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MECHANICAL AND WEAR BEHAVIOUR OF AL 6063 REINFORCED WITH SNAIL SHELL AND COPPER NANOPARTICLES

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Abstract: This work investigates the mechanical and wear behaviours Al 6063 reinforced with snail shell (SS) and copper nanoparticles (CuNP). The production of Al6063 alloy based composites using two step stir casting process coupled with and spin casting technique. Charge calculation was properly worked out and charged into the crucible furnace from which as-cast aluminium was obtained. The mechanical properties of the composites produced were assessed by hardness, ultimate tensile strength test and wear test. It was observed that composite reinforced with 8% of snail shell and with addition of 2% of CuNP has the highest hardness and ultimate tensile strength values while composite with 2% of snail shell and 8% CuNP has the lowest wear rate and highest wear resistance of 2.76 x 10^{-6} cm^2 and 3.63x 10^7 cm^{-2} respectively
Keywords: Copper nanoparticles; Snail shell; Al 6063 composites; Wear test; Hardness test

1. INTRODUCTION

Cu nanoparticles currently attract significant research attention owing to their widespread application in powder metallurgical materials, casting and electronic circuits. Copper nanoparticles have also been considered [1,2] as an alternative for noble metals in many applications, such as heat transfer and microelectronics [3]. The microfabrication of conductive features like ink-jet printing technology is common. So far, electronic devices have utilized noble metals like gold and silver for printing highly conductive elements.

There are various methods used to synthesize copper nanoparticles such as chemical method and physical methods. Under the chemical methods we have chemical reduction, microemulsion /colloidal method, sonochemical method, microwave method, electrochemical method, solvothermal decomposition, while under the physical methods we have Pulse laser ablation /deposition, mechanical/ball milling method, mechanochemical synthesis, Pulsed wire discharge method, Snail shell (SS) is a waste product obtained from the consumption of snail which is found in southern parts of Nigeria. The snail belongs to the phylum Mollusca and class Gastropods. The gastropods are the largest class of the phylum Mollusca [4]. The family members include:

I. Achatina achatina,
II. Achatina maginata
III. Achatina fulica and
IV. linicolarial species [5].

The main constituent of the shell is calcium carbonates. After consumption, the snail shell constitutes a problem to the environment. It is important to turn waste to wealth by using the pulverized snail shell as reinforcement in aluminium.

Composite materials has gained tremendous importance in the field of engineering in the recent Owing to the positive combination of properties such as low density, high specific strength and elastic modulus, aluminum matrix composites with designed properties are becoming increasingly widely used in the fields such as aerospace, automotive engine, electronic packaging, precision instruments and sports equipment, [6, 7, 8]. The aim of this work is to study the effect of copper nanoparticles and snail shell on mechanical and wear behaviour Al 6063 composite.

2. MATERIALS AND METHODS

The materials used for this study were pulverized snail shell (SS), Al 6063 alloy which was used as the matrix was purchased at NIGALEX PLC., Lagos, Nigeria and synthesized copper nanoparticles of particle size 500nm. The chemical compositions of snail shell particles and Al-Mg-Si alloy are shown in Tables 1 and 2 respectively.

Table 1: Chemical Composition of snail shell using XRF

Compound	Al_2O_3	CaO	SiO_2	Mn_2O	Fe_2O_4	Cr_2O_3	TiO_2	CuO
% conc	0.30	97.06	1.54	0.34	0.64	0.04	0.06	0.002

Table 2: Chemical Composition of Al 6063

Element	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
Wt %	0.40	0.24	0.03	0.04	0.55	0.03	0.01	0.02	98.68

Table 3: Elemental analysis of weight percentage of CuNP

Element	O	Cu
Wt %	4.51	95.49

— Snail shell preparation

The snail shells as shown in Figure 1 were obtained from a disposal site around riverine areas in Alagbado, Lagos State, Nigeria. The snail shells were washed with water to remove the dirt then broken into smaller pieces. These were then milled by using the ball mill to pulverize the snail shell after which it was sieved to particle size < 75 μm as shown in Figure 2 using sieve shaker.

