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# Tensile Behaviors of Al-Si-Mg Alloy Reinforced with Periwinkle Shell and Mangifera Indica Particulates

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***Abstract:*** **Tensile behaviors 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 tensile behaviors were also investigated. The structural analysis of the developed biocomposites was done using scanning electron microscopy (SEM). The biocomposites demonstrated excellent tensile behaviors at different concentrations of the reinforcements with maximum ultimate tensile strength of 233 MPa obtained by Al-12wt%-2wt%Mg-6PSp-2wt%MIp biocomposite. The biocomposite recorded higher strength than the alloy matrix. The improvements of mechanical properties are guaranteed by the distribution of PSp and MIp particles in the alloy matrix as evidenced in the microstructural analysis.**

***Keywords:*** **Aluminum Alloy, Periwinkle shell. Mangifera Indica Particulate, Tensile behaviors.**

## 1. INTRODUCTION

Engineering materials play a significant role in industries because they serve as the raw materials which are considered first in every manufacturing process. Engineering materials are commonly classified into two types based on the constituent element (Mu et al., 2022; Gao et al., 2022;). They are as follows: ferrous and non-ferrous metals or alloys. Ferrous metals contain iron as their major constituent element (Ilona et al., 2016) The various ferrous metals used in industry are pig iron, cast iron, wrought iron and steel. Non-ferrous metals are based on some elements other than iron as the base or constituent element. They include aluminium, copper, magnesium, zinc, tin, lead, nickel and their respective alloys. Non-ferrous metals have lower melting temperature than ferrous metals (Ilona et al., 2016; Nwambu et al., 2017). They usually possess lower strength at high temperature. They generally suffer from hot shortness and their solidification shrinkage is more than that of ferrous metals.

Natural fiber composites (Bio-Composites) have emerged as a viable alternative to synthetic fiber reinforced composites especially in automotive and building product applications (Giugliano et al., 2017; Ekwedigwe et al., 2023; Galyshev and Atanov, 2022). The main trends in the development of the next generation of materials, products, and processes are principally guided by sustainability, industrial ecology, eco-efficiency, and green environment. The use of natural fibers as reinforcement for composite materials reduced the dependence on non-renewable energy/material sources, lower pollution and greenhouse emission. From the previous studies composites material reinforced with natural fibers has been found to possess better electrical resistance, chemical resistance; good thermal and acoustic insulating properties (Achebe *et al.*, 2020; Ezenwa *et al.*, 2020).

Mangifera indica, commonly known as the mango tree, is indeed a tropical fruit-bearing tree that belongs to the Anacardiaceae family (Jhaumeer et al., 2018; Tollenaere et al., 2022). It is native to South Asia, specifically India, Bangladesh, and Myanmar, but it has been introduced and is now cultivated in various tropical and subtropical regions across the globe (Kumar et al., 2021). Mango is a rich source of vitamins, minerals, and dietary fiber (Neuana et al., 2020). They also contain several antioxidants, such as beta-carotene and phenolic compounds, which help protect the body against oxidative stress and inflammation (Kumar et al., 2021).

Periwinkle shell is a waste product gotten from the consumption of small marine snail (periwinkle) which is housed in a v-shaped spiral shell and is found in many coastal communities in Nigeria (Adedipe et al., 2023). It is also available in many coastal areas worldwide and is very strong, hard and brittle material. Stretching from the Niger Delta between Calabar in the East and Badagry in the Western part of Nigeria, the people in these areas take the edible part as sea food and dispose of the shell as waste product, though a few persons use the shell as coarse aggregate in concrete in places where there are neither stones nor granite for such purposes. The shell is recently revealed as a potential reinforcing material for improving the hardness of steel and composite materials (Odeyemi *et al*., 2020; Edoziuno *et al*., 2021; Adedipe *et al*., 2023).

