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The damage tolerance of Al-Si-Mg Alloy Reinforced with Periwinkle Shell and Mangifera Indica Particulates

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ABSTRACT: *The damage tolerance of Al-12wt%-2wt%Mg based biocomposites containing different concentrations of periwinkle shell and Mangifera indica particulates (PSp and MIp) have been explored experimentally. The effects of hybrid concentrations on the damage tolerance were also investigated. The structural analysis of the developed biocomposites was done using scanning electron microscopy (SEM). The statistical significant effects of the reinforcements and their hybrids on the damage tolerance were established using Response surface optimal design (RSOD) and the optimal composition obtained and validated. The biocomposites demonstrated excellent damage tolerance at different concentrations of the reinforcements with maximum of hardness151 BHN obtained by Al-12wt%-2wt%Mg-6PSp-2wt%MIp biocomposite. The biocomposite recorded higher hardness than the alloy matrix. The improvements of property are guaranteed by the distribution of PSp and MIp particles in the alloy matrix as evidenced in the microstructural analysis. The statistical data revealed that PSp and MIp have significant effects on the tested properties. The optimization results revealed Al-12wt%Si-2wt%Mg-11wt%PSp-0.281wt%MIp as the optimal composition.*

***KEYWORDS**: Aluminium, Magnesium, Periwinkle Shell, Mangifera indica, damage tolerance.*

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I. INTRODUCTION

The most important motivation for the development of composites is the possibility of taking advantage of particular properties of the constituent materials to meet specific demands. (Ekwedigwe *et al.*, 2023 & Okafor et al., 2022). Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase (polymer, ceramic, metal) and their reinforcement (oxides, carbides, and nitrides) respectively, shape (continuous fibers, short fibers, whiskers, particulates) (Nwankwo et al., 2023) and orientation (processing routes) (Nwambu, 2022). In addition, there are some reports that indicated the emergence of intermetallic- matrix and carbon-matrix composites (Achebe *et al.*, 2020 & Edoziuno *et al.*, 2021). In aluminium matrix composites, one of the constituents is aluminium/aluminium alloy, which forms percolating network and is termed as matrix phase (Ilona *et al.*, 2016 & Lv et al., 2023). The other constituent is embedded in this aluminium/aluminium alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as SiC and Al_2O_3 (Giugliano et al., 2017 & Galyshev and Atanov, 2022). There are several advantages of aluminium matrix composite compared to unreinforced materials such as higher strength, improved stiffness, reduced density(weight), improved high temperature properties, controlled thermal expansion coefficient, thermal/heat management, enhanced and tailored electrical performance, improved abrasion and wear resistance, control of mass (especially in reciprocating applications) and improved damping capabilities (Oluwagbenga et al., 2014; Odeyewi *et al.,* 2020; Neuana *et al*., 2021) These advantages can be quantified for better application. For example, elastic modulus of pure aluminium can be enhanced from 70GPa to 240GPa by reinforcing with 60 vol.% continuous aluminum fibre (Omole *et al*., 2014; Lv *et al.,* 2023). On the other hand, incorporation of 60 vol% alumina fibre in pure aluminium leads to decrease in the coefficient of expansion from 24 ppm/^{O}C to 7 ppm/^{o}C. All these examples illustrate that it is possible to alter several technological properties of aluminium/aluminium alloy by more than two- three orders of magnitude by incorporating appropriate reinforcement in suitable volume fraction (Giugliano *et al.,* 2017 & Galyshev and Atanov, 2022). The key benefits of aluminium matrix composites in transportation sector are lower fuel consumption, less noise and lower airborne emissions. With increasing stringent environmental regulations and emphasis on improved fuel economy, use of aluminium matrix composites in transport sector will be inevitable and desirable in the coming years (Nwambu *et al.,* 2017).

Earlier researches reported extensively the significant effects of different concentrations of agricultural wastes on the physical and mechanical properties of Al-based biocomposites. The effects of hybrids of different ecofriendly plants wastes were also reported by various researchers, among which were rice husk ash, groundnut shell ash, bamboo leaf ash, Corn cob ash, palm oil clinker, coconut fibre, carbonized maize stalk, horse eye bean, periwinkle, coconut shell, and bamboo leaf etc (Okafor et al 2022 & Ekwedigwe et al. 2023).
Therefore, it is observed from the reviewed literatures that little or no study have been carried out on the influence of hybrids of periwinkle shell and mangifera indica particulates on the structure and mechanical properties of Al-12wt%Si eutectic biocomposite, hence this recent study was initiated to close the gap.

