American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-3, pp-186-192
www.ajer.org
Research Paper Open Access

Wear behaviour of Al6063 Alloy Based Reinforced with Graphite-Rice Husk Ash-Copper Nanopaticles

[1]Talabi Henry K., [1]Adewuyi Benjamin O., [1]Olaniran O., [1] Oladele Isiaka O.
[1]*Metallurgical and Materials Engineering Department, Federal University of Technology, PMB 704, Akure, Ondo State, Nigeria.*

ABSTRACT: *Al6063 alloy based reinforced with graphite-rice husk ash-copper nanopaticles was investigated. The weight percent of graphite and rice husk ash were fixed while copper nanoparticles was varied from 1 to 4 % and were produced using double-stir casting method coupled with spin casting technique was used for the composite. As copper nanoparticles in the composite increases, the porosity reduces and the density increases. The low porosity level was attributed primarily to double-stir casting method coupled with spin casting technique. It was found that addition of copper nanoparticle increased the wear resistance which resulted in low wear rate when compared with unreinforced aluminium alloy. As copper nanoparticles in aluminium hybrid reinforced composite increases so also the wear rate reduces.*

Keywords: *Copper nanoparticles; Composite; Wear; Reinforced; Casting.*

Date of Submission: 25-02-2020 Date of acceptance:08-03-2020

I. INTRODUCTION

In many engineering applications, metal matrix composites (MMCs) are preferred to pure metals, due to the fact that the mechanical properties of composites can be controlled to a greater degree. Metal matrix composites (MMCs) possess improved properties such as high specific strength; specific modulus, damping capacity and better wear resistance compared to unreinforced metal. Aluminum matrix composites (AMCs) remain an exciting class of metal matrix composites which is still stimulating interest among researchers because of its suitability for vast conventional and emerging technological applications also areas of Al based composites applications is expected to continue growing, this is possible by virtue of the attractive property spectrum possessed by AMCs and the relative low cost of production in comparison with other competing MMCs (such as Magnesium, Copper, Titanium and Zinc) for similar applications (Surappa, 2003). Some of the core areas were AMCs have successfully been used in aerospace industry, defence industry, automotive industry, and marine industry (Lee et al., 2012; Alidokht et al., 2011; Zhang et al., 2014). The reliability of AMCs in several applications arises from the attractive combination of properties such as high specific strength, low density, high specific stiffness, high elastic modulus, good wear resistance among others (; Zhang et al., 2014; Wang et al., 2014). These outstanding properties of AMCs can be further optimized by selecting suitable process parameters and reinforcement materials. Aluminium matrix composites (AMCs) reinforced with ceramic particles exhibit high strength, high elastic modulus and improved resistance to wear, creep and fatigue compared to unreinforced metals that make them promising structural materials for aerospace and automobile industries (Rana et al., 2012; Narula et al., 1996; Maruyama, 1998; Anandkumar et al., 2012; Shabani and Mazahery, 2013; Anandkumar et al., 2007; Gingu et al., 1999; Torralba et al., 2003; Mazahery and Shabani, 2012). There are lot of researches in the area of use of derivatives alternative from agro-waste and industrial by products have emphasized the advantages of the derivatives over traditional ceramic reinforcement materials (Lancaster et al., 2013; Arora and Sharma, 2017). 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 (Hoover et al., 2006; Niu and Crooks, 2003) as an alternative for noble metals in many applications, such as heat transfer and microelectronics (Eastman et al., 2001; Talabi et al., 2019). With recent advances in producing nanoparticles such as copper nanoparticles, it is expected that significant improvements can result from the incorporation of nanoparticles in metals to further enhance the properties obtained most especially the wear. The tribological behaviour of copper nanoparticles suspended in oil has been investigated experimentally by researchers. The friction coefficient for raw oil and nano-oil mixed with copper nanoparticles was investigated by (Choi et al., 2009) using a disc-on-disc tribotester between mixed and full-film lubrication regime and it was found that the nano-oil mixed with copper nanoparticles has a lower friction coefficient and less wear on the friction surface, indicating that copper nanoparticles improve the lubrication properties of raw oil. The aim of this work is to incorporate copper nanoparticles into aluminium composite.

II. EXPERIMENTAL PROCEDURE

Materials

The aluminium 6063 alloy was sourced from Tower Aluminium Ota in Ogun, Nigeria is presented in Table 1, while graphite was procured and copper nanoparticles (40 nm) was synthesized

Table 1. Chemical Composition of Aluminum Alloy 6063.

