Novelty Journals

ISSN 2394-7357

International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 10, Issue 3, pp: (1-7), Month: September - December 2023, Available at: www.noveltyjournals.com

Mechanical characteristics of stir-cast Irvingia wombolu reinforced Al-4wt%Cu composite

Kingsley C. Nnakwo[1], Jerome U. Odo[2]*, Agatha I. Ijomah[3]

Metallurgical and Materials Engineering Department, Nnamdi Azikiwe University, Awka, Nigeria

Corresponding author email address: *ju.odo@unizik.edu.ng*

DOI: https://doi.org/10.5281/zenodo.8344944

Published Date: 14-September-2023

Abstract: **Irvingia wombolu shell particulates are not commonly used as reinforcing materials in aluminium composites, which makes this research novel and interesting. Investigating their potential as reinforcement can offer new insights into sustainable and cost-effective composite materials. In this experimental study, the microstructure, tensile strength, hardness, and impact energy of Irvingia wombolu reinforced Al-4wt%Cu composites were investigated. The Al-4wt%Cu composites containing 2, 5, 8, 11, and 14wt% IWSp were fabricated using the stir-casting technique. The microstructure of the developed composites was analyzed using optical microscope. The OM results revealed even dispersion of IWSp in the Al matrix, leading to increase in the ultimate tensile strength, hardness, and impact energy of the Al-4wt%Cu matrix, with maximum values of 152 MPa, 257 HV, and 58 J obtained at 8wt%, 14wt%, and 5wt% IWSp, respectively. Incorporation of IWSp above 8wt% led to a sudden decrease in ultimate tensile strength due to excess of hard IWSp in the Al matrix. The alloy matrix recorded a better percentage elongation value compared with the composite samples. The study concludes that IWSp has the potential to serve as an alternative reinforcing material for Al-4wt%Cu composites.**

Keywords: **Al-Cu; microstructure; impact energy; strength; Irvingia wombolu.**

1. INTRODUCTION

Aluminium alloys are essential materials in modern industry, offering a unique combination of properties that make them valuable for a wide range of applications. Through alloying and reinforcement techniques, their mechanical properties can be tailored to meet specific requirements in various industries [1-8]. Metal matrix composites (MMCs) are a class of advanced materials that combine two or more distinct materials to create a material with enhanced properties. In MMCs, a metal matrix serves as the primary structural component, while a reinforcement phase, typically made of ceramics, carbon fibers, natural materials like green plant waste, or other high-strength materials, is dispersed within the matrix to improve the properties compared to the base metal. MMCs have better resistance to deformation under high temperatures and loads, making them suitable for applications where dimensional stability is crucial. The addition of ceramic reinforcements can significantly enhance thermal conductivity, hardness, tensile, impact energy, and compressive strength making them useful in heat exchangers and thermal management systems, wear-resistant components, aircraft and automobile components (engine parts, brake rotors, engine parts, and suspension components), armor and ballistic shielding components [2-15]. MMCs can be complex and costly, requiring specialized techniques such as powder metallurgy or infiltration methods, unlike traditional materials, which limit their widespread adoption in some industries [16-20].

The use of various eco-friendly green plant waste materials as reinforcing agents in aluminum (Al) alloy-based composites has been reported [21-31]. These materials include rice husk shell, groundnut shell, corn cob, eggshell, coconut shell, bamboo leaf, coconut fiber, periwinkle shell, horse eye bean seed shell, and African walnut kernel. However, there has been little report on the reinforcing characteristics of Irvingia wombolu shell in Al alloy-based composites. Irvingia wombolu, also known as African mango or wild mango, is a tropical fruit tree native to West Africa [32-37]. Its shell may have untapped potential as a reinforcing material for improving the properties of Al alloy-based composites. Hence, this research is aimed at exploring for the first time the mechanical characteristics of stir-cast Irvingia wombolu reinforced Al-4wt%Cu composite.