Figure 1. Snail shell (SS)

Figure 2. Pulverized snail shell (SS)

— Composite production

The various proportions of pulverized snail shell (SS) and copper nanoparticles (CuNP) were determined and double stir casting process was used. The Al6063 alloy ingots were charged into the crucible furnace and allowed to melt completely at 750^{0}C ± 30^{0}C. At 600^{0}C, the preheated pulverized snail shell was charged into the aluminium melt also charged was copper nanoparticles and stir manually for 5 minutes, allowed the composite mixture to super heat above the liquous and stir mechanically for 10 minutes before casting [9]. The sample designation was shown in Table 3. The masses of the composites as well as the control sample were as shown in Table 4.

Table 3: Sample designation

Designation	Al6063	Snail shell (SS)	CuNP
A	90%	8%	2%
B	90%	6%	4%
C	90%	2%	8%
Control	100%	-	-

Table 4: Mass of sample constituents (g)

Designation	Al6063 (g)	Snail shell (g)	CuNP (g)
A	282.597	25.12	6.27
B	295.101	19.67	13.11
C	319.97	2.951	28.44
Control	300	-	-

— Density Measurement

The determination of the experimental densities of the various casting products were carried out measuring the weight of the test samples using a high precision electronic weighing balance with a tolerance of 0.1mg. The weights of the measured samples were divided by their respective volume. The theoretical density was evaluated by using the rule of mixtures given by:

$$\rho Al6063 / SS / CuNP = Vol.\ Al\ 6063 \times \rho Al6063 + Vol.\ SS \times \rho SS + Vol.\ CuNP \times \rho CuNP$$

where: ρ Al6063 = Density of Al6063, Vol. Al 6063 = Volume fraction of Al 6063, Vol. SS = Volume fraction SS, ρSS = Density of SS, Vol. CuNP = Volume fraction of CuNP and ρCuNP = Density of CuNP.

$$\text{Experimental density} = \frac{\text{mass of the sample}}{\text{volume of the sample}} \qquad (1)$$

The percentage porosity of the cast aluminium was determined by use of equation

$$\%\ \text{Volume porosity} = \frac{\rho cal - \rho exp}{\rho cal} \qquad (2)$$

where ρ_{cal} = theoretical density (g/cm^3), ρ_{exp} = experimental density (g/cm^3) [10, 11]

— Mechanical testing

The test samples were machined from the as-cast composite rods using lathe machine for hardness, tensile and wear tests specimens following standard procedures.

— Hardness test

The hardness test in accordance with the specification of ASTM E-384 standard [12] was conducted on the prepared composite samples. The hardness of the composites was measured by applying a direct load of 120 kgf for 10 seconds on flat smoothly polished plane parallel specimens of the composites. Multiple hardness tests of five measurements were performed on each sample and the average value was taken as a measure of the hardness of the specimen within the tolerance of ± 2%.

— Tensile test

Tensile tests were performed on the composites produced following standard procedures in accordance with ASTM E8M-15a standard [13]. The samples for the test were machined to dimensions of 6mm diameter and 30 mm gauge length. The test was performed at room temperature using an Instron universal testing machine which was operated at 10^{-3} s^{-1} strain rate. The tensile property evaluated from the tensile test was ultimate tensile strength.

— Wear test

The wear test of the composites was performed using a Pin on disc wear testing machine in accordance with ASTM G99-04a standard [14]. The wear test entailed mounting disc shaped prepared samples having 200 mm diameter and 5 mm thick on the turntable platform of the wear machine. The samples were gripped at a constant pressure by two abrasive wheels lowered onto the sample surface. The turntable rotates with the samples which drive the abrasive wheels in contact with its surface. The rubbing action between the sample and the abrasive wheel generates loose composite wear debris as the rotating motion continues on the machine. The test was conducted for 15 min; and the sample weights before and after the tests recorded.

