UNIZIK JOURNAL OF ENGINEERING AND APPLIED SCIENCES (UJEAS)

Research Article

Effect of rice husk ash and periwinkle shell ash on mechanical properties of recycled aluminium composite

Olorunfemi B.J, Bakare O.A, Oginni O.T

Special Issue
A Themed Issue in Honour of Professor Clement Uche Atuanya on His retirement.

This themed issue pays tribute to Professor Clement Uche Atuanya in recognition of his illustrious career in Metallurgical and Materials Engineering as he retires from Nnamdi Azikiwe University, Awka. We celebrate his enduring legacy of dedication to advancing knowledge and his impact on academia and beyond through this collection of writings.

Edited by
Chinonso Hubert Achebe PhD.
Christian Emeka Okafor PhD.

UJEAS

UNIZIK JOURNAL OF ENGINEERING
AND
APPLIED SCIENCES

UNIZIK Journal of Engineering and Applied Sciences 3(3), September (2024), 836-845
Journal homepage: https://journals.unizik.edu.ng/index.php/ujeas
PRINT ISSN: 2992-4383 || ONLINE ISSN: 2992-4391

Effect of rice husk ash and periwinkle shell ash on mechanical properties of recycled aluminium composite

Olorunfemi B.J[1*], Bakare O.A[2] and Oginni O.T[3]
[1]Department of Mechanical Engineering, Federal University Oye-Ekiti, Nigeria.
[2]Agricultural and Bio-resources Engineering, Federal University Oye-Ekiti, Nigeria.
[3]Department of Mechanical Engineering, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Nigeria.
*Corresponding Author's E-mail: oginni.olarewaju@bouesti.edu.ng

Abstract

The need to enhance the mechanical strength and performance of recycled aluminum composites, which are increasingly utilized in various engineering applications for their sustainability, has attracted both academic and industrial attention. This paper investigates the impact of incorporating rice husk ash (RHA) and periwinkle shell ash (PSA) on the mechanical properties of recycled aluminum composite materials using stir casting technique. RHA and PSA were introduced as partial replacements for conventional fillers in the composite matrix. The effects on tensile strength, flexural strength, and impact resistance were examined. The results reveal that the addition of RHA and PSA led to notable improvements in the mechanical properties of the composite, with optimal compositions achieving a significant increase in strength and toughness. The tensile strength and hardness of the composites increases upon the addition of RHA and increases as the weight percentage of PRA increases from 2% to 10%. The ultimate tensile strength of composites increases from 127.21 MPa for the control sample to 188.26 MPa for the Al/2% RHA/10% PRA composite. The findings aid in the sustainable development of lightweight and high-strength composite materials, particularly in recycling aluminum for eco-friendliness, environmental conservation, material science advancement, and high-performance alternatives for various engineering applications.

Keywords: composite, high-strength, light-weight, recycle, replacement

1. Introduction

Waste disposal has become a pressing environmental concern due to the increasing volumes of waste generated worldwide. Improper waste management practices lead to pollution, resource depletion, and ecological damage (Santos, 2020). There is a growing need for sustainable waste management strategies that minimize environmental impact and promote resource conservation (Yusuf *et al., 20*21). Recycling aluminum plays a crucial role in sustainable resource management and environmental conservation. A high percentage of drink cans and food cans are made of steel, which has aluminum's unique properties with a light metal density of 2.7 g/cm^3 (Sohel, 2019). The aluminum end altered the galvanic reaction between the drink and the steel, resulting in a drink with twice the shelf life of that stored in all-steel cans. Collection and sorting systems, shredding and pre-processing steps, smelting and refining processes, and casting and forming techniques are key stages in the aluminum recycling process (Ahmed and Ali, 2019). Composite materials are engineered materials composed of two or more constituent materials with different properties.

The combination of these materials results in a new material with improved characteristics compared to the individual components alone (Zhang, 2021). The constituents of composites consist of a matrix material, which serves as a binder, and a reinforcement material, which provides strength and other desired properties. The matrix material, typically a polymer, metal, or ceramic, holds the reinforcement together and transfers loads between the reinforcement elements. The reinforcement material can be fibers, particles, or laminates, which enhance the strength, stiffness, and other properties of the composite (Deshpade, 2020; Haneef, 2021). The importance of composite materials in various industries stems from their unique properties and advantages (Hassan et al., 2020). By utilizing composite materials, industries can take advantage of their unique properties and benefits to improve product performance, efficiency, and sustainability, as follows:

High Strength-to-Weight Ratio: Composite materials offer excellent strength-to-weight ratios, providing high strength and stiffness while being lightweight. This property is particularly crucial in industries such as aerospace and automotive, where reducing weight is essential for improved fuel efficiency and performance (Jain, 2019; Tuncer and Paulsen, 2021).
Corrosion Resistance: Composite materials exhibit excellent resistance to corrosion, making them suitable for applications in marine environments, chemical processing, and infrastructure. Their corrosion resistance is particularly advantageous compared to traditional materials like steel (Hamada and Rikards, 2017).
Design Flexibility: Composite materials offer design flexibility and can be molded into complex shapes, allowing for intricate and optimized designs. This property is valuable in industries such as aerospace, automotive, and architecture (Kumar et al., 2019).
Electrical and Thermal Insulation: Composite materials possess excellent electrical and thermal insulation properties, making them suitable for applications in electronics, electrical systems, and building insulation. (Airoldi et al., 2020).
Fatigue Resistance: Composites exhibit superior fatigue resistance compared to many traditional materials, making them suitable for applications subject to cyclic loading (González, 2020).
Environmental Benefits: Composite materials contribute to environmental sustainability by reducing fuel consumption and emissions due to their lightweight nature. They can also be recyclable, reducing waste and promoting a circular economy (Zini, 2017).