International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 10, Issue 3, pp: (1-7), Month: September - December 2023, Available at: www.noveltyjournals.com

2. EXPERIMENTAL PROCEDURE

The Al-4wt%Cu alloy matrix was prepared using aluminum wire and copper rods with purities of 99.8% and 99.9%, respectively. The reinforcement; Irvingia wombolu shells was obtained from Uzo-uwani, Enugu State, Nigeria. The obtained shells were extracted, washed with distilled water, and sun-dried for 5 days. The dried shells were ground and sieved to a particle size of 65 µm. The Al-4wt%Cu alloy matrix was melted in a bailout crucible furnace and cast in a steel mold of dimension 250 x 16 mm^2. For each composite formulation, the temperature of the molten Al-4wt%Cu alloy matrix was reduced and the required weight percent (2%, 5%, 8%, 11%, or 14%) of Irvingia wombolu shell particulates (IWSp) was incorporated into the molten matrix. The mixture was stirred for 2 minutes to ensure uniform dispersion of IWSp. The molten composite mixture was then poured into a preheated mold and cooled inside the mold. Double-layer feeding stir casting technique was adopted in the preparation of the samples.

Tensile strength test was conducted on samples with dimensions: 50 mm gauge length, 8 mm gauge diameter, and 120 mm total length, using a 10kN capacity JPL tensile strength tester (Model:130812) in accordance to ASTME8/E8M-21 (2018) standard. The hardness test was conducted using a Vickers hardness tester (Model: VM-50) at a load and dwell time of 183.9 kgf and 5 s, respectively. Three indentations were made on each sample surface and the diagonals of indentations were measured using a 20X Olympus BH optical microscope. The average diameter of the indentations was determined and the Vickers hardness values were calculated using an appropriate equation 1. The impact energy test was conducted on samples of dimensions 55 x 10 x 10 mm^3 with notch depths of 2 mm according to ASTM D638 standards. Prior to the microstructural analysis, the cast samples were subjected to pretreatment steps: grinding, polishing, and etching in Keller's reagent. Optical microscopy (OM) was used for the microstructure analysis.

$$HV = 1.8544 \cdot \frac{P}{d^2} \quad (1)\ [38]$$

HV = Vickers hardness (HV), P = applied load (kgf), d = average diagonals of indentations (µm)

3. RESULTS AND DISCUSSION

3.1. Mechanical characteristics of Al-4wt%Cu and Al-4wt%Cu/IWSp composites

The percentage elongation, ultimate tensile strength, hardness, and impact energy of Al-4wt%Cu and Al-4wt%Cu/IWSp composites are presented in Figs. 1-4. The Al-4wt%Cu alloy matrix exhibited a percentage elongation of 38%. Incorporation of 2 wt% of IWSp led to a decrease in the percentage elongation of Al-4wt%Cu alloy matrix from 38 % 32 %. The percentage elongation showed a decreasing trend with increasing concentrations of IWSp. This behavior can be associated with increasing dispersion of IWSp in the Al matrix. (Fig. 5). The ultimate tensile strength and hardness of Al-4wt%Cu alloy matrix recorded about 4.7% and 3.7%, respectively after incorporation of 2wt%IWSp. The Al-4wt%Cu/IWSp composites recorded maximum ultimate tensile strength and hardness of 152 MPa and 257 HV at 8 wt% and 14 wt% IWSp additions. Further increase in the concentration of IWSp above 8 wt% led to a decrease in ultimate tensile strength of the Al-4wt%Cu/IWSp composites. This decline in properties can be linked to excessive dispersion of IWSp in the Al matrix. The impact energy of the Al-4wt%Cu alloy matrix increased from 46 J to 50 J after incorporating 2 wt% IWSp. The impact energy value increased further to 58 J after increasing the concentration of IWSp to 5 wt%, but recorded a decreasing trend after increasing the IWSp to 8 wt%.

3.2. Microstructure of Al-4wt%Cu and Al-4wt%Cu/IWSp composites

The microstructures of the developed Al-4wt%Cu and Al-4wt%Cu/IWSp composites are presented in Fig. 5. The OM image of the Al-4wt%Cu alloy matrix revealed the α-solid solution regions and secondary phases in the Al-matrix (Fig. 5a). The solid solution region indicates the solid solution of copper in aluminium. The secondary phase which is known to be Al_2Cu is presented as needle-like precipitate scarcely dispersed in the Al-matrix. The OM images of the Al-4wt%Cu/IWSp composites reveal particulates of IWSp in the Al-matrix (Fig. 5 b and Fig. 5c). This can be attributed to the improvement of the ultimate tensile strength and hardness of Al-4wt%Cu alloy matrix. The dispersion and quantity of these particulates are seen to increase in the Al-matrix with increasing concentrations of IWSp, leading to further increase in the hardness of Al-4wt%Cu/IWSp composite (Fig.4 and Fig. 5 c).