3. RESULTS AND DISCUSSION

— Porosity

The theoretical, experimental densities and percentage porosity is shown in Figure 4. It was observed that composition B has the highest level of porosity value when compared with other composite samples. This may be as a result of gas entrapment during stirring period.

It was also observed that the porosity of the composites is less than 2%, this may be attributed to the rotational movement of the spin casting machine which allows escape of gasses during casting operation. There was an increase in the theoretical density of the composites despite the fact that the density of snail shell was lesser than the density of Al6063, which was 1.63 g/cm^3. The density of CuNP which was 8.9 g/cm^3 led to the increase in the density of the composites.

Table 4. Theoretical and experimental densities of composites with percentage porosity

Designation	Theoretical density (g/cm^3)	Experimental density(g/cm^3)	Porosity (%)
A	2.820	2.780	1.42
B	2.940	2.890	1.70
C	3.200	3.170	0.94
Control	2.700	2.690	0.37

— Mechanical properties

≡ Hardness

The hardness value of Al6063 alloy and its composites is shown in Figure 3. It was observed that the hardness of the composites were more than that of the unreinforced Al6063 alloy while the composite reinforced with 8% of snail shell and with addition of 2% of CuNP has the highest hardness value, this highest hardness value can be attributed to the higher volume fraction of snail shell coupled with CuNP which created a severe strain fields around the Al6063 which impede the motion of dislocations and thereby causing increased hardness [15]. As the volume fraction of snail shell reduced to 6% and CuNP increased to 4%, there was drop in the hardness value.

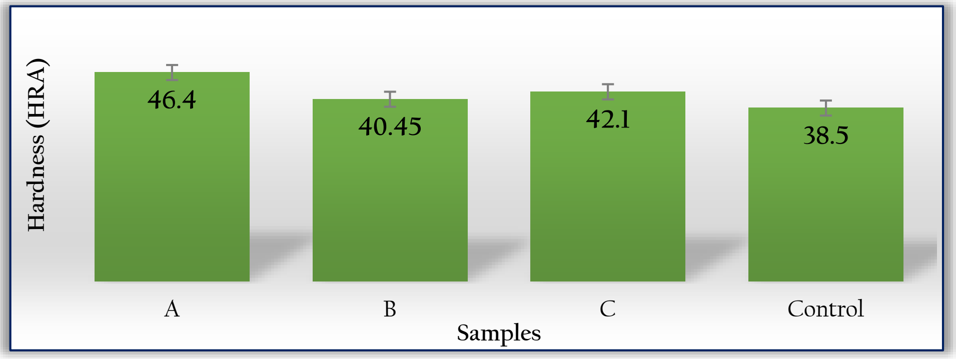

Figure 3. Hardness value of Al6063 alloy and its composites

≡ Ultimate Tensile Strength (UTS)

The tensile strength results of the aluminium composite samples produced is shown in Figure 4. It was observed that composition A have highest ultimate tensile strength than the other composites and the control. Also composition C is higher than the composition B. The reduction in strength of the composites suggests an agglomeration of the reinforcing particles which is caused as a result of increase in volume fraction of CuNP, as nanoparticles has high surface area to volume ratio.