Element	Si	Mg	Fe	Mn	Cr	Zn	Ti	Al
(%) composition	0.48	0.86	0.46	0.9	0.04	0.005	0.01	98.82

Experimental

Production of Composites

The composites were produced via a two-step stir casting technique described by Talabi et al., (2019) and Alaneme and Aluko (2012) coupled with spin casting method. This involves carrying out charge calculation to determine the quantities of rice husk ash, graphite and copper nanoparticles needed to produce aluminium based composites. Weight ratios of mixed rice husk ash, graphite and copper nanoparticles reinforcing phase produced are shown in Table 2. Preheating of the RHA and graphite was done before adding to the melt to reduce dampness of the reinforcing materials and to improve wettability. Aluminium 6063 alloy was charged and heated in a gas fired crucible furnace to a temperature of 750°C above the liquidus. The liquid aluminium alloy was then allowed to cool down to a semi-solid state at about 600°C. At this stage, the preheated RHA, and graphite was introduced into the molten alloy with CuNP and stirred manually for 5-10 minutes. The composites slurry was later superheated to a temperature of about 850°C and a second stirring was carried out mechanically for 10 minutes to improve the distribution of the reinforcing particles in the matrix. The molten composites were later poured into a prepared sand mould using spin casting machine which was set at 700 rpm to produce as-cast Al6063 alloy based composites reinforced with RHA, graphite and CuNP. Fettling operations were carried out on the produced samples and samples machined for test. The experimental density of the composites was measured by Archimedes principle. The study was evaluated using ball-on-disk tribological technique and the wear behaviour of the Al6063 and reinforced hybrid composite. ASTM G99-05 standard test method was used to carry out the dry sliding wear tests with a ball-on-disk tribometer. The relative humidity and temperature were kept constant at 50% and 25 °C, respectively. The wear studies were carried out using a CETR UMT−2 tribometer (now Bruker) with a rotary wear module. A tungsten carbide (WC) ball with 10 mm in diameter was used as a counterface rubbing against the composites. Loads of 5 N was applied at a frequency of 1 Hz corresponding to 60 rev /min. The coefficient of friction (COF) and wear were monitored carefully during the test also micrograph images of the worn surface of Al6063 alloy and reinforced hybrid composites were studied.

Table 2: Sample Designation and Reinforcement Weight Ratio

DESIGNATION	COMPOSITION
Control	Al6063 alloy
Sample A	Al6063/ 3RHA/1Gr
Sample B	Al6063/ 3RHA/1Gr/1CuNP
Sample C	Al6063/ 3RHA/1Gr/2CuNP
Sample D	Al6063/ 3RHA/1Gr/3CuNP
Sample E	Al6063/ 3RHA/1Gr/4CuNP

III. RESULTS AND DISCUSSION

Microstructure Examination

Figure 1 shows representative optical micrographs of Aluminium hybrid composites reinforced with RHA, graphite and CuNP. It was observed that the reinforcements were uniformly distributed without clustering in the alloy matrix which revealed that the quality of the cast was good.

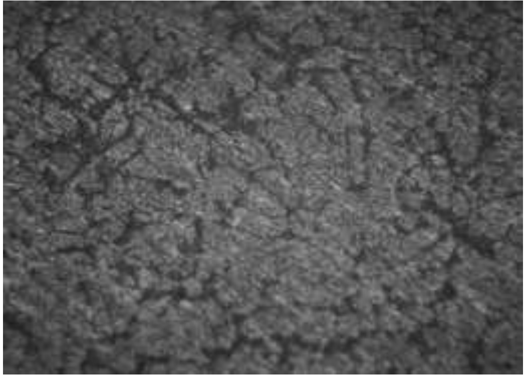

Figure 1: Photomicrograph of Al6063/ 3RHA/1Gr/3CuNP

Density Measurement

The measured density values by Experimental and Theoretical density for composites were compared and presented in Figure 2. It shows that sample A (Al6063/ 3wt%RHA/ 1wt% Graphite) with experimental density of 2.560 g/cm^3 and theoretical density of 2.611 g/cm^3 has the least experimental and theoretical density lower than the base material (Al6063), followed by sample B (Al6063/ 3wt%RHA/ 1wt% Graphite/ 1wt% CuNP) with 2.695 g/cm^3 and 2.734 g/cm^3 values respectively. The addition of copper nanoparticles to sample B led to the increase of sample densities. The density of sample C, D and E increases with increase in weight percent of copper nanoparticles added to the composites, this is as a result of copper nanoparticles density (8.9 g/cm^3) higher than other reinforcing materials. From Figure 2, it can clearly be seen that the experimental and the theoretical density values were close and this confirms the suitability of double stir casting and spin casting techniques for composite preparation.