Okafor *et al.,* (2022) used Response Surface Methodology (RSM) and the Normal Boundary Intersection (NBI) method to model and optimize carbonized wood/silicon dioxide composites. Variables like particle size, carbonization temperature, filler content, curing temperature, and curing time were adjusted to improve tensile strength, hardness, density, and water absorption. The optimal compromise solutions were found, which were then used in shoe sole manufacturing. FTIR and SEM were used for material characterization (Okafor *et al.,* 2022). Austine et al., (2024) evaluated an exhaust pipe suspender made of natural rubber and styrene butadiene rubber filled with rice husk ash and periwinkle shell. The results showed that adding rice husk ash and periwinkle shell to the NR/SBR blend increased tensile strength, tensile modulus, hardness, and abrasion resistance, while decreasing elongation at break, compression set, and flex fatigue.

The tensile strength and modulus improved with the addition of either RHA or PS, but degraded at 50 phr. Ani et al., (2020) The mobile motorized rice threshing machine, developed using locally sourced materials, reduces drudgery, debris infiltration, and breakage, enhancing rice production. Its performance test analysis showed average throughput and threshing efficiency of 82.9 kg/hr and 92.7%, making it an ideal choice for medium- and large-scale rice production. Adah et al., (2024) research explores the use of Periwinkle shell waste in Nigeria's Calabar coastal region for creating composites with good mechanical properties. The composites were made from recycled high-density polyethylene, recycled linear low-density polyethylene, recycled polystyrene, and recycled polystyrene. The crushed shell was calcined, and Ashed Periwinkle Shell Powder (APSP) was used to reinforce the composites. The composites showed better tensile and flexural strengths, hardness, impact, and moisture absorption, making them a green alternative to existing vehicle bumpers. In addition, a study by Nwa-David, 2023) on nano-concrete, made with nanosized sawdust ash and rice husk ash, found that strength decreased with temperature and NRHA content, but increased with NRHA replacement at 400°C and beyond. The study suggests nanosization improves concrete's mechanical properties, making it suitable for fire resistance design.

Rice husk ash (RHA) and periwinkle shell ash (PSA) are two waste materials that are generated in substantial quantities (Aigbodion *et al.,* 2014). Rice husk is an abundant agricultural by-product produced during rice milling. Traditionally, rice husks were often burned, contributing to air pollution and releasing greenhouse gases. Periwinkle Shell Ash (PSA) is an agro-waste material often discarded as waste from the seafood industry that has shown potential as a reinforcement in composites. These shells, comprising mainly calcium carbonate, also accumulate and create disposal challenges (Montalbano, 2021). Incorporating rice husk ash (RHA) and periwinkle shell ash (PSA) as reinforcements in recycled aluminum composites has gained significant attention. These agricultural waste by-products have shown promise as potential additives due to their unique properties and potential benefits for composite materials. The abundant availability, low cost, and potential for improving the mechanical properties and characteristics of the composites are encouraging (Babarinde et al., 2018). A high amount of amorphous silica, which can improve the mechanical properties and thermal stability of composites, makes RHA indispensable. The amorphous silica acts as a filler and enhances the interfacial bonding between the recycled aluminum matrix and the reinforcement phase. This has improved tensile strength, hardness, and impact resistance (Montgomery et al., 2019). PSA is rich in calcium carbonate and exhibits alkaline properties, which enhance the hardness, wear resistance, and thermal stability of composites (Hassan and Ogungbuyi, 2020).

The incorporation of RHA and PSA in recycled aluminum composites offers several advantages, such as a sustainable approach, reducing the environmental impact associated with waste disposal, cost advantages compared to traditional reinforcement materials, and improvement in the mechanical properties for industrial applications (Joshi et al., 2021; Mouritz, 2011). Some of the applications of RHA include aggregates and fillers for concrete and board production, an economical substitute for microsilica fumes, absorbents for oils and chemicals, soil ameliorants as a source of silicon, insulation powder in steel mills, repellents in the form of "vinegar tar," and an insulation material for homes and refrigerants (Abdullah, 2017). The combination of RHA and PSA has shown positive effects on the mechanical properties, thermal stability, and water absorption characteristics of composites, leading to their improved performance and sustainability (Nay and Hakraborty, 2014; Ogungbuyi and Hassan, 2017). The production of aluminum composite materials using recycled aluminum has several environmental and economic benefits (Patra *et al.,* 2022; Radwan, 2021; Samanta, 2020). However, the mechanical properties of these materials are not as good as those produced using virgin aluminum. Therefore, this paper aimed to improve the mechanical properties of recycled aluminum composites by adding rice husk ash and periwinkle shell ash.

