algarni, E., Abdelhai, N., Abushal, S. A., & Aljuraide, N. I. (2024). Mechanical and Physiochemical Characteristics of Sandcrete Blocks Produced with Sustainable Biomaterials. Science of Advanced Materials, 16(4), 518–531. https://doi.org/10.1166/sam.2024.4656

[22] Atif, R., Shyha, I., & Inam, F. (2016). Mechanical, Thermal, and Electrical Properties of Graphene-Epoxy Nanocomposites—A Review. Polymers, 8(8), 281. https://doi.org/10.3390/polym8080281

[23] Backes, E. H., Sene, T. S., Passador, F. R., & Pessan, L. A. (2017). Electrical, Thermal and Mechanical Properties of Epoxy/CNT/Calcium Carbonate Nanocomposites. Materials Research, 21(1). https://doi.org/10.1590/1980-5373-mr-2017-0801

[24] Dong, J., Wang, C., Fan, X., Wei, L., Shen, G., Sun, R., & Li, R. (2022). Mechanical and Dielectric Properties of a Flexible Anisotropic Rubber-Based Composite. Nanomaterials, 12(13), 2182. https://doi.org/10.3390/nano12132182

[25] Tien, D. H., Park, J., Han, S. A., Ahmad, M., Seo, Y., & Shin, K. (2011). Electrical and Thermal Conductivities of Stycast 1266 Epoxy/Graphite Composites. Journal of the Korean Physical Society, 59(4), 2760–2764. https://doi.org/10.3938/jkps.59.2760

[26] Yim, Y.J., & Park, S.J. (2019). Effect of silver-plated expanded graphite addition on thermal and electrical conductivities of epoxy composites in the presence of graphite and copper. Composites Part A: Applied Science and Manufacturing, 123, 253–259. https://doi.org/10.1016/j.compositesa.2019.05.021

[27] Umurhurhu, B. & Uguru, H. (2019). Tensile Behaviour of Oil Bean Pod Shell and Mahogany Sawdust Reinforced Epoxy Resin Composite. *International Journal of Science, Technology and Society*, 7(1), 1. https://doi.org/10.11648/j.ijsts.20190701.11

[28] Bera, T., Acharya, S.K. & Mishra, P. (2018). Synthesis, mechanical and thermal properties of carbon black/epoxy composites. *International Journal of Engineering, Science and Technolog*y. 10(4), 12-20.

[29] Edafiadhe, E.D., Nyorere O and Uguru H. (2019). Compressive behaviours of oil bean shell and wood particulates/ epoxy composite board. *Archives of Current Research International*, 16(3), 1-8

[30] Abdul Motaleb ,K. Z. M. , Islam, M. and Hoque, M.B. (2018). Improvement of physicomechanical properties of pineapple leaf fiber reinforced composite. *International Journal of Biomaterials*. 2018, 1-8

[31] Uguru, H. & Oghenerukevwe, P. (2021). Effect of organic fillers on the tensile characterization of calcium carbonate hybridized epoxy composite. Journal of Engineering and Information Technology. 8, 42-48.

[32] Akpenyi-Aboh, O.N., Akwenuke MO &Edafıadhe ED (2023). Influence of treatments on the mechanical properties of epoxy resin hybrid composites reinforced with pineapple fiber and snail shell particulates. *Turkish Journal of Agricultural Engineering Research*, 4(2), 278-288.

[33] Omah, A. D., Oji, E. O., Madu, S. C., Okonkwo, E. G., & Ezema, I. C. (2018). Electrical resistivity measurements of carbonized cattle bone/epoxy composite for electrical insulation. Nigerian Journal of Technology, 37(4), 1032. https://doi.org/10.4314/njt.v37i4.24

[34] ASTM D3039 / D3039M-17 (2017). Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International, West Conshohocken, PA, 2017. https://www.astm.org/Standards/D3039

[35] ASTM D257-14(2021) Standard Test Methods for DC Resistance or Conductance of Insulating Materials. https://www.astm.org/d0257-14r21e01.html

[36] Eboibi, O., Akpokodje, O. I., & Uguru, H. (2022). Evaluation of organic enhancer on the mechanical properties of periwinkle shells concrete. Journal of Engineering Innovations and Applications, 1(1), 13–22. https://doi.org/10.31248/jeia2022.020

[37] Feller, J. F., Linossier, I., & Levesque, G. (2002). Conductive polymer composites (CPCs): comparison of electrical properties of poly(ethylene-co-ethyl acrylate)-carbon black with poly(butylene terephthalate)/poly(ethylene-co-ethyl acrylate)-carbon black. Polymers for Advanced Technologies, 13(10–12), 714–724. Portico. https://doi.org/10.1002/pat.254

[38] Oxfall, H., Ariu, G., Gkourmpis, T., Rychwalski, R. W., & Rigdahl, M. (2015). Effect of carbon black on electrical and rheological properties of graphite nanoplatelets/poly(ethylene-butyl acrylate) composites. Express Polymer Letters, 9(1), 66–76. https://doi.org/10.3144/expresspolymlett.2015.7

[39] Ma, C. G., & Liu, M. (2012). Carbon Black Selective Dispersion and Electrical Properties of Epoxy Resin/Polystyrene/Carbon Black Ternary Composites. *Advanced Materials Research,* 548, 94–98. https://doi.org/10.4028/www.scientific.net/amr.548.94

[40] Okieke, U. F., Odoh, F. E., Ebisine, E. E., & Edafiadhe, E. D. (2022). Research on the Electrical and Mechanical Properties of Conductive Epoxy Composite. ABUAD *International Journal of Natural and Applied Sciences*, 2(3), 155-160. https://doi.org/10.53982/aijnas.2022.0203.03-j

[41] Idama, O., Uguru, H., & Akpokodje, O. I. (2021). Mechanical Properties of Bell Pepper Fruits, as Related to the Development of its Harvesting Robot. Turkish Journal of Agricultural Engineering Research, 2(1), 193–205. https://doi.org/10.46592/turkager.2021.v02i01.015

[42] Ekruyota, O.G. & Uguru, H. (2021). Characterizing the mechanical properties of eggplant (Melina F1) fruits, for the design and production of agricultural robots. *Direct Research Journal of Engineering and Information Technology*, 8(2), 21. https://doi.org/10.26765/drjeit13383770

[43] Lee, J.H., Jang, Y.K., Hong, C.E., Kim, N.H., Lee, P., & Lee, H.K. (2009). Effect of carbon fillers on properties of polymer composite bipolar plates of fuel cells. *Journal of Power Sources* 193, 523–529.

[44] Radzuan, N.F.M, Sulong, A.B. & Sahari, J. (2017). A review of electrical conductivity models for conductive polymer composite. *International Journal of Hydrogen Energy*, 42, 9262 – 9273.

[45] Sadiq, A., Abdelmalik, A.A., Sadiq, U., Abdulraheem, A., & Balogun, M. (2020).Influence of periwinkle shell microparticle on the mechanical properties of epoxy polymer composite. *Nigerian Research Journal of Chemical Sciences*, 8(2), 25-36.

[46] Udo, M., Afolalu, S. A., Ikumapayi, O. M., Babalola, P., Obasa, V., & Akpalikpo, O. (2022). Effect of particle size and weight percentage variation on the mechanical properties of periwinkle shell reinforced polymer (epoxy resin) matrix composite. International Journal of Applied Science and Engineering, 19(3), 1–7. https://doi.org/10.6703/ijase.202209_19(3).004