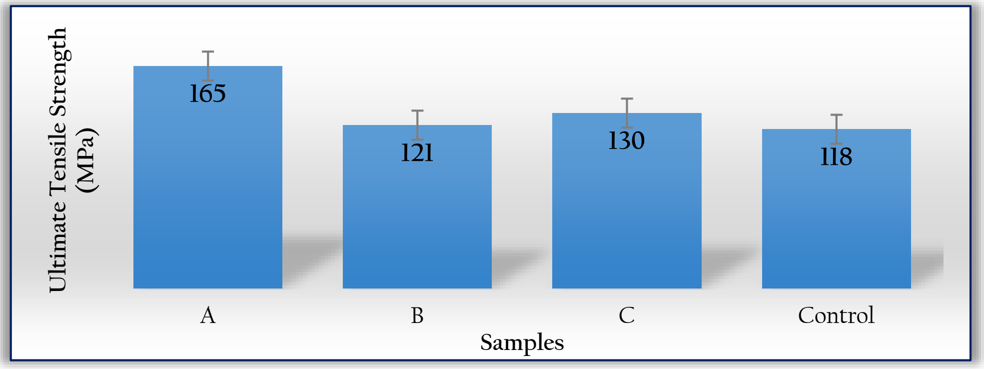

Figure 4. Ultimate tensile strength value of Al6063 alloy and its composites

≡ Wear

From Figure 5 and 6, it shows that the control sample had the highest mass loss and wear volume of 0.12g and 0.01558 cm^3 respectively while sample C had the lowest mass loss and wear volume of 0.08g and 0.01039 cm^3 respectively. As the percentage fraction of CuNP increases and snail shell reduces, mass loss tends to reduce. This may be attributed to CuNP being nanometal solid lubricant.