2.0 Material and methods

2.1 Materials preparation

Recyclable aluminum was obtained from industrial scrap, post-consumer waste, and aluminum recycling facilities, sorted, and processed for applications. The scrap is cleaned from impurities and melted in a furnace. The molten aluminum is subjected to degassing to remove gases and impurities, ensuring a high-quality matrix material. The recycled aluminum was cast by shaping the molten aluminum into the desired form for production volume. The molten aluminum is poured into the mold and allowed to solidify and cool to minimize casting defects. Trimming, machining, and surface treatments were carried out to achieve the desired dimensions, surface finish, and overall quality of the recycled aluminum matrix.

2.1.1 Preparation of rice husk ash (RHA) and periwinkle shell ash (PSA)

Rice husk was sourced from rice mills and agricultural farms and stored for further processing. The collected rice husk is mechanically separated from any contaminants and subjected to combustion in a controlled environment at high temperatures to remove organic matter and convert it into RHA in the form of powders. Periwinkle shells are obtained from the seafood processing market and cleaned from organic matter by rinsing, scrubbing, and soaking the shells in water and mild solutions. The cleaned periwinkle shells are dried to remove moisture and subjected to a calcination process at high temperatures to convert the calcium carbonate into periwinkle shell ash (PSA). The calcined PSA is then ground into fine particles, or powders, and sieved.

2.2 Composite Fabrication

The process of incorporating rice husk ash (RHA) and periwinkle shell ash (PSA) into the recycled aluminum matrix involves mixing and blending techniques. The recycled aluminum matrix is weighed and mechanically mixed with RHA and PSA in a predetermined ratio. The mixture is then stirred for homogeneity and to improve the bonding between the ash particles and the aluminum matrix. Stir casting is carried out for solidification to obtain the final composite material. The RHA/PSA particles are mixed with aluminum powder and subjected to heat and pressure to consolidate the composite, achieving desirable mechanical and thermal properties.

2.3 Mechanical Testing

Tensile, hardness, and impact tests using a universal testing machine were conducted to measure tensile strength, yield strength, elongation, and hardness and assess the impact resistance of the composite material.

3.0 Results and Discussions

Table 1 shows the results of the Rockwell hardness test for the control sample and the composites. The effect of the weight fraction of RHA and PSA particles on the hardness of the developed composites is depicted in Figure 1. It is very obvious from the results that the RHA and PSA particles have significant effects on the microhardness of the composites. The hardness of the composites increases with the addition of RHA and an increase in the weight fraction of PSA from 2% to 10% in conjunction with Nay and Hakraborty, (2014) and Ogungbuyi and Hassan, (2017). This is attributed to increases in the surface area of the matrix, which then reduces the grain sizes. The presence of reinforcing particles, RHA and PSA, with a hard surface area offers more resistance to plastic deformation and then increases hardness.

Table 1: Hardness Results

	Run Time				
Samples	**1**	**2**	**3**	**4**	**Average**
	HRB	HRB	HRB	HRB	HRB
1	58.0	63.5	66.0	71.0	64.63
2	66.0	62.0	66.5	71.0	66.38
3	63.0	64.0	69.0	70.5	66.63
4	64.5	73.5	67.0	69.5	68.63
5	73.1	72.0	63.0	69.0	69.28
6	74.0	69.0	70.5	72.5	71.50

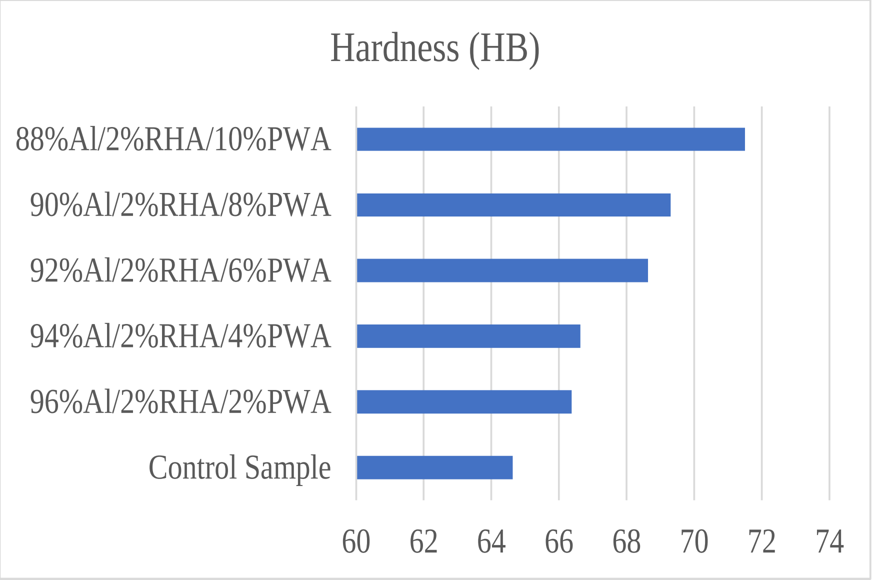

Figure 1: Hardness of control sample and composites

Tensile test results are presented in Tables 2–7 with varying compositions. Figures 2–7 show the load extension graph for the control sample and all composites. The graphs showed almost the same pattern, indicating better performance. The ultimate tensile strength of the control sample and the composites is presented in Table 8 and Figure 8.