II. MATERIALS AND METHODS

The aluminium wire was sourced from Cutix Cable Plc Nnewi, Nigeria while silicon and magnesium powder were obtained from Bridge-Head market Onitsha, Nigeria. The periwinkle and Mangifera indica shells used in this research work were sourced from Obolo Afor in Udenu Local Government Area of Enugu State, Nigeria. The Al-12wt%Si-2wt%Mg-xPSp, Al-12wt%Si-2wt%Mg-xMIp, Al-12wt%Si-2wt%Mg-xPSp-xMIp biocomposites samples were casted using a permanent mold according to British standards; BS EN ISO 6892-1:2016. The mold cavity of dimension 250mm length and 16mm diameter were prepared using a steel plate. The thick steel plate was split into two parts. The dome and pin were inserted on the surface of the two split die mold for easy coupling and removal of the cast. The sourced Mangifera indica fruits were washed thoroughly and the mesocarps extracted. The endocarps were sun dried and cleaned to remove sand and dirt. The endocarps were ground and sieve into a particle size of 63µm using an electric grinder. The periwinkle shell was washed thoroughly with distilled water, sun dried, ground, and sieved into a particle size of 63µm. The composites formulations were designed using Design Expert Software (DX-10). The predetermined quantity (in weight percent) of aluminium, silicon, magnesium, periwinkle shell and Mangifera indica particulates were calculated taking into consideration the total charge and the oxidation loss of the base metals. The calculated weight in percent of the metals were measured using electronic weight balanace (GF-203A) and stored in batches based on the designed compositions.

The designed biocomposites compositions: Al-12wt%Si-2wt%Mg-xPSp, Al-12wt%Si-2wt%Mg-xMIp, and Al-12wt%Si-2wt%Mg-xPSp-xMIp (x equals 2, 5, 8, and 11 weight percent) were melted using a steel crucible pot. The fabrication was done at Unique Foundry Ltd, Onitsha, Anambra State. For fabrication of the Al-12wt%Si-2wt%Mg based alloy matrix, the pure aluminium was first charged into the heated crucible pot and allowed to melt to molten state at about 660^{o}C. The molten aluminium was superheated for 5 minutes to increase its fluidity. After superheating, the pure silicon and magnesium powders were wrapped in an aluminium foil and introduced into the molten aluminium . After 5 minutes, the mixture was stirred properly and poured into a preheated fabricated mold cavity. The Al-12wt%Si-2wt%Mg-xPSp, Al-12wt%Si-2wt%Mg-xMIp, and Al-12wt%Si-2wt%Mg-xPSp-xMIp compositions were casted using the same fabrication route.

The developed biocomposites samples were machined to the required dimension according to the British Standards; BS EN ISO 6505-1:2014, and BS EN ISO 148-1:2016 for Brinell hardness and Charpy impact strength tests respectively using lathe machine at Delta State Polytechnic, Ogwashi-uku. The samples for impact strength test were machined to 55mm x 10mm x 10mm in size with a 2mm deep notch (D45^{o}) inscribed at the center of the sample using lathe machine while the hardness samples were machined to 20mm length and 16mm diameter. The machined samples were stored for structural analysis and mechanical properties tests. All the samples for the microstructural analysis were cut into dimensions of 20 x 10 mm^2. The surfaces were ground using an electric grinder (ZMAK-GA5030/2) and silicon carbide paper of 400, 600, 800 and 1200µm grits size. The surfaces were polished using an aluminium powder and etched in a Keller's reagent solution with composition; 8 g $FeCl_3$ + 20 ml HCl+120 cm^3 H_2O. The etched surfaces were dried using Bosch GHG660LCD heat gun machine. The microstructure was observed using L2003A type optical microscope (OM) and JSM-5600LV type scanning electronic microscopy (SEM) at magnifications of X400 and X1500 respectively.