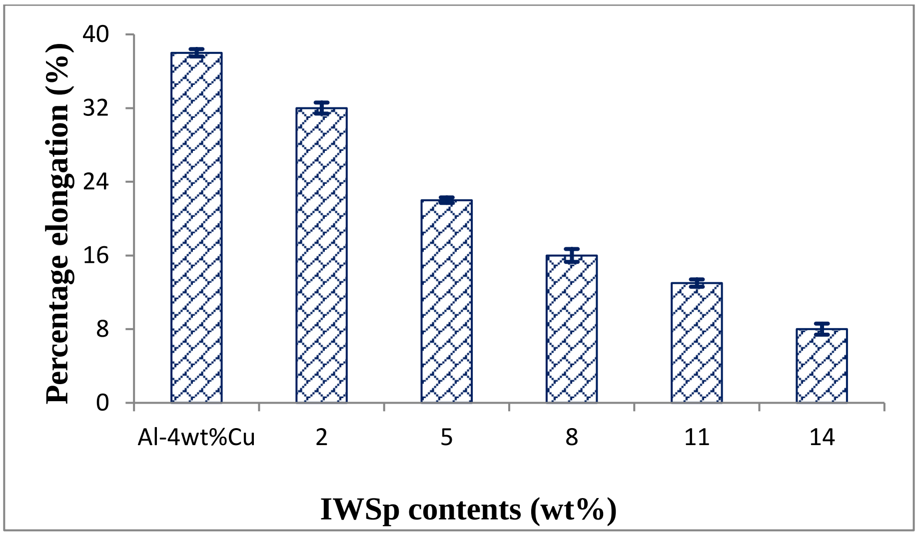

Fig. 1: Percentage elongation of Al-4wt%Cu/IWSp composite

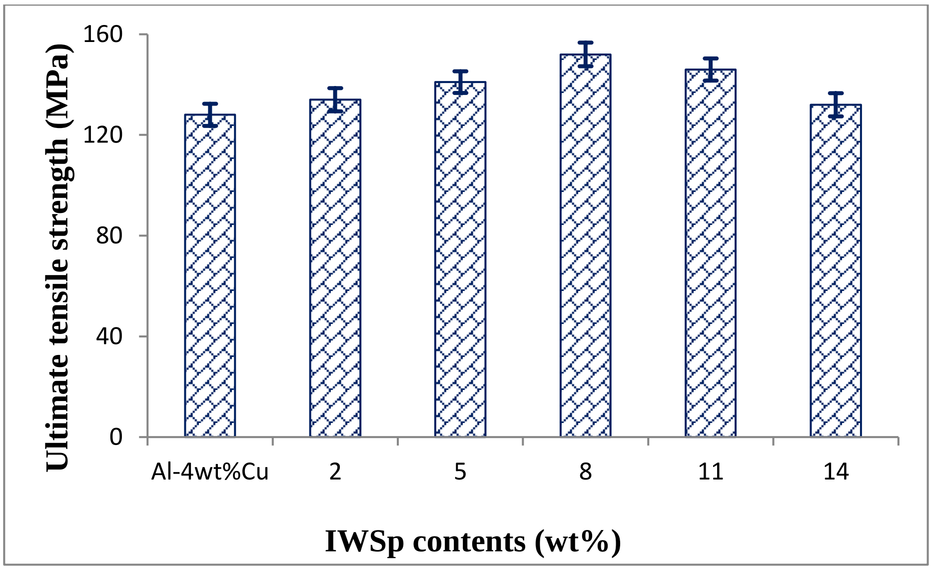

Fig. 2: Ultimate tensile strength of Al-4wt%Cu/IWSp composite

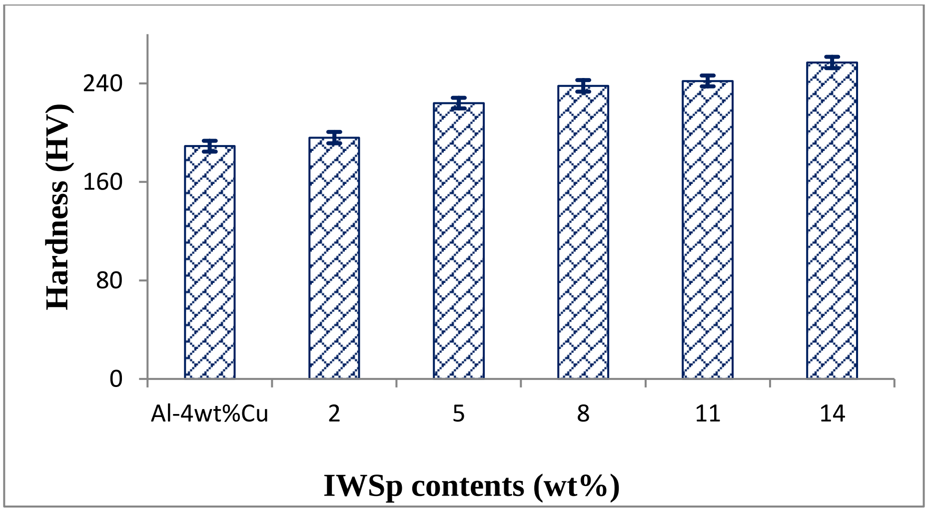

Fig. 3: Hardness of Al-4wt%Cu/IWSp composite

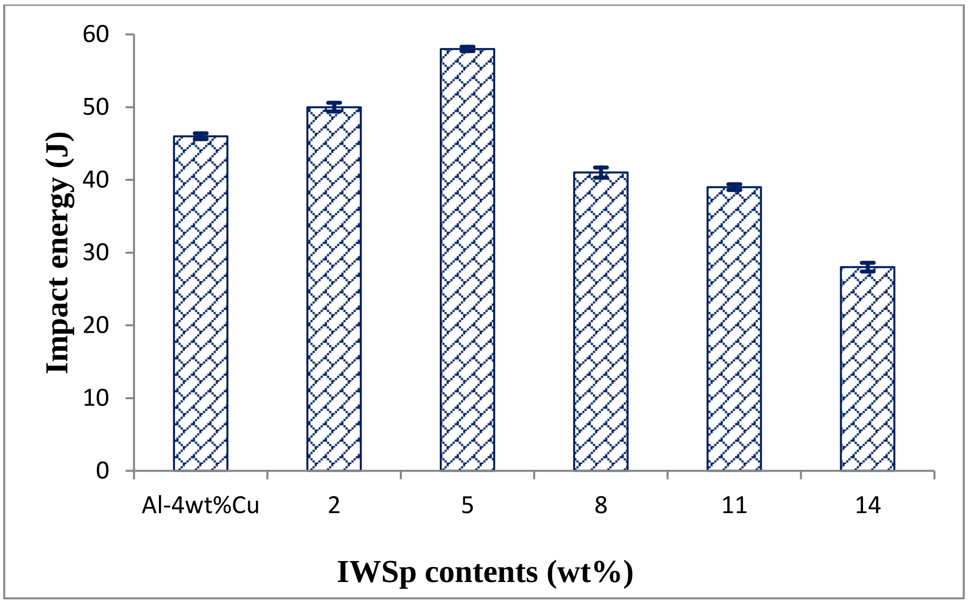

Fig. 4: Impact energy of Al-4wt%Cu/IWSp composite

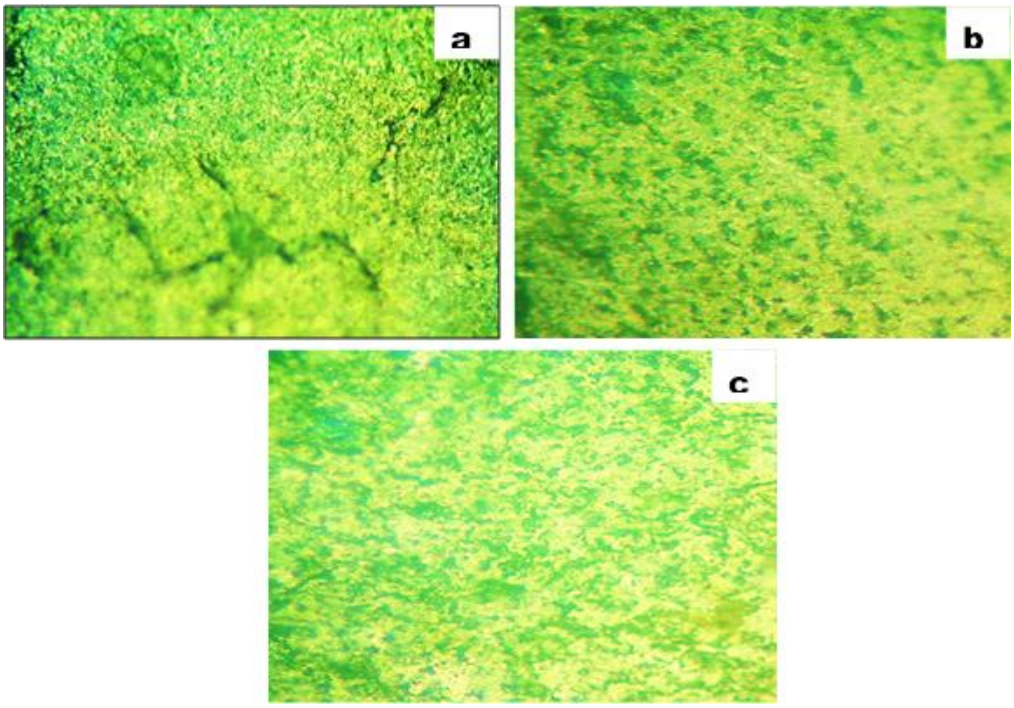

Fig. 5. Microstructure (OM) of (a) Al-4wt%Cu (b) Al-4wt%Cu-8wt%IWSp (c) Al-4wt%Cu-14wt%IWSp

4. CONCLUSION

The present research explored the mechanical characteristics of stir-cast Irvingia wombolu reinforced Al-4wt%Cu composite. The tensile strength, hardness, and impact energy of Al-4wt%Cu alloy matric containing different concentrations of IWSp are investigated. Results of the study showed that the Al-4wt%Cu/IWSp composites demonstrated excellent mechanical characteristics. The incorporation of IWSp into the Al-4wt%Cu alloy matrix has varying effects on mechanical