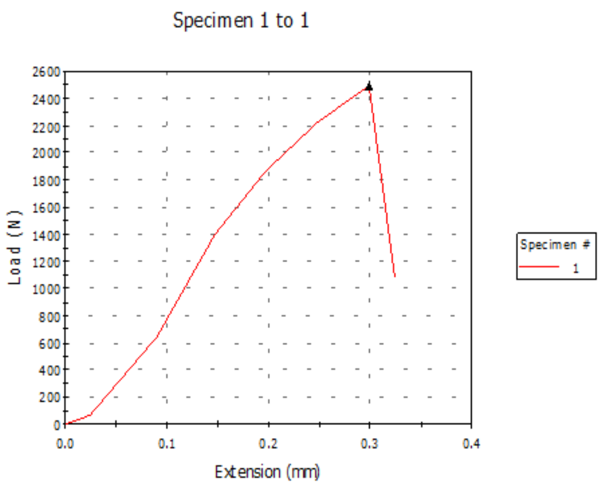

Fig.2: L-E on Al/2%RHA/2%PSA

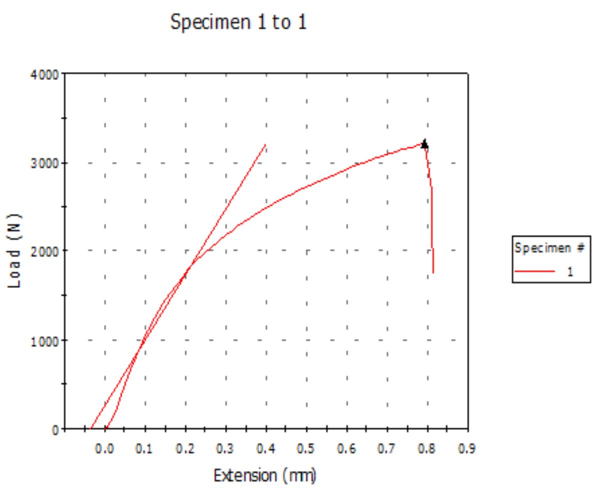

Fig. 3: L-E on Control Sample

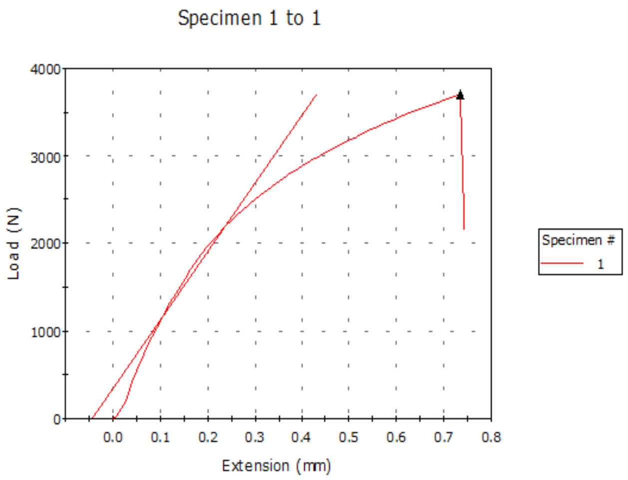

Fig. 4: L-E on Al/2%RHA/6%PSA

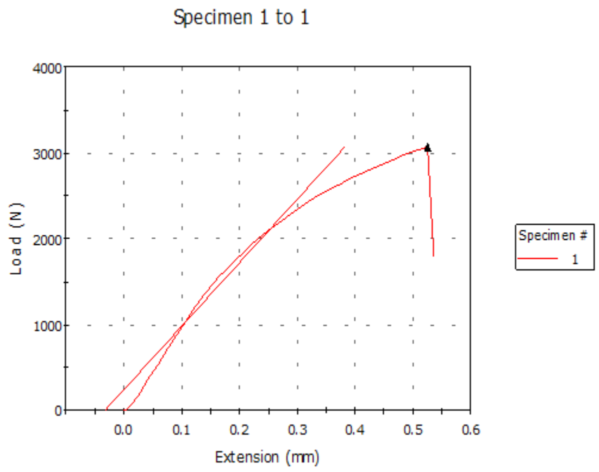

Fig. 5: L-E on Al/2%RHA/4%PSA

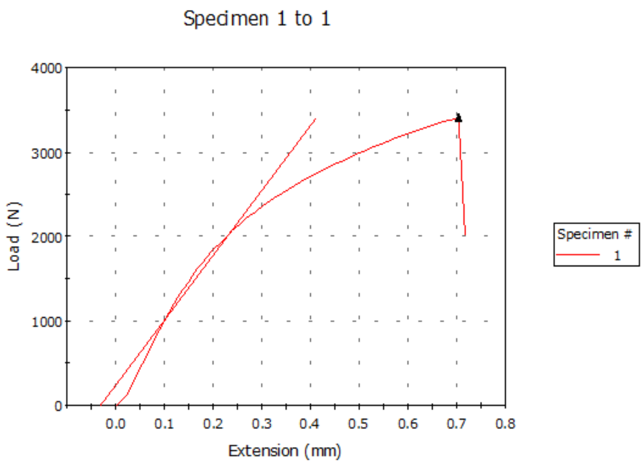

Fig.6: L-E on Al/2%RHA/10%PSA

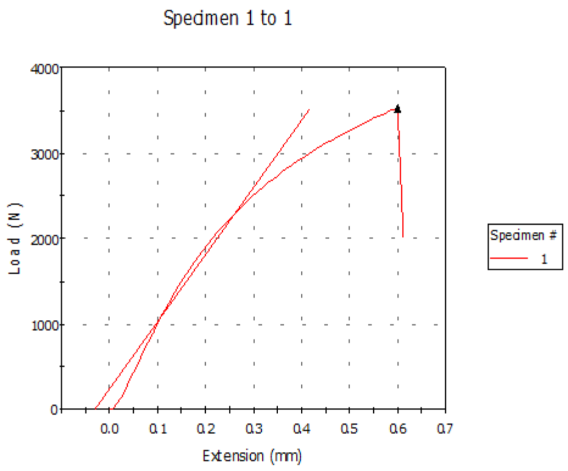

Fig.7 L-E on Al/2%RHA/8%PSA

Table.2: Tensile Test Results for Control Sample

	Specimen label	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Load at Break (Standard (N)	Extension at Maximum Load (mm)
1	Control	2,497.86	127.21	0.50	2,497.86	0.29919
Maximum	A	2,497.86	127.21	0.50	2,497.86	0.29919
Mean	B	2,497.86	127.21	0.50	2,497.86	0.29919
Median	C	2,497.86	127.21	0.50	2,497.86	0.29919
Minimum	D	2,497.86	127.21	0.50	2,497.86	0.29919

Table 3: Tensile Test Results for Al/2%RHA/2%PSA

	Specimen label	Max. Load (N)	Tensile stress at Max. Load (MPa)	Tensile strain at Max. Load (%)	Load at Break Standard(N)	Extension at Max. Load (mm)
1	Control	3,213.91	163.68	1.32	3,213.91	0.79475
Maximum	A	3,213.91	163.68	1.32	3,213.91	0.79475
Mean	B	3,213.91	163.68	1.32	3,213.91	0.79475
Median	C	3,213.91	163.68	1.32	3,213.91	0.79475
Minimum	D	3,213.91	163.68	1.32	3,213.91	0.79475

Table 4: Tensile Test Results for Al/2%RHA/4%PSA

	Specimen label	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Load at Break (Standard)(N)	Extension at Maximum Load (mm)
1	Control	3,696.48	188.26	1.22	3,696.48	0.73500