III. RESULTS AND DISCUSSIONS

Figs.1(a&b) depict the effect of periwinkle shell and Mangifera indica particulates on the hardness of Al-12wt%Si-2wt%Mg based biocomposites. Figs showed clearly that addition of PSp and MIp significantly improved the hardness of Al-12wt%Si-2wt%Mg alloy matrix. The hardness of Al-12wt%Si-2wt%Mg alloy matrix increased by $\approx$ 12% and $\approx$ 6.5% after additions of 2wt%PSp and 2wt%MIp respectively. The hardness of the composite increased with increase in periwinkle shell and Mangifera indica particulates concentrations which indicates clusters of PSp and MIp particles in the alloy matrix as can be seen in the structural analysis, Figs. 7-8. The comparative effects of PSp and MIp concentrations, and hybrid on the hardness of Al-12wt%Si-2wt%Mg based biocomposites are presented in Figs. 2 and 3. It is noted that hybrid recorded the highest hardness values with maximum value of 151 BHN obtained by Al-12wt%Si-2wt%Mg-6wt%PSp-2wt%MIp biocomposite.

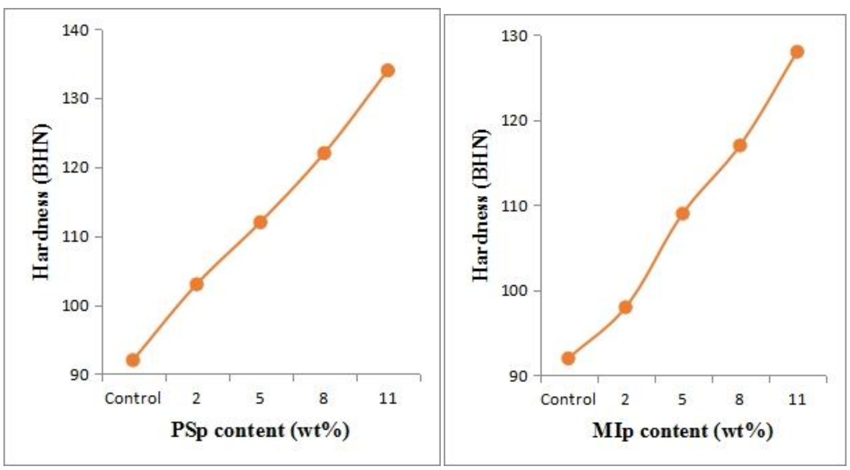

Fig. 1: Hardness of Al-12wt%Si-2wt%Mg/PSp and Al-12wt%Si-2wt%Mg/MIp biocomposite

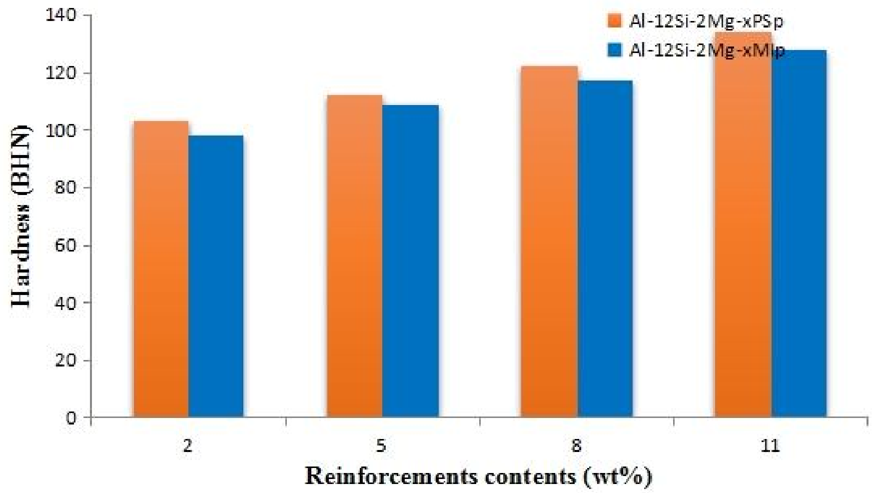

Fig. 2: Comparative effect of PSp and MIp content on the hardness of Al-12wt%Si-2wt%Mg based biocomposite