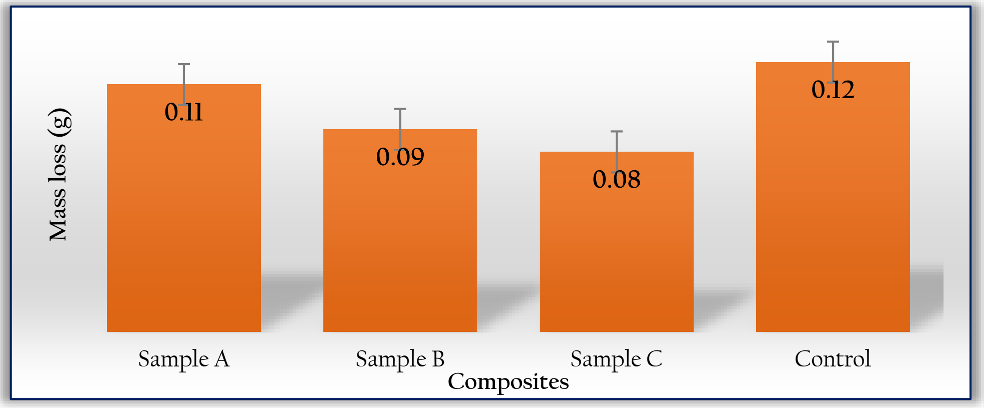

Figure 5. Wear value of Al6063 alloy and its composites

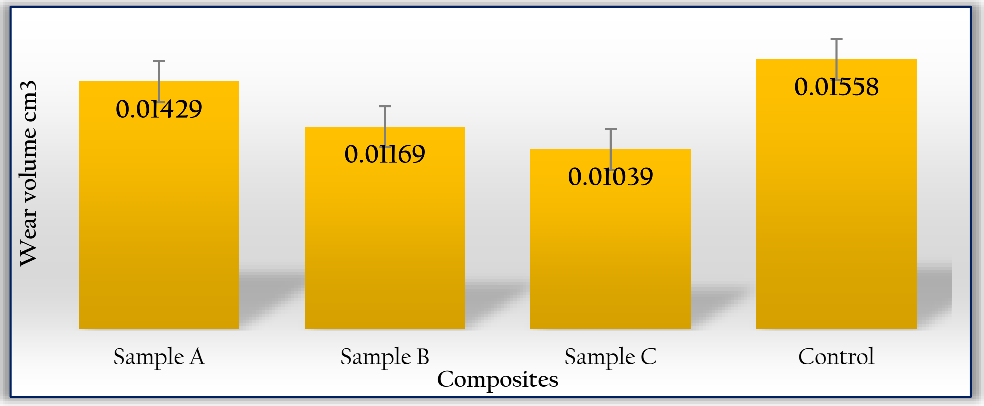

Figure 6. Wear volume value of Al6063 alloy and its composites

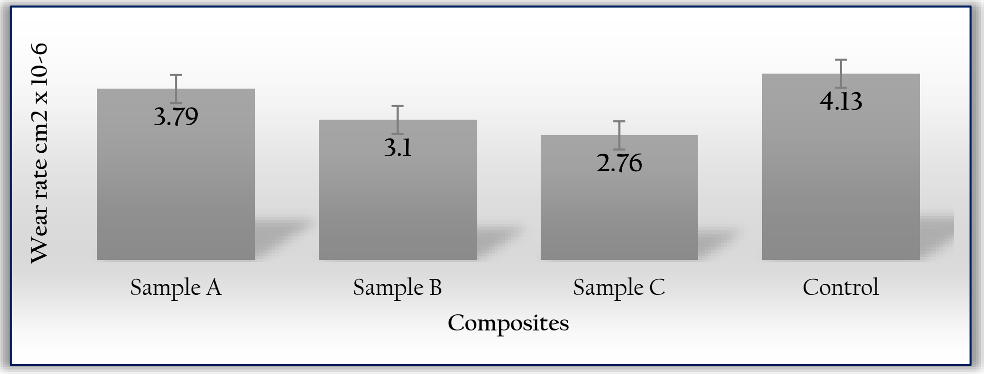

Figure 7. Wear rate value of Al6063 alloy and its composites

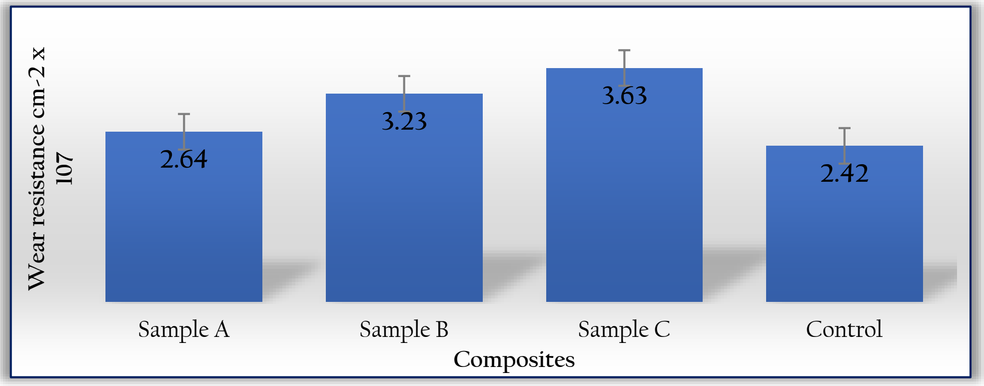

Figure 8. Wear resistance value of Al6063 alloy and its composites

From Figure 7 and 8, it shows that the higher the wear rate, the lower the wear resistance and the lower the wear rate, the higher the wear resistance, these explained the relationship. From Figure 7 and 8, the controlled sample had the highest wear rate and lowest wear resistance of 4.13 x 10^{-6} cm^2 and 2.42 x 10^7 cm^{-2} respectively while sample C had the lowest wear rate and highest wear resistance of 2.76 x 10^{-6} cm^2 and 3.63 x 10^7 cm^{-2} respectively.

4. CONCLUSIONS

The effect of copper nanoparticles on Al 6063 metal matrix composite reinforced with Snail Shell was investigated. From the results obtained, the following conclusions were drawn:

- The production of Al6063 alloy based composites using two step stir casting process coupled with and spin casting technique has a low porosity (< 2%).
- The composite A reinforced with 8% of snail shell and with addition of 2% of CuNP has the highest hardness value. It was observed that composition A have highest ultimate tensile strength than the other composites and the control.
- Sample C has the lowest wear rate and highest wear resistance of 2.76 x 10^{-6} cm^2 and 3.63x 10^7 cm^{-2} respectively.

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