Maximum	A	3,696.48	188.26	1.22	3,696.48	0.73500
Mean	B	3,696.48	188.26	1.22	3,696.48	0.73500
Median	C	3,696.48	188.26	1.22	3,696.48	0.73500
Minimum	D	3,696.48	188.26	1.22	3,696.48	0.73500

Table 5: Tensile Test Results for Al/2%RHA/6%PS

	Specimen label	Max. Load (N)	Tensile stress at Max. Load (P)	Tensile strain at Max. Load (%)	Load at Break Standard (N)	Extension at Max. Load (mm)
1	Control	3,529.76	179.77	1.00	3,529.76	0.60000
Maximum	A	3,529.76	179.77	1.00	3,529.76	0.60000
Mean	B	3,529.76	179.77	1.00	3,529.76	0.60000
Median	C	3,529.76	179.77	1.00	3,529.76	0.60000
Minimum	D	3,529.76	179.77	1.00	3,529.76	0.60000

Table 6: Tensile Test Results for Al/2%RHA/8%PSA

	Specimen label	Max. Load (N)	Tensile stress at Max. Load (P)	Tensile strain at Max. Load (%)	Load at Break Standard (N)	Extension at Max. Load (mm)
1	Control	3,069.69	156.34	0.87	3,069.69	0.52487
Maximum	A	3,069.69	156.34	0.87	3,069.69	0.52487
Mean	B	3,069.69	156.34	0.87	3,069.69	0.52487
Median	C	3,069.69	156.34	0.87	3,069.69	0.52487
Minimum	D	3,069.69	156.34	0.87	3,069.69	0.52487

Table 7: Tensile Test Results for Al/2%RHA/10%PSA

	Specimen label	Maximum Load (N)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Load at Break (Standard)(N)	Extension at Maximum Load (mm)
1	Control	3,213.91	163.68	1.32	3,213.91	0.79475
Maximum	A	3,213.91	163.68	1.32	3,213.91	0.79475
Mean	B	3,213.91	163.68	1.32	3,213.91	0.79475
Median	C	3,213.91	163.68	1.32	3,213.91	0.79475
Minimum	D	3,213.91	163.68	1.32	3,213.91	0.79475