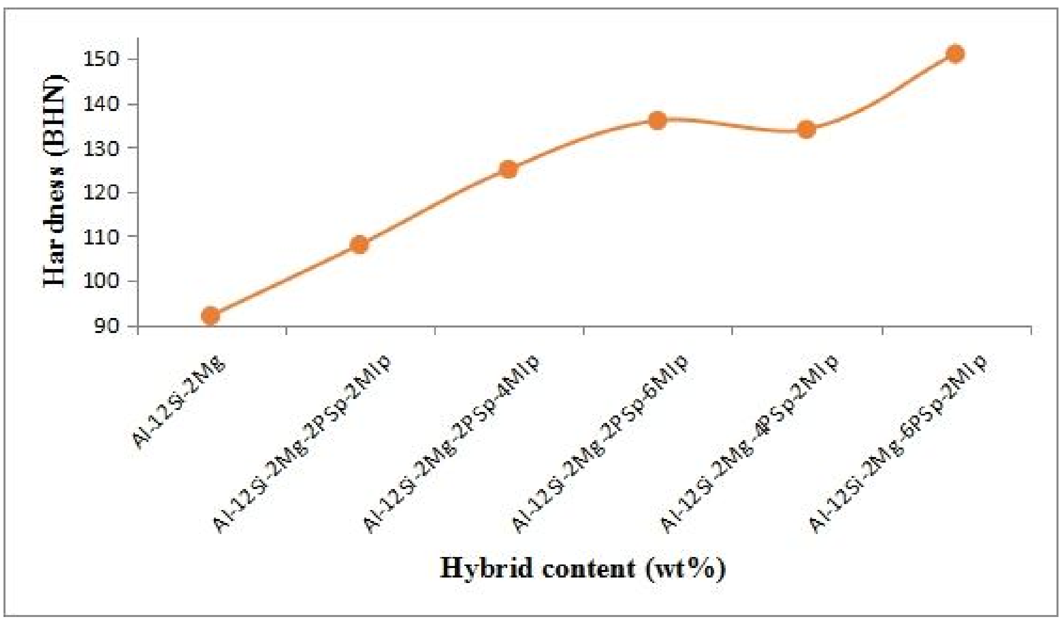

Fig. 3: Hardness of PSp/MIp hybrid reinforced Al-12wt%Si-2wt%Mg based biocomposite

The variations of impact strength of Al-12wt%Si-2wt%Mg based biocomposite with increasing concentrations of periwinkle shell and Mangifera indica particulates contents are showed in Figs. 4-6. Fig. 4 (a&b) showed that the Al-12wt%Si-2wt%Mg alloy matrix recorded an impact strength value of 69 J. Additions 2wt% periwinkle shell and Mangifera indica particulates significantly decreased the impact strength to 54 J and 57 J respectively. The impact strength decreased correspondingly with increasing concentrations of PSp and MIp as a result of the distribution of hard particles of the reinforcement in the matrix. Comparatively, MIp reinforced Al-12wt%Si-2wt%Mg based biocomposite recorded the highest impact strength with maximum value obtained at 2wt%MIp addition. The Al-12wt%Si-2wt%Mg based biocomposite containing hybrid of PSp and MIp recorded the least impact strength (Figs.5 and 6).

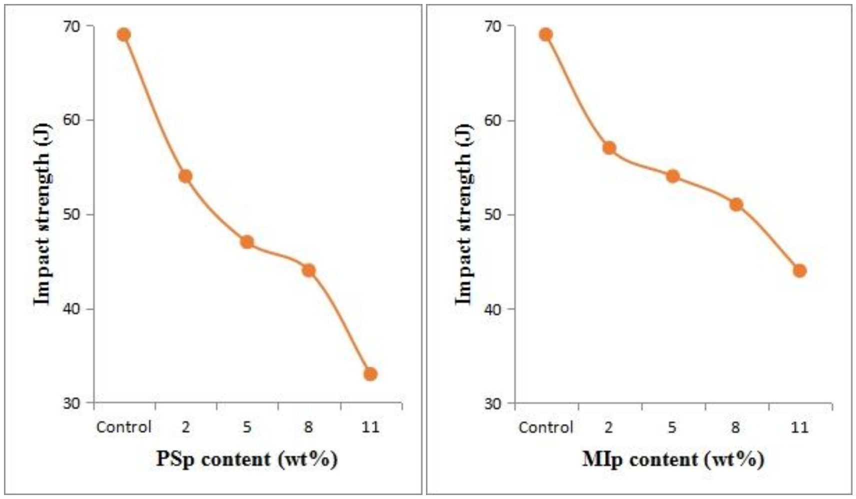

Fig. 4: Impact strength of Al-12wt%Si-2wt%Mg/PSp and Al-12wt%Si-2wt%Mg/MIp biocomposite