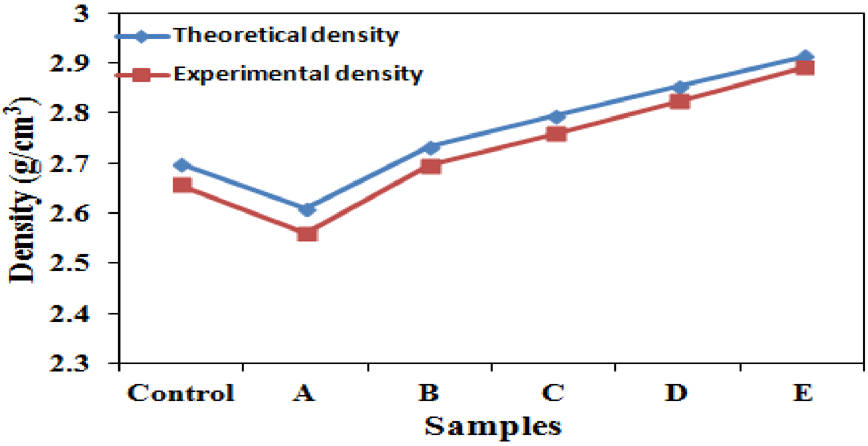

Figure 2: Density of the developed composites and the control sample

Porosity Measurement

Figure 3 shows the porosity values for the developed hybrid composites. From the results, it was observed that the sample E has the lowest level of porosity while sample A has the highest value of porosity of all the developed composites. As copper nanoparticles in the composite increases, the porosity reduces and the density increases. The low porosity level is attributed primarily to the two-step stirring process adopted for producing the composites so also the casting technique (spin casting). 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, this also reduce particles agglomeration (Talabi et al., 2019). The manual mixing operation performed in the semi-solid state helps to break the surface tension between the Al6063 melt and the particulates. This facilitates easier wetting and mixing of the particulates in the melt

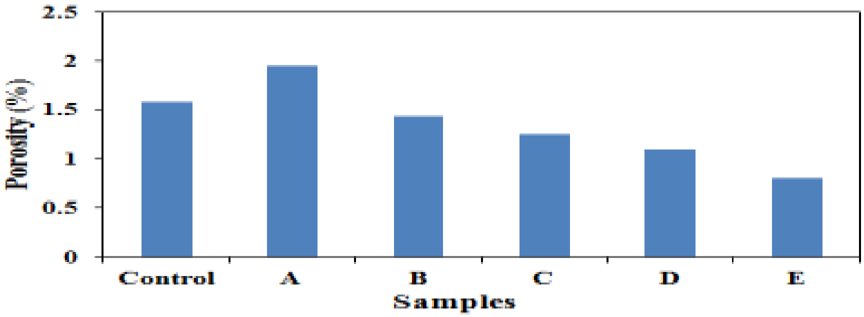

Figure 3: Porosity of the developed composites and the control sample

Wear volume and wear rate

The result of Wear volume for control and developed hybrid composites with load of 5 N was presented in Figure 4. With unreinforced aluminium alloy having the highest wear volume of 0.001481481 mm^3. The result of Wear resistance for control and developed hybrid composites with load of 5 N was presented in Figure 5. Wear resistance of composite materials reinforced with RHA and graphite in sample A increases as compared to the control, which means the wear rate reduces. With the addition of CuNP into the composite, the wear rate reduces. It was observed in Tables 3 and 4, as the weight loss increases so also the wear volume.

It was observed that composite E has the superior wear resistance in comparison with unreinforced aluminium alloy and other composites. The unreinforced aluminium alloy was noticed to exhibit greatest wear susceptibility of wear resistance 2.09826E-07 m^3/m which was followed by composite A. The increase in weight percent of copper particles from 1wt % to 4wt % respectively was responsible for continuous increase in wear resistance of the developed hybrid reinforced composites, since it acts as solid lubricant also with present graphite, they makes a tinny layer between the copulating surfaces, this helps in decrease of metal to metal interaction. Similar result was obtained by Baradeswaran and Perumal, (2014) when they investigated wear and mechanical characteristics of Al 7075/graphite composites.