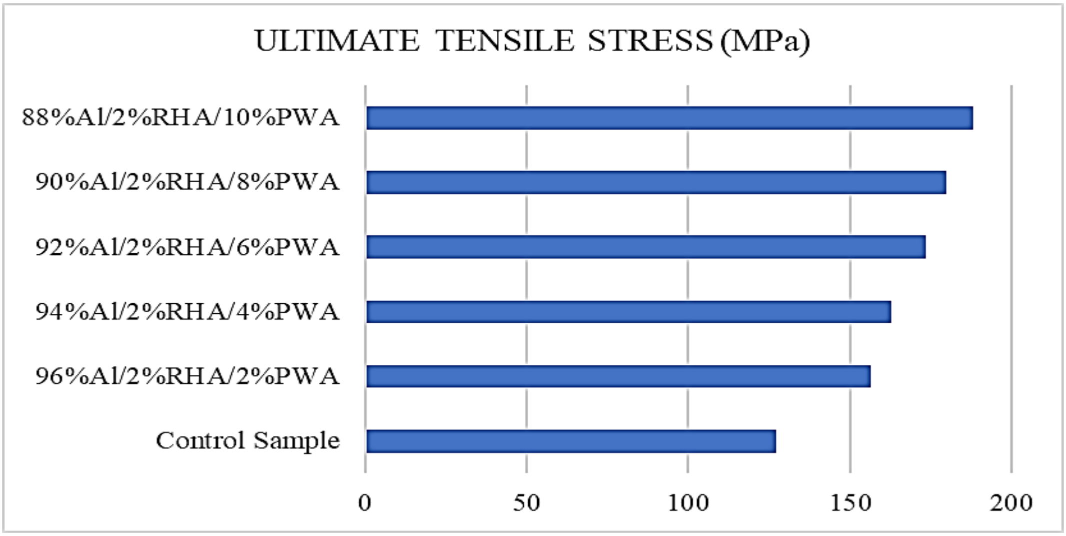

Figure 8: Ultimate Tensile Strength for Control Sample and Composites

The tensile test results for the control sample and the composites are shown at 4.2–4.8. The graph showing the relationship between the ultimate tensile strength of the control sample and fabricated composites is in Figure 4.8. It can be observed that the tensile strength of the composites increases significantly upon the addition of RHA and increases as the weight percentage of PRA increases from 2% to 10%. The ultimate tensile strength of composites increases from 127.21 MPa for the control sample to 188.26 MPa for the Al/2% RHA/10% PRA composite. The improvement in the UTS of the composites is linked not only to the high rate of diffusion of reinforcements and their deep penetration into the matrix of Al alloy, forming a good interfacial adhesion between the Al matrix, RHA, and PRA, but also to the to the increased packing density of each of the reinforcements, which was uniformly dispersed throughout the Al matrix. The impact energy test is shown in Table 4.8, while Figure 4.9 shows the graph of the impact test for the control sample and composites. Tables 8 and 9 depict that the impact energy of all composites decreased from the control sample of 82.5 J to 76 J for the 88% Al/2% RHA/10% PRA composite. The decrease in impact energy may be attributable to the extreme hardness of the new phases, which imparts brittleness to the Al matrix. Hence, the addition of reinforcements to the Al matrix enhanced the strength and grain refinement but reduced the impact energy. The composites showed better tensile and flexural strengths, and hardness, impact, making them a green alternative to existing vehicle bumpers as contained in Nwa-David, (2023) study.

Table 8: Result of Impact test

Sample	Izod Impact Energy (J)
Control Sample	82.5
Al with 2%RHA and 2%PSA	80.0
Al with 2%RHA and 4%PSA	80.0
Al with 2%RHA and 6%PSA	79.5
Al with 2%RHA and 8%PSA	78.0
Al with 2%RHA and 10%PSWA	76.0