properties. While it generally increases ultimate tensile strength and hardness initially, there is an optimal concentration (8 wt% for ultimate tensile strength and 14 wt% for hardness) beyond which these properties decline due to excessive dispersion of IWSp. Impact energy also exhibits non-linear behavior with increasing IWSp content, with an initial increase followed by a decrease.

International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 10, Issue 3, pp: (1-7), Month: September - December 2023, Available at: www.noveltyjournals.com

REFERENCES

[1] Dobrzanski LA, Wodarczyk A and Adamiak M. Composite Material Based on EN AW-Al Cu4Mg1(A) Aluminium Alloy Reinforced with the Ti(C,N) Ceramic Particles. *Materials Science Forum* 2006; 530-531: 243-248.

[2] Miracle DB. Metal Matrix Composites – from Science to Technological Significance. *Composite Science Technology* 2005; 25: 26–40.

[3] Abdollahzadeh A, Bagheri B, Abbasi M, Sharifi F and Ostovari MA. Mechanical, wear and corrosion behaviors of AZ91/SiC composite layer fabricated by friction stir vibration processing. *Surface Topography: Metrology and Properties* 2021; 3. https://doi.org/10.1088/2051-672X/ac2176.

[4] Bagheri B, Abbasi M, Abdollahzadeh A and Mirsalehi SE. Effect of second-phase particle size and presence of vibration on AZ91/SiC surface composite layer produced by FSP. *Transactions of Nonferrous Metals Society of China (English Edition)* 2020; 4: 905–916.

[5] Bagheri B, Abdollahzadeh A, Sharifi F, Abbasi M and Moghaddam AO. Recent developments in friction stir processing of aluminum alloys: Microstructure evolution, mechanical properties, wear, and corrosion behaviors. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering* 2021. https://doi.org/10.1177/09544089211058007.

[6] Bagheri B, Alizadeh M, Mirsalehi SE, Shamsipur A and Abdollahzadeh A. Nanoparticles addition in AA2024 aluminium/pure copper plate: FSSW approach, microstructure evolution, texture study, and mechanical properties. JOM 2022; 74: 4420–4433.