At elevated temperature, aluminium matrix exhibits change of structure, and consequently drastic decrease of the mechanical properties such as stiffness, hardness and strength (Nwambu *et al*., 2017). There are reasonable presumptions, that this effect can be avoided by utilization of metal matrix composite with an appropriate reinforcement structure. The widespread adoption of particulate metal matrix composites for engineering applications has been hindered by the high cost of producing components, hence the need for alternative materials. Low cost and high-quality reinforcements from industrial wastes and by-products as well as plant cellulosic materials are advised. Periwinkle shell and Mangifera Indica belong to the said plant cellulosic materials.

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 tensile behaviors of Al-12wt%Si eutectic biocomposite, hence this recent study was initiated to close the gap.

## 2. EXPERIMENTAL PROCEDURE

The analytical grades aluminium wire was sourced from Cutix Cable Plc Nnewi, Anambra State, Nigeria while silicon and magnesium powder were obtained from Bridge-Head market Onitsha, Anambra state, 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 6892-1:2016, for tensile strength test using lathe machine at Delta State Polytechnic, Ogwashi-uku. The measurement of tensile strength of the fabricated Al-12wt%-2wt%Mg based biocomposites was performed at room temperature using 100KN capacity JPL tensile strength tester in acordance to ASTM E8M standard at Cutix Plc, Nnewi, Anambra State, Nigeria. The measurement of tensile strength of the fabricated Al-12wt%-2wt%Mg based biocomposites was performed at room temperature using 100KN capacity JPL tensile strength tester in acordance to ASTM E8M standard at Cutix Plc, Nnewi, Anambra State, Nigeria. 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.

## 3. RESULTS AND DISCUSSION

Figures show the variations of percentage elongation and ultimate tensile strength of Al-12wt%Si-2wt%Mg based biocomposites with increasing concentrations of periwinkle shell particulates (PSp), Mangifera indica particulate (MIp) and their hybrids. It is noted from the figures that the tensile strength of the Al-12wt%Si-2wt%Mg matrix changed significantly with the additions of the reinforcements.

The variations of percentage elongation of Al-12wt%Si-2wt%Mg matrix with increasing concentrations of periwinkle shell particulate (PSp) and Mangifera indica particulate (MIp) are presented in Figures 1 and 2. It is shown from the Figure 1 that the aluminium alloy matrix (control) recorded a percentage elongation of 83%. This result indicates that the alloy matrix has excellent ductility in an unreinforced state. The percentage elongation dropped to 41% and 56% after additions of 2wt% PSp and 2wt%MIp respectively. This behavior can be associated with the dispersion of PSp and MIp particulates in the alloy matrix. Figures 1 and 2 show that the percentage elongation decreased correspondingly with increasing concentrations of PSp and MIp. The percentage elongation of the aluminium alloy matrix decreased from 83% to 18% and 23% after being reinforced with 11wt% PSp and 11wt%MIp respectively. This can be attributed to increase in dispersion of hard particulates of the reinforcements in the alloy matrix as evidenced in the microstructures of the developed biocomposites.

Figures 3 and 4 show the comparative effects of PSp and MIp, and hybrid concentrations on the percentage elongation of Al-12wt%Si-2wt%Mg alloy matrix. It is noted from Figures 3 that MIp reinforced Al-12wt%Si-2wt%Mg based biocomposite recorded higher values of percentage elongation. The hybrid reinforced Al-12wt%Si-2wt%Mg based biocomposites recorded lowest percentage elongation values.