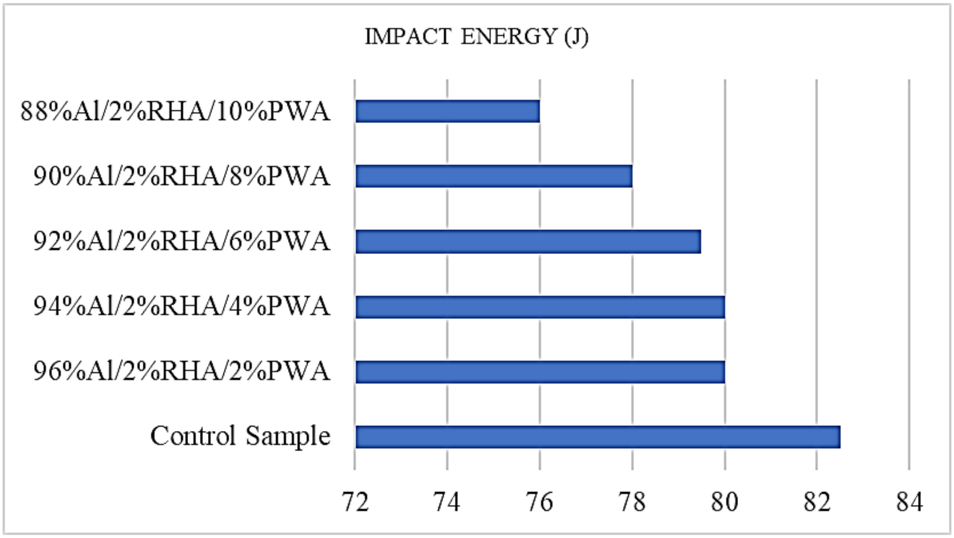

Figure 9: Impact Energy of Control Sample and Composites

4.0. Conclusion

Recycled aluminum and agricultural waste products of rice husk ash and periwinkle shell ash were used as reinforcements for the mechanical properties of composite materials. Successful production of RHA and PSA as reinforcements in their purest form in aluminum matrix was done. Composites with improved mechanical properties were examined and confirmed to be better than their individual elements. The results of hardness of the composites increases on addition of RHA, and an increase in the weight fraction of PSA from 2% to 10%. In addition, the impact energy of all composites decreased from the control sample of 82.5 J to 76 J for the 88% Al/2% RHA/10% PRA composite. The outcome of ultimate tensile strength of composites increases from 127.21 MPa to 188.26 MPa for the Al/2% RHA/10% PRA composite. The combination of RHA and PSA showed a positive effect on the mechanical properties and thermal stability characteristics of composites, leading to their improved performance and sustainability. Therefore, the conversion of waste to wealth through the use of recycled aluminum cans to fabricate the aluminum alloy matrix is possible. The paper provides insights into the effect of adding rice husk ash and periwinkle shell ash on the mechanical properties of recycled aluminum composite, which could be useful in designing and producing high-performance composite materials. The findings of this study contribute to the development of sustainable and eco-friendly aluminum composite materials, reduce the environmental impact of producing composite materials, and eliminate possible health hazards.

5.0 Recommendation

Future studies should be intensified on the microstructural analysis of composite product.

Acknowledgements

We sincerely appreciate all FUOYE scientists who collaborated with the authors in carrying out the samples test.

References

Abdullah, H., 2017. Utilization of Rice Husk Ash as Reinforcement in Polymer Composites: A Comprehensive Review. Journal of Cleaner Production, 142, 461- 472. doi: 10.1016/j.jclepro.2016.09.156

Adah, P.U., Nuhu, A.A., Salawu, A.A., Hassan, A.B., Ubi, P.A., 2024. Characterization of Periwinkle Shell Ash Reinforced Polymer Composite for Automotive Application. Fudma Journal of Sciences, 8(1), 83 - 92.

Ahmed, S. F. and Ali, S. A., 2019. Investigation on Properties of Rice Husk Ash Particulate Reinforced Aluminum Matrix Composite. Materials Today: Proceedings, 18, 519-528. doi: 10.1016/j.matpr.2019.07.358

Aigbodion, V.S., Hassan, S.B., Agunsoye, J.O., 2014. Microstructural and mechanical properties of periwinkle shell ash reinforced polyester matrix composites. Journal of Minerals and Materials Characterization and Engineering, 2(4), 293-303.

Airoldi, A., 2020. Electrical Conductivity of Carbon Nanotube Composites: A Review. Journal of Composite Materials, 54(3), 3209-3237. doi:10.1177/0021998320908577

Ani, O.I., Onoh, G.N., Akpor, O.J., Ukpai, C.A., 2020. Design, development and performance evaluation of a mobile rice threshing machine. International Journal of Emerging Trends in Engineering and Development, 10, 7-17.

Austine, A., Tenebe, O.G., Ichetaonye, S.I., Muhammed, A.A., 2024. The Assessment of Exhaust Pipe Suspender Produced from Blend of NR and SBR Reinforced with Rice Husk Ash and Periwinkle Shell. Academy Journal of Science and Engineering, 18(1), 22-34.

Babarinde, I.A., Popoola, A.P., Folorunso, D.O., 2018. Mechanical and thermal properties of rice husk ash filled recycled aluminum alloy composites. Journal of Minerals and Materials Characterization and Engineering, 6(6), 471-477.

Deshpande, P. D., 2020. Composite Materials for Aerospace Applications. Comprehensive Composite Materials II, pp. 315-352. Elsevier. doi:10.1016/B978-0-12-803581-8.11873-4

González, C., 2020. Review of Fatigue Failure Mechanisms in Fiber-reinforced Polymer Composites. Composite Structures, 235, 111806. doi: 10.1016/j.compstruct.2019.111806

Hamada, H., Rikards, R., 2017. Carbon Fibre Reinforced Polymer for Corrosion Protection of Steel Reinforcements in Concrete: A Review. Journal of Cleaner Production, 156, 333-348. doi: 10.1016/j.jclepro.2016.06.168

Haneef, M., 2021. Rice Husk Ash Reinforced Polymer Composites: A Review. Materials Today Communications, 29, 102913. doi: 10.1016/j.mtcomm.2021.102913

Hassan, S.B., Aigbodion, V.S., Lawal, G.I., 2020. Characterization and properties of recycled aluminum reinforced with periwinkle shell ash. IOP Conference Series: Materials Science and Engineering, 876, 012007.