[7] Bagheri B and Abbasi M. Development of AZ91/SiC surface composite by FSP: effect of vibration and process parameters on microstructure and mechanical characteristics. Advances in Manufacturing 2020; 8: 82–96.

[8] Achebe CH, Obika EN, Chukwuneke JL, and Ani OI. Optimisation of hybridized cane wood-palm fruit fibre frictional material. *Proc. IMechE Part L: J. Materials: Design and Applications* 2019; 12: 2490 – 2497.

[9] Mohanty AK, Misra M, Drzal LT. Sustainable bio-composites from renewable resources: opportunity and challenges in the green materials world. *J. Polym. Environ.*, 10: 19–26.

[10] Obika EN, Achebe CH, Chukwuneke JL and Ezenwa ON. Effect of cane wood and palm kernel fibre filler on the compressive strength and density of automobile brake pad. *Advances in Mechanical Engineering* 2020; 7: 1 – 9.

[11] Chukwuneke JL, Umeji AC, Obika EN, Fakiyesi OB. Optimization of composite briquette made from sawdust/rice husk using starch and clay binder. *International Journal of Integrated Engineering* 2021; 4: 208–216.

[12] Prasad V, Joy A, Venkatachalam G, Narayanan S and Rajakumar S. Finite element analysis of jute and banana fibre reinforced hybrid polymer matrix composite and optimization of design parameters using ANOVA technique. *In Procedia Engineering* 2014; 97: 1116 – 1125.

[13] Chukwuneke JL, Umeji AC, Sinebe JE and Fakiyesi OB. Optimization of composition of selected biomass for briquette production. *Universal Journal of Mechanical Engineering* 2020; 4: 227-236.

[14] Achebe CH, Umeji AC and Chukwuneke JL. Energy evaluation of various compositions of biomass waste briquettes. *Advances in Research* 2018; 6: 1-11.

[15] Sinebe JE, Chukwuneke JL and Omenyi SN. Surface energetic effects on mechanical strength of fibre reinforced polymer metrix. *Journal of Physics: Conference Series* 2019; 4:042016.

[16] Sarki J, Hassana SB, Aigbodiona VS and Oghenevwetaa JE. Potential of using coconut shell particle fillers in eco-composite materials. *Journal of Alloys and Compounds* 2011; 509: 2381–2385.

[17] Alaneme KK, Bodunrin MO and Awe AA. Microstructure, mechanical and fracture properties of groundnut shell ash and silicon carbide dispersion strengthened aluminium matrix composites. *Journal of King Saud University–Engineering Sciences* 2016; http://dx.doi.org/10.1016/j.jksues.2016.01.001.

[18] Alaneme KK, Ademilua BO and Bodunrin MO. Mechanical properties and corrosion behaviour of aluminium hybrid composites reinforced with silicon carbide and bamboo leaf ash. *Tribology in Industry* 2013; 1: 25-35.

[19] Oghenevweta J.E., V.S. Aigbodion, G.B. Nyior and F. Asuke (2016) Mechanical properties and microstructural analysis of Al–Si–Mg/carbonized maize stalk waste particulate composites. *Journal of King Saud University - Engineering Sciences*, 28(2): 222–229.

[20] Aigbodion VS and Ezema IC. Multifunctional A356 alloy/ PKSAnp composites: Microstructure and mechanical properties. *Defence Technology* 2020; 3: 731–736.

[21] Achebe CH., Chukwuneke JL, Anene FA, Ewulonu CM. A retrofit for asbestos-based brake pad employing palm kernel fiber as the base filler material. *Proc. IMechE Part L: J. Materials: Design and Applications* 2019; 9: 1906-1913.

[22] Nwigbo SC, Nnakwo NC and Nnakwo KC**.** Effect of fiber content on the physio-mechanical properties of irvingia gabonensis shell fiber reinforced polyester composite. *International Journal of Innovative Research and Advanced Studies* 2016; 10: 107-111.

[23] Adedipe O, Aigbodion VS, Agbo NA, Lawal SA, Oyeladun OWA, Mokwa, JB and Dauda ET. Unveiling high-performance carburized mild steel using coconut shell ash and CaCO3 nanoparticles derived from periwinkle shell. International Journal of Advanced Manufacturing Technology 2023; 126: 4711–4721.