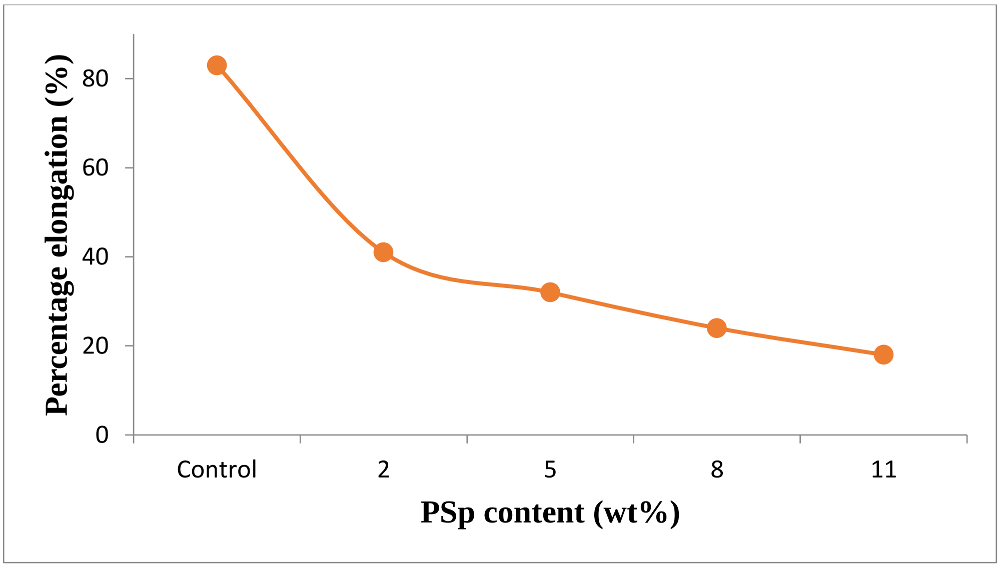


**Figure 1: Percentage elongation of Al-12wt%Si-2wt%Mg/PSp biocomposite**

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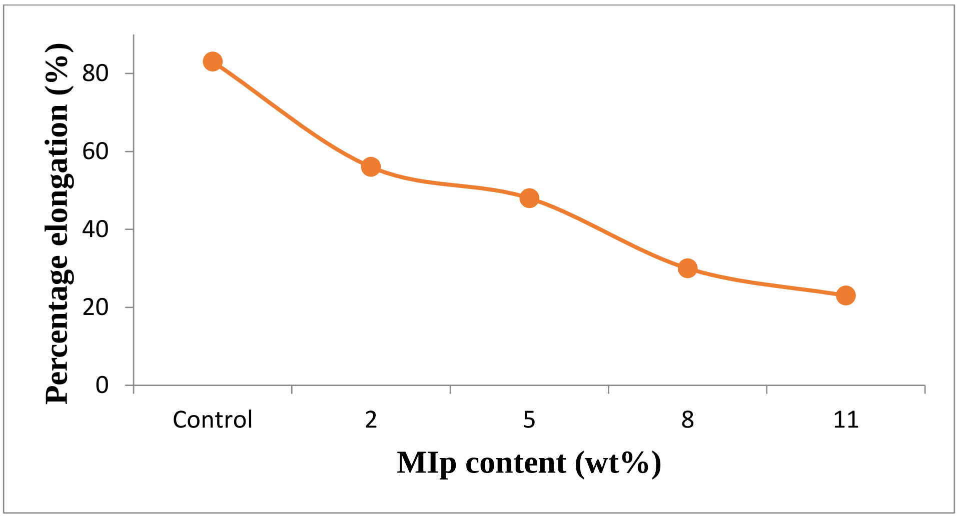