Hassan, S.B., Ogunbiyi, M.O., 2016. Optimization of Mechanical Properties of Periwinkle Shell Ash Reinforced Polyester Composites. Journal of Materials Science and Chemical Engineering, 4(08), 1-9. doi:10.4236/msce.2016.48001

Jain, V., 2019. Casting Process Optimization for Aluminum Recycling: A Review. Journal of Cleaner Production, 21(6), 96-108. doi: 10.1016/j.jclepro.2019.01.212

Joshi, M.R., Marra V., Agathopoulos, S., 2021. Sustainable utilization of rice husk ash in ceramic-based composites. Journal of Asian Ceramic Societies, 9(1), 29-43.

Kumar, N., Sharma, R., Dwivedi, R., 2019. Optimization of Mechanical Properties of Aluminum Alloy AA6063 Reinforced with Rice Husk Ash Particulates. Materials Today: Proceedings, pp 23.

Montalbano, S., 2021. Effectiveness of Flame Treatment for the DE lacquering of Aluminum Packaging Waste: A Comparative Study. Waste Management, 124, 12-20. doi: 10.1016/j.wasman.2021.05.001

Montgomery, V., Okafor, E.C., Akpan, E.I., 2019. Mechanical properties of rice husk ash-reinforced recycled aluminum matrix composites. Heliyon, 5(9), 02492.

Mouritz, A.P., 2011. Review of Advanced Composite Structures for Naval Ships and Submarines. Composite Structures, 93(3), 548-561. doi: 10.1016/j.compstruct.2010.08.027

Nayak, S.K., Chakraborty, A.K., 2014. Development of Rice Husk Ash (RHA) for Composite Structural Applications. In Handbook of Ecomaterials (pp. 1-19). Springer. doi:10.1007/978-3-319-08215-7_17-1

Nwa-David, C.D., 2023. Effect of Elevated Temperatures on Mechanical Properties of Concrete Blended with Nanosized Sawdust Ash and Rice Husk Ash. UNIZIK Journal of Engineering and Applied Sciences, 2(2), 404-415.

Ogunbiyi, M. O., Hassan, S. B., 2017. Mechanical Properties of Periwinkle Shell Ash Reinforced Polymer Composites. Journal of Minerals and Materials Characterization and Engineering, 5(2), 95-107. doi:10.4236/jmmce.2017.52009

Okafor, C.E., Okpe, D.U., Ani, O.I., Okonkwo, U.C., 2022. Development of carbonized wood/silicon dioxide composite tailored for single-density shoe sole manufacturing. Materials Today Communications, 32, 104184.

Okafor, C.E., Onovo, A.C., Ani, O.I., Obele, C.M., Dziki, D., Ihueze, C.C., Okonkwo, U.C., 2022. Mathematical study of bio-fibre comminution process as first step towards valorization of post-harvest waste materials. Cleaner Materials, 4, p.100067.

Patra, A., Rath, S.S., Sahu, S.K., Sahoo, S. K., 2022. A Comprehensive Study on Aluminum Recycling: A Technological Perspective. Journal of Cleaner Production, 317, 128545.

Radwan, M.M., 2021. An Integrated Framework for the Shredding and Sorting of Aluminum Cans for Recycling. Journal of Cleaner Production, 293, 126223. doi: 10.1016/j.jclepro.2021.126223

Samanta, S.K., 2020. Assessment of Energy and Environmental Performance of an Aluminum Recycling Process with Impurity Removal. Journal of Cleaner Production, 262, 121353. doi: 10.1016/j.jclepro.2020.121353

Santos, F.S., 2020. Recycling of Aluminum Beverage Cans: A Techno-economic Analysis of Different Collection and Sorting Systems. Waste Management, 112, 251-263. doi: 10.1016/j.wasman.2020.07.051

Smail, I., Bouakkadia, S., Bouzoubaâ, N., Fathy, K., 2021. Aluminum Recycling: An Essential Contribution to Sust/ainable Development. Journal of Cleaner Production, 278, 123725.

Sohel, K.M., 2019. Analysis of Carbon Fiber Reinforced Polymer and Steel Reinforced Concrete Structures Subjected to Corrosion and Corrosion-Induced Cracking. Construction and Building Materials, 198, 465-480. doi: 10.1016/j.conbuildmat.2018.11.057

Tuncer, B., Paulsen, A.D., 2021. Evaluation of Material Recycling Facilities Using a Hybrid Input-output Life Cycle Assessment Model: A Case Study on Aluminum Recycling in California. Resources, Conservation and Recycling, 164, 105159. doi: 10.1016/j.resconrec.2020.105159

Yusuf, A.M., 2021. Potential Use of Periwinkle Shell Waste as Reinforcement in Polymer Composites: A Comprehensive Review. Journal of Cleaner Production, 291, 125813. doi: 10.1016/j.jclepro.2020.125813

Zhang, H., 2021. Evaluation of the Machinability of Recycled Aluminum Alloy Chips for Sustainable Manufacturing. Journal of Cleaner Production, 318, 128521. doi: 10.1016/j.jclepro.2021.128521

Zini, E., 2017. Environmental Life Cycle Assessment of Composite Materials: A Literature Review. Journal of Cleaner Production, 155, 142-154. doi: 10.1016/j.jclepro.2017.03.118