[24] Kumar A, Singh RC and Chaudhary R. Investigation of microstructure and several quality characteristics of AA7075/Al_2O_3/coconut shell ash hybrid nano composite prepared through ultrasonic assisted stir-casting. *Journal of Materials Engineering and Performance* 2022; https://doi.org/10.1007/s11665-022-07780-7.

[25] Oluwagbenga BF, Joshua IA and Anthony AA. Microstructure and mechanical behaviour of stir-cast Al-Mg-Si alloy matrix hybrid composite reinforced with corn cob ash and silicon carbide. *International Journal of Engineering and Technology Innovation* 2014; 4: 251-259.

[26] Onwumere RA, Nnakwo KC and Boniface AO. Effect of alkaline treatment on mechanical and thermal properties of coconut shell particulates reinforced epoxy composite. *American Journal of Chemistry and Materials Science (ajcms)* 2019; 1: 10-14.

[27] Omole SO, Akinfolarin JFO and Raymond T. Assessment of hardness and tensile properties of stir-cast aluminium matrix reinforced with tetracarpidium conophorum kernel. *International Journal of Engineering and Applied Sciences* 2014; 10: 19-22.

[28] Ononiwu NH, Ozoegwu CG, Madushele N and Akinlabi ET. Carbonization temperature and its effect on the mechanical properties, wear and corrosion resistance of aluminum reinforced with eggshell. *Journal of Composites Science* 2021; 10: https://doi.org/10.3390/jcs5100262

[29] Emeruwa OE, Nnakwo KC and Atuanya CU. Investigative study of the structure and mechanical behaviour of horse eye bean seed shell ash reinforced aluminium alloy matrix composite. *International Journal of Scientific Research in Science, Engineering and Technology* 2017; 5: 8-13.

[30] Ononiwu NH, Ozoegwu CG, Madushele N and Akinlabi ET. Machinability studies and optimization of AA6082/fly ash/carbonized eggshell matrix composite. *Revue Des Composites et Des Materiaux Avances* 2021; 4: 207–216.

[31] Daniel-Mkpume CC, Okonkwo EG, Aigbodion VS, Offor PO and Nnakwo KC. Silica sand modified aluminium composite: an empirical study of the physical, mechanical and morphological properties. *Materials Research Express* 2019; 6: 076539.

[32] Agbor LON. Marketing Trends and Potentials for Irvingia Gabonensis Products in Nigeria. *ICRAF-IITA Conference on Irvingia gabonensis; Ibidan, Nigeria* 1994.

[33] Ndoye O and Tchamou N. Utilization and Marketing Trends for Irvingia Gabonensis Products in Cameroon. *ICRAF-IITA Conference on Irvingia gabonensis; Ibidan, Nigeria* 1994.

[34] Okolo CO, Johnson PB, Abdurahman EM, Abdu-Aguye I and Hussaini IM. Analgesic Effect of Irvingia Gabonensis Stem Bark Extract. *Journal of Ethnopharmacology* 1995; 2:125-129.

[35] Ayuk ET, Duguma B, Franzel S, Kengue J, Mollet M, Tiki-Manga T and Zenkeng P. Uses, Management and Economic Potential of Irvingia gabonensis in the Humid Lowlands of Cameroon. *Forest Ecology and Management* 1999; 1:1-9.

[36] Mbah CN, Onah CC and Nnakwo KC. Effectiveness of irvingia wombolu extract on corrosion inhibition of mild steel in hydrochloric acid solution. *Engineering Research Express* 2020; 1, 015039.

[37] Onah CC, Mbah CN and Nnakwo KC. Inhibitive characteristics of Irvingia Gabonensis extract on mild steel corrosion in hydrochloric acid. *American Journal of Chemistry and Materials Science* 2019; 2: 15-20.

[38] Nnakwo KC, Odo JU, Eweka KO, Okafor JS, Ijomah AI, Maduka EA and Ugwuanyi BC. Evaluation of the electrical conductivity and mechanical properties of Cu–3Ti–1.5Ni–0.5Si quaternary alloy, *JOM: the journal of the minerals, metals, and materials society* 2022; 5: 4174-4180.