**Figure 2: Percentage elongation of Al-12wt%Si-2wt%Mg/MIp biocomposite**

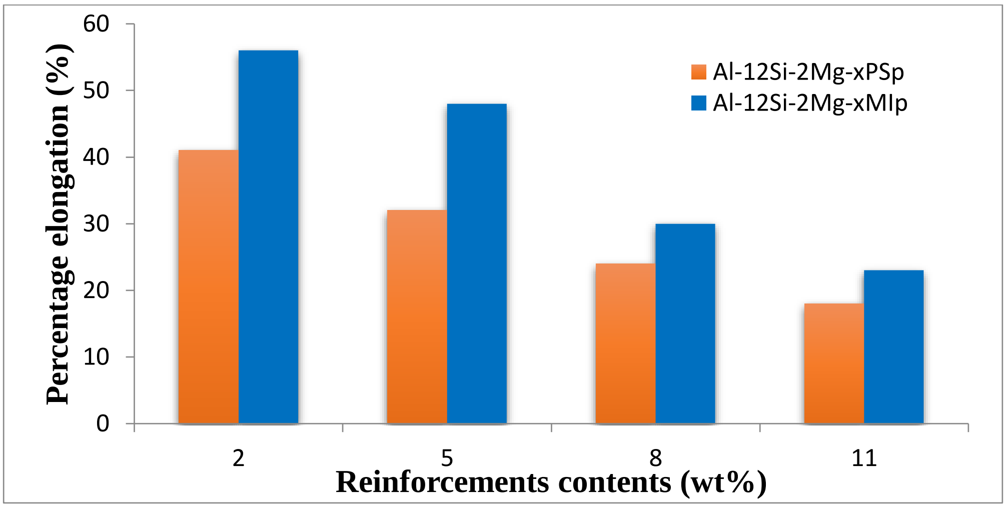


**Figure 3: Comparative effect of PSp and MIp content on the percentage elongation of Al-12wt%Si-2wt%Mg based biocomposite**

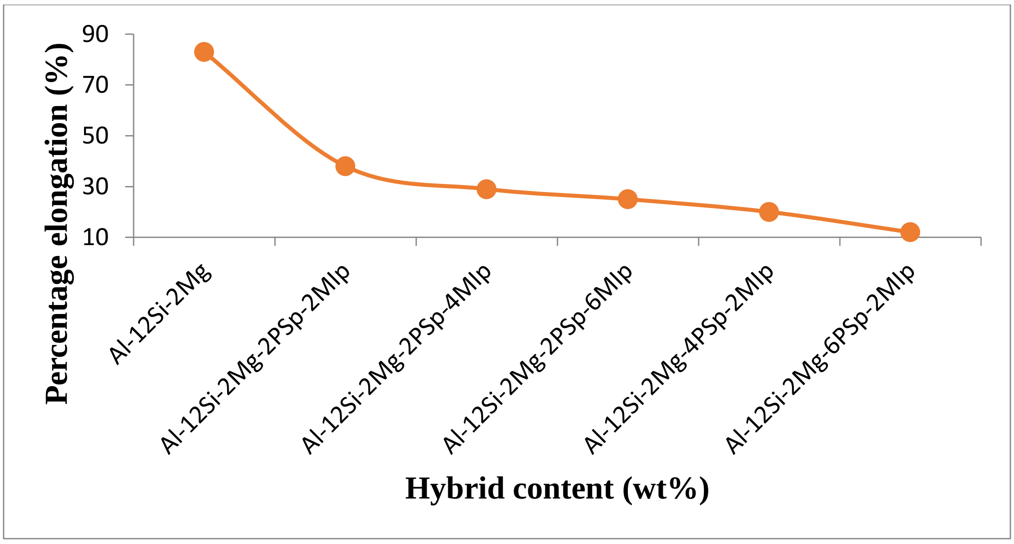


**Figure 4: Percentage elongation of PSp/MIp hybrid reinforced Al-12wt%Si-2wt%Mg based biocomposite**

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**The** effects of periwinkle shell and Mangifera indica particulates on the ultimate tensile strength of Al-12wt%Si-2wt%Mg alloy matrix are presented in Figures 5 and 6. They show significant changes in the ultimate tensile strength of Al-12wt%Si-2wt%Mg alloy matrix at varying concentrations of periwinkle shell and Mangifera indica particulates. The Al-12wt%Si-2wt%Mg alloy matrix recorded an ultimate tensile strength value of 108 MPa. The ultimate tensile strength increased to 143 MPa and 138 MPa after adding 2wt% PSp and 2wt% MIp respectively to the matrix. These significant improvements can be linked to the clustering of reinforcement particles in the alloy matrix as shown in microstructural analysis. The periwinkle shell particulate showed maximum effect on the ultimate tensile strength of Al-12wt%Si-2wt%Mg alloy matrix at 8wt% concentration, with maximum values of 213 MPa. Further increase in the concentration of PSp to 11wt% led to a decrease in the ultimate tensile strength by ≈3.4%. This can be associated with the increasing distribution of hard but brittle particles of PSp in the alloy matrix. Mangifera Indica particulate showed a different effect on the ultimate tensile strength of the Al-12wt%Si-2wt%Mg alloy matrix. The ultimate tensile strength of the Al-12wt%Si-2wt%Mg based biocomposites increased correspondingly with increase in the concentration of MIp up to 11wt%.