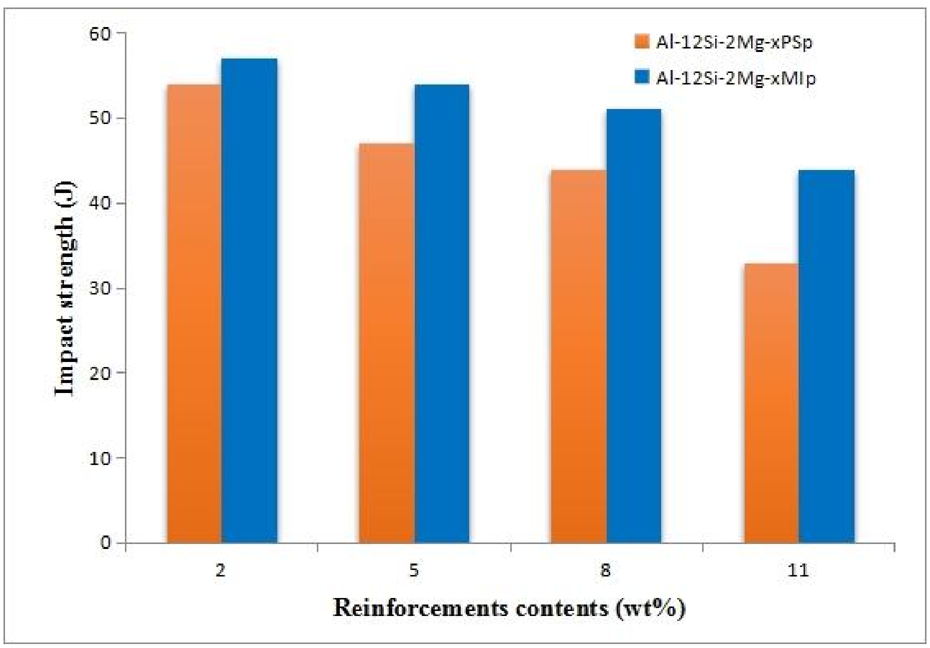

Fig. 5: Comparative effect of PSp and MIp content on the impact strength of Al-12wt%Si-2wt%Mg based biocomposite