Figures 7 and 8 show the comparative effects of PSp and MIp concentrations and PSp/MIp hybrid on the ultimate tensile strength of Al-12wt%Si-2wt%Mg based biocomposites. Comparatively, the hybrid showed a predominant effect on the ultimate tensile strength of the developed composite, with Al-12wt%Si-2wt%Mg-6wt%PSp-2wt%MIp biocomposite recording the highest value of 233 MPa.

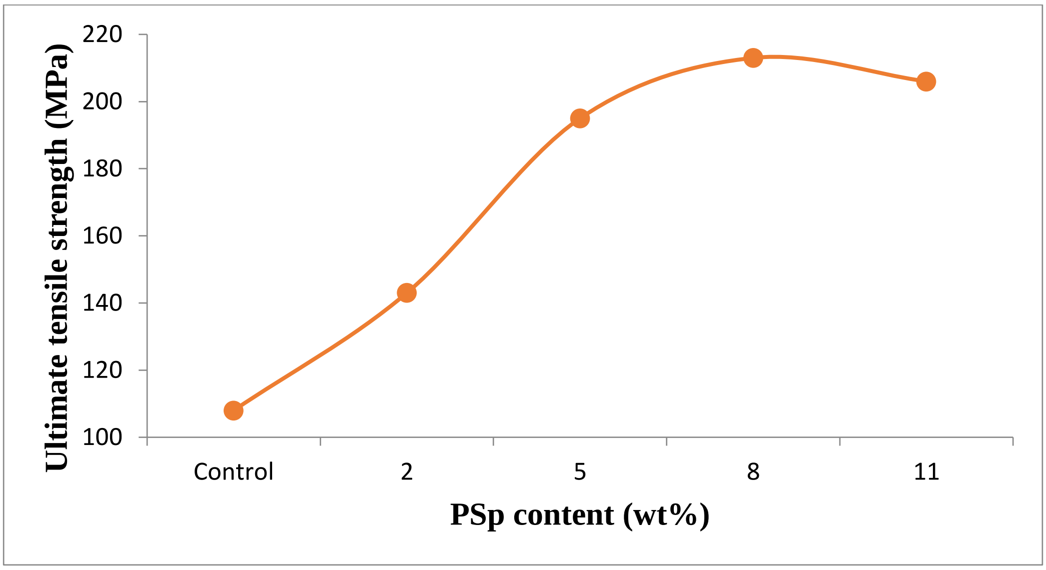


**Figure 5: Ultimate tensile strength of Al-12wt%Si-2wt%Mg/PSp biocomposite**

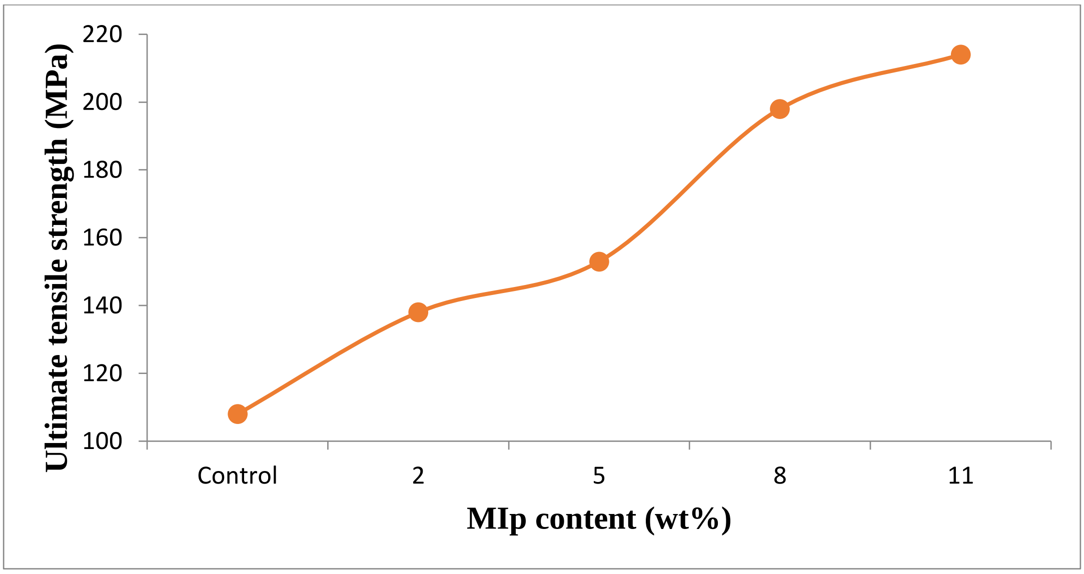


**Figure 6: Ultimate tensile strength of Al-12wt%Si-2wt%Mg/MIp biocomposite**

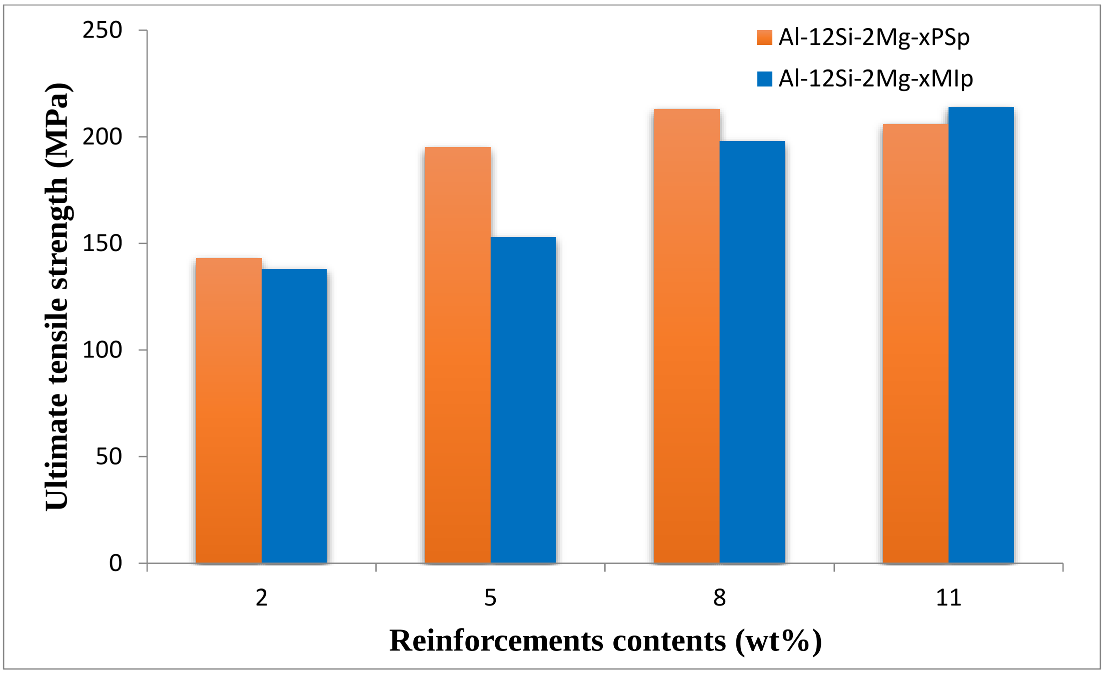


**Figure 7: Comparative effect of PSp and MIp content on the ultimate tensile strength of Al-12wt%Si-2wt%Mg based biocomposite**

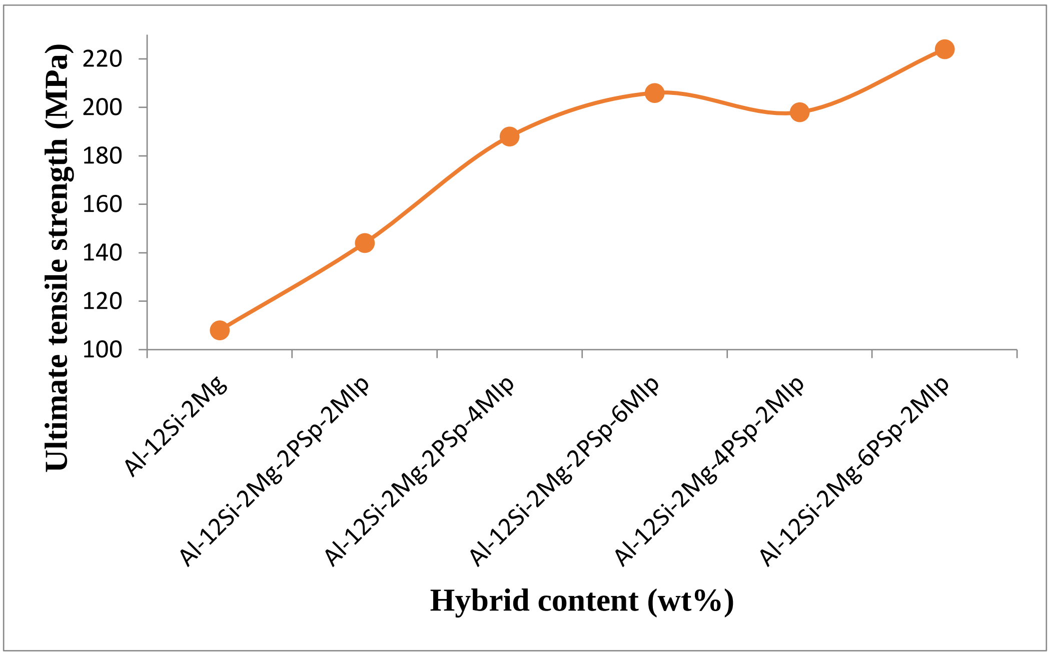


**Figure 8: Ultimate tensile strength of PSp/MIp hybrid reinforced Al-12wt%Si-2wt%Mg based biocomposite**

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

The SEM microstructure of Al-12wt%Si-2wt%Mg alloy matrix is presented in Figure 9. The SEM microstructure clearly reveals the solid solution region and needle-like patterns of the intermetallic compound in the alloy structure (Figure 9). SEM microstructures of Al-12wt%Si-2wt%Mg-6PSp-2wt%MIp and Al-12wt%Si-2wt%Mg-2PSp-6wt%MIp biocomposites are presented in Figures 10 and 11. 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.

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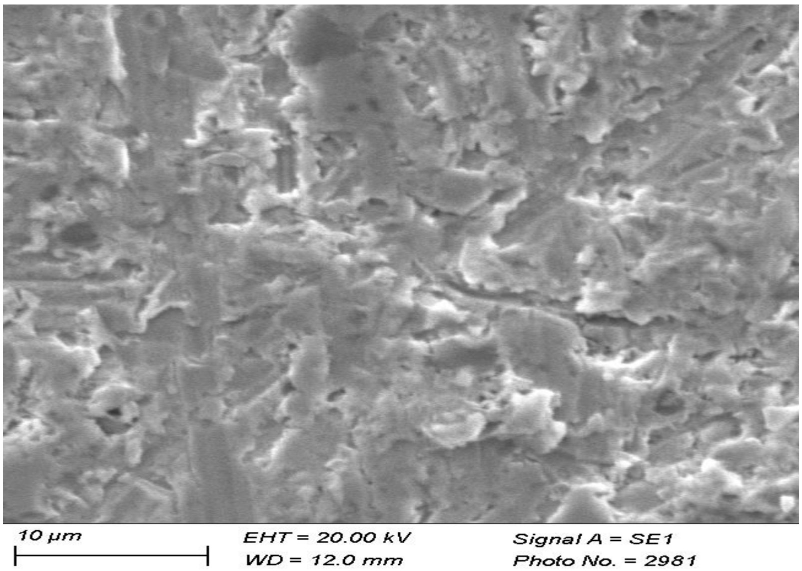