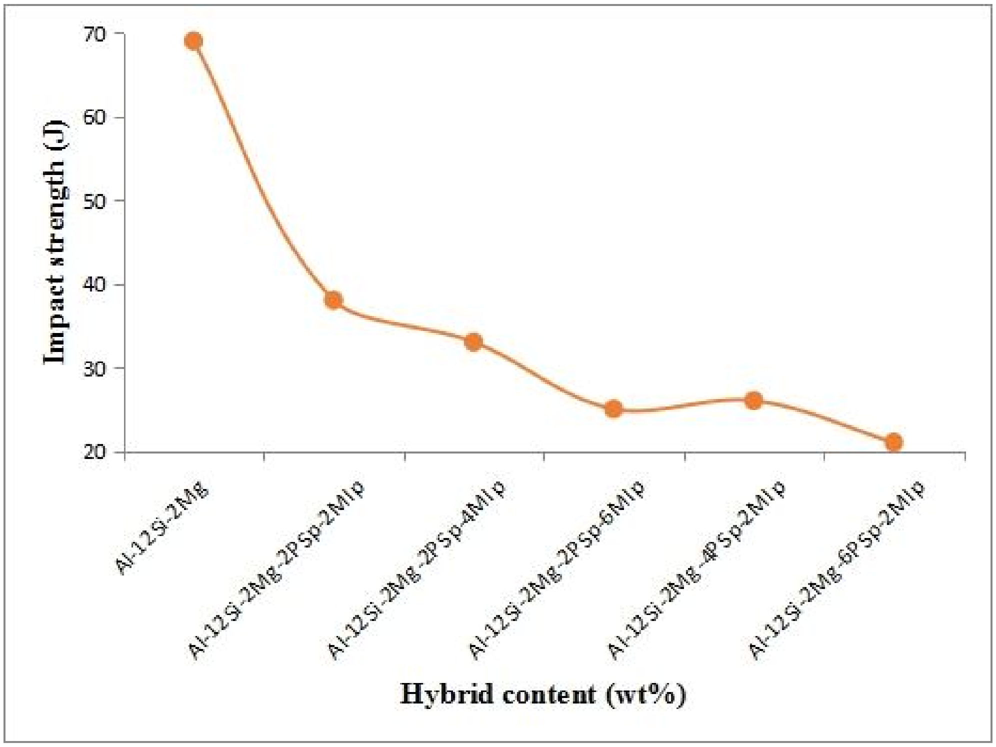

Fig. 6: Impact strength of PSp/MIp hybrid reinforced Al-12wt%Si-2wt%Mg based biocomposite

SEM microstructure of Al-12wt%Si-2wt%Mg based biocomposite:

The SEM microstructure of Al-12wt%Si-2wt%Mg alloy matrix is presented in Fig. 7. The SEM microstructure clearly reveals the solid solution region and needle-like patterns of the intermetallic compound in the alloy structure (Fig. 1.7). SEM microstructures of Al-12wt%Si-2wt%Mg-6PSp-2wt%MIp and Al-12wt%Si-2wt%Mg-2PSp-6wt%MIp biocomposites are presented in Figs. 8 and 9. The microstructures reveal adequate distributions of reinforcements' particulates in the alloy matrix, leading to increase in the ultimate tensile strength and hardness of the Al-12wt%Si-2wt%Mg based biocomposites.

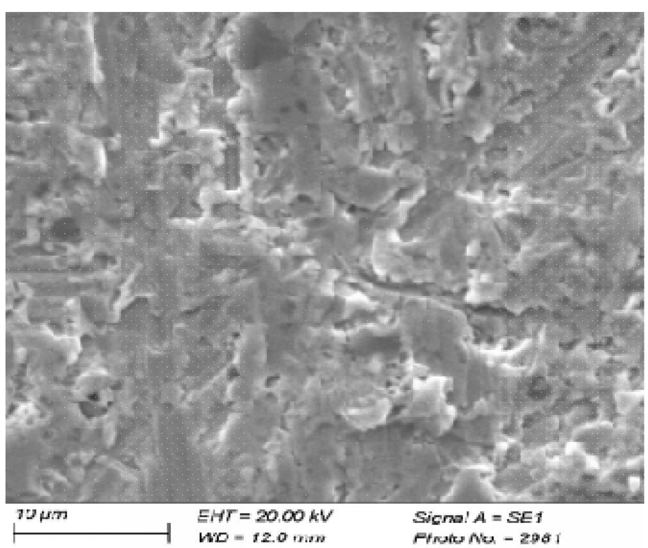

Fig. 7: SEM microstructure of Al-12wt%Si-2wt%Mg alloy matrix

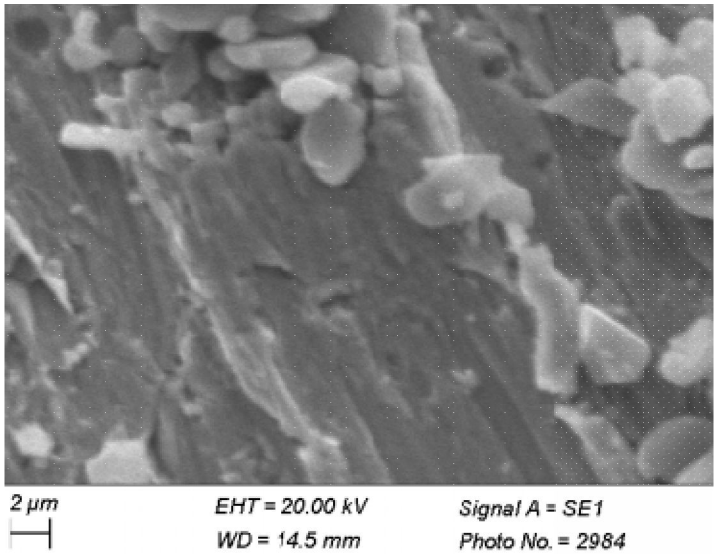

Fig. 8: SEM microstructure of Al-12wt%Si-2wt%Mg-2wt%PSp-6wt%MIp alloy matrix

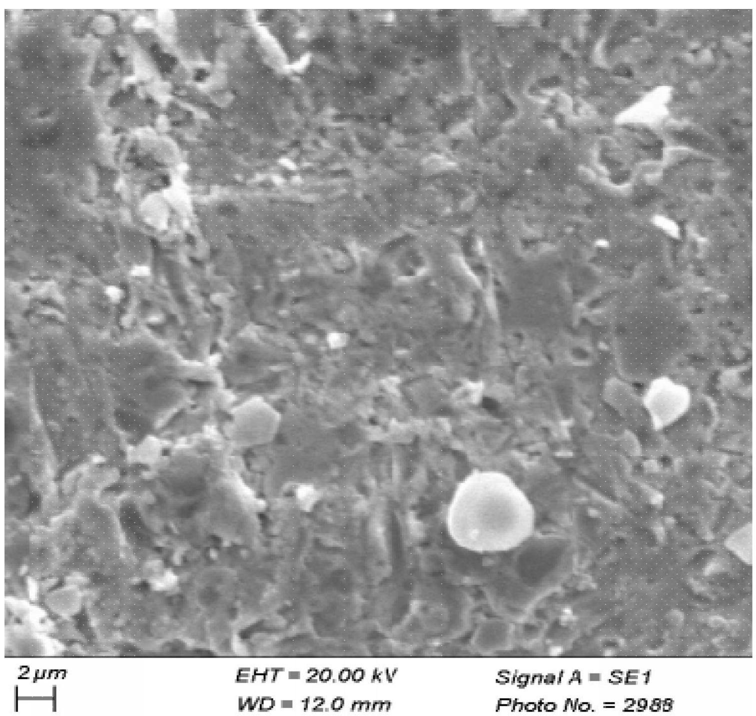

Fig. 9: SEM microstructure of Al-12wt%Si-2wt%Mg-6wt%PSp-2wt%MIp alloy matrix

IV. CONCLUSIONS

The study has investigated the effects of periwinkle shell and Mangifera indica particulates concentrations on the damage tolerance of Al-12wt%-2wt%Mg based biocomposites were explored in detail. The results of the study indicated that the developed biocomposites recorded excellent damage tolerance at different concentrations of the reinforcements. The results of the study revealed that periwinkle shell and Mangifera indica particulates significantly improved the hardness Al-12wt%-2wt%Mg alloy matrix as a result of the linked with the uniform dispersion of particles of PSp and MIp in the alloy matrix. Hybrid of PSp and MIp showed predominant effect on the hardness of the developed biocomposite with maximum value of 151 BHN obtained by Al-12wt%-2wt%Mg-6wt%PSp-2wt%MIp biocomposite. The impact strength of the Al-12wt%-2wt%Mg alloy matrix decreased drastically with increasing concentrations of reinforcements. optimal composition of Al-12wt%Si-2wt%Mg based biocomposite for optimal mechanical properties has been established. Al-12wt%Si-2wt%Mg based biocomposite with excellent hardness, and impact strength has been developed through additions of MIp. It is recommended that addition of periwinkle shell particulate to Al-12wt%Si-2wt%Mg based composite should not be more than 11wt% as it could cause a drastic decrease of damage tolerance.

References

Achebe C, Chukwuneke J, Anene F, et al., (2019). A retrofit for asbestos based brake pad employing palm kernel fiber as the base filler material. Proc Inst Mech Eng Part L J Mater Des App 2019; 233: 906–1913. 12.