**Figure 9: SEM microstructure of Al-12wt%Si-2wt%Mg alloy matrix**

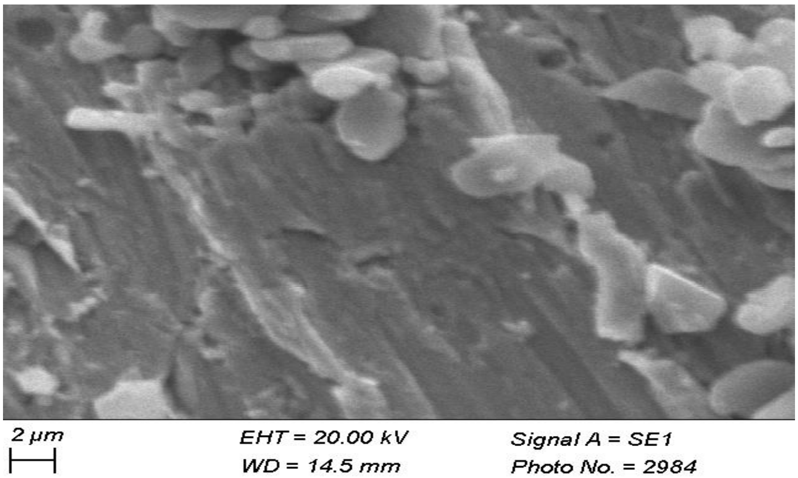


**Figure 10: SEM microstructure of Al-12wt%Si-2wt%Mg-2wt%PSp-6wt%MIp alloy matrix**

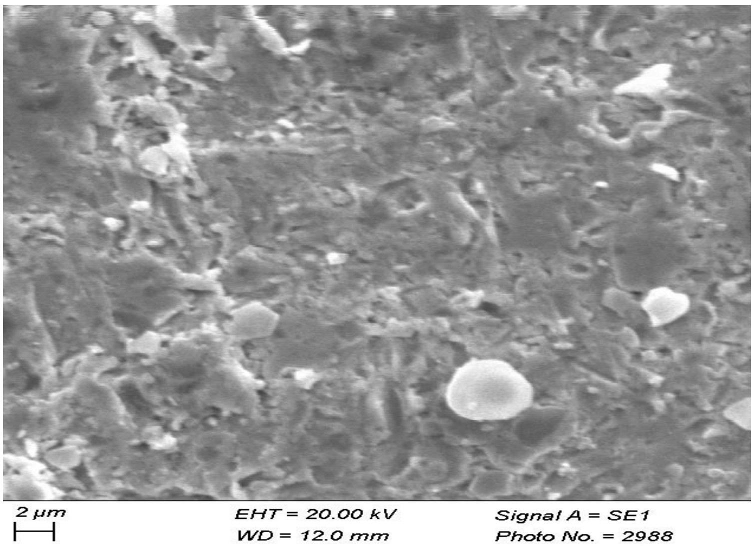


**Figure 11: SEM microstructure of Al-12wt%Si-2wt%Mg-6wt%PSp-2wt%MIp alloy matrix**

## 4. CONCLUSIONS

In this experimental study, the effects of periwinkle shell and Mangifera indica particulates concentrations on the percentage elongation, ultimate tensile strength of Al-12wt%-2wt%Mg based biocomposites were explored in detail. The effects of hybrid concentrations on the tested properties were also investigated. The results of the study indicated that the developed biocomposites recorded excellent tensile behaviors at different concentrations of the reinforcements. The results of the study can be summarized thus: Periwinkle shell and Mangifera indica particulates significantly improved the ultimate tensile strength Al-12wt%-2wt%Mg alloy matrix. These improvements are linked with the uniform dispersion of particles of PSp and MIp in the alloy matrix. The percentage elongation of the developed Al-12wt%-2wt%Mg based biocomposites composites decreased with increasing concentrations of PSp and MIp. This is associated with the distribution of hard particles of the reinforcements in the Al-alloy matrix. Hybrid of PSp and MIp showed predominant effect on the ultimate tensile strength of the developed biocomposite with maximum values of 233 MPa obtained by Al-12wt%-2wt%Mg-6wt%PSp-2wt%MIp biocomposite. Al-12wt%Si-2wt%Mg based biocomposite with excellent percentage elongation, ultimate tensile strength has been developed through additions of MIp.

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