Alaneme K. K., Bodunrin M. O. and Awe A. A. (2016) Microstructure, mechanical and fracture properties of groundnut shell ash and silicon carbide dispersion strengthened aluminium matrix composites. *Journal of King Saud University – Engineering Sciences*,

Ekwedigwe C, Nnakwo K, Nwambu C (2023) Viscoelastic properties of alkaline treated walnut shell/rice straw fiber/epoxy biocomposite. Journal Civil Engeering and Environmental Science 9(1): 009-013.

C Ekwedigwe, C Nwambu, F Osakwe, E Nnuka (2023) Mechanical Properties of Hybrid Rice Straw Fibre and Walnut Shell ASH Particulate/Epoxy Composite, International Journal of Science and Engineering Invention, 01-07

C Ekwedigwe, C Nwambu, E Nnuka (2023) Effects of rice straw fibre and walnut shell ash particulates on the mechanical behavior of epoxy composite, UNIZIK Journal of Engineering and Applied Sciences 1 (1), 69-77

Edoziuno, F. O., Akaluzia, R. O., Odoni, B. U., and Edibo, S. (2021). Experimental study on tribological (dry sliding wear) behaviour of polyester matrix hybrid composite reinforced with particulate wood charcoal and periwinkle shell. *Journal of King Saud University - Engineering Sciences*, *33*(5), 318–331.

Galyshev, S., and Atanov, B. (2022) The dependence of the strength of a carbon fiber/aluminum matrix composite on the interface shear strength between the matrix and fiber. *Metals*, *12*(10).

Giugliano, D., Barbera, D., and Chen, H. (2017) Effect of fiber cross section geometry on cyclic plastic behavior of continuous fiber reinforced aluminum matrix composites. *European Journal of Mechanics, A/Solids*, *61*, 35–46.

Lv, Z. zhao, Wang, J., Guo, Y. chun, Dong, S. quan, Sha, J. jun, and Cheng, X. peng. (2023) Effect of Cu coating thickness on carbon fiber surface on microstructure and mechanical properties of carbon fiber reinforced aluminum matrix composites. *Materials Today Communications*, *34*.

Neuana, N. F., de Sousa Barboza, J. C., dos Santos, E. P., and da Silva, M. L. C. P. (2021) A novel application of mangifera indica L and eugenia uniflora L extracts as antioxidants to control biodiesel oxidation stability. *Environmental Progress and Sustainable Energy*, *40*(3), 1-11.

CN Nwambu (2022) Mechanical properties of asymmetric bouligand structured carbon fibre reinforced plastics, University of Edinburgh, PhD Thesis

CN Nwambu, IM Anyaeche, TT Tsetim, EE Nnuka (2017) Physical and mechanical characterization of aluminum bronze (Cu-10% Al) alloy with tungsten, International Journal of Scientific & Engineering Research 8 (1).

EI Ilona, CN Nwambu, EE Nnuka (2016) Effect of Modification on the Structure and Mechanical Properties of Aluminium-12% Silicon Alloy, International Journal of Scientific and Engineering Research 7 (1), 471-475

Odeyemi, S. O., Abdulwahab, R., Adeniyi, A. G., and Atoyebi, O. D. (2020) Physical and mechanical properties of cement-bonded particle board produced from African balsam tree (Populous Balsamifera) and periwinkle shell residues. *Results in Engineering*, *6*. 100126.

Okafor, C. E., Kebodi, L. C., Kandasamy, J., May, M. and Ekengwu, I. E. (2022); Properties and performance index of natural fiber reinforced cross-ply composites made from dioscorea alata stem fibers; Composites Part C, Vol. 7 pp. 100213.

Oluwagbenga B. F., Joshua I. A. and Anthony A. A. (2014) 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*, 4 (4), 251-259.

Omole S. O., Akinfolarin J. F. O. and Raymond T. (2014) Assessment of hardness and tensile properties of stir-cast aluminium matrix reinforced with tetracarpidium conophorum kernel. *International Journal of Engineering and Applied Sciences*, 4 (10), 19-22.

Nwankwo E N., Nwambu C. N., Onyedikachukwu D. E., Obiorah S.M.O., (2023) Optimization of the Tensile Behaviour of Natural Fibre Reinforced Composite for Hockey Stick Application with Taguchi method. *Journal of Inventive Engineering and Technology (JIET),* Vol. 4 (2) 1-10.