Table 3: Weight loss values before and after wear for 5 N load

Samples	Weight before Wear W_0 (g)	Weight after Wear W_1 (g) 5 N	Weight loss (W_0-W_1) 5N
Control	5.0201	5.0161	0.0040
Sample A	4.5644	4.5606	0.0038
Sample B	5.0211	5.0182	0.0029
Sample C	3.6329	3.6307	0.0022
Sample D	3.9719	3.9699	0.0020
Sample E	3.6766	3.6749	0.0017

Table 4: Calculated wear volume and wear rates for 5 N load

Sample	Wear Vol (mm^3) 5N	Wear rate (m_3/m) 5 N
Control	0.001481481	2.09826E-07
Sample A	0.001455381	1.77765E-07
Sample B	0.001060717	1.69768E-07
Sample C	0.000787402	1.53907E-07
Sample D	0.000700771	1.26755E-07
Sample E	0.000583391	1.17118E-07

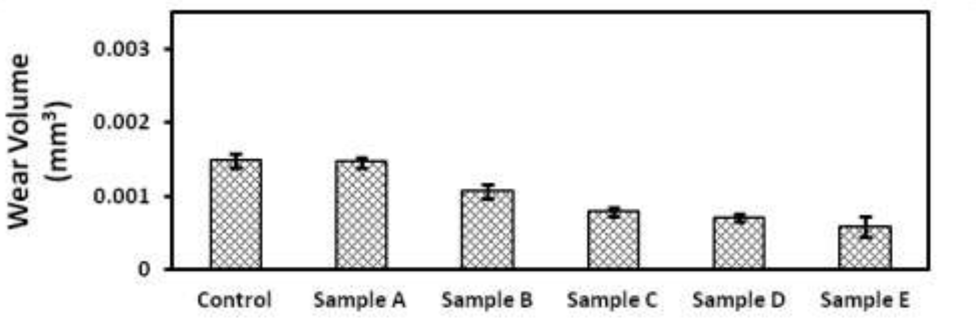

Fig 4: Wear Volume under 5 N applied Load

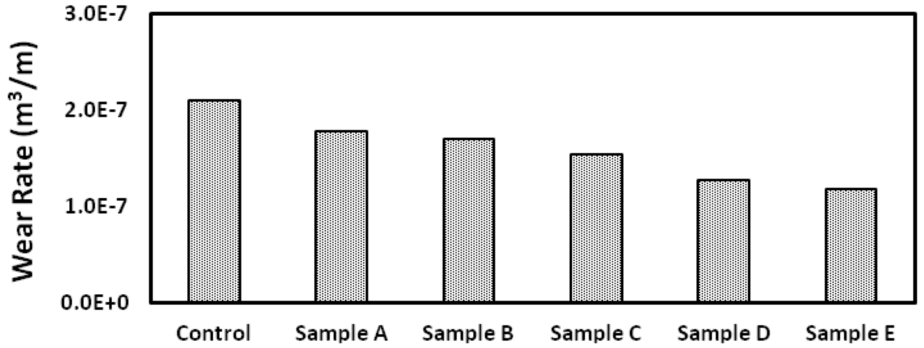

Fig 5: Wear rate under 5 N applied Load

Coefficient of Friction

Figure 6 shows variation in wear coefficient of friction under 5 N applied Load with Figure 7 shows the Mean coefficient of friction under 5 N Load. The coefficient of friction is determined by the ratio of the friction force to the loading force on the ball. The results show that the COF decreases with increasing copper nanoparticles content from 1wt% to 4 wt%. Lower friction means lower wear rate which translate to higher wear resistance. It can be deduced from the graphs that composite E exhibited lowest wear coefficients which makes it to have the highest resistance to wear which is due to lubricating effect of copper nanoparticles (Wang et al., 2013). The mean coefficient of friction under 5N applied Load in Figure 7 shows that as the CuNP increases, the coefficient of friction decreases. With addition of 1 wt% Gr and 3wt% RHA to Al6063, there was reduction in COF for sample A from 0.522 to 0.501µ and 0.536 to 0.516µ under load of 5N. With the addition of CuNP, there was reduction in COF, for sample E which has the least COF of 0.262µ under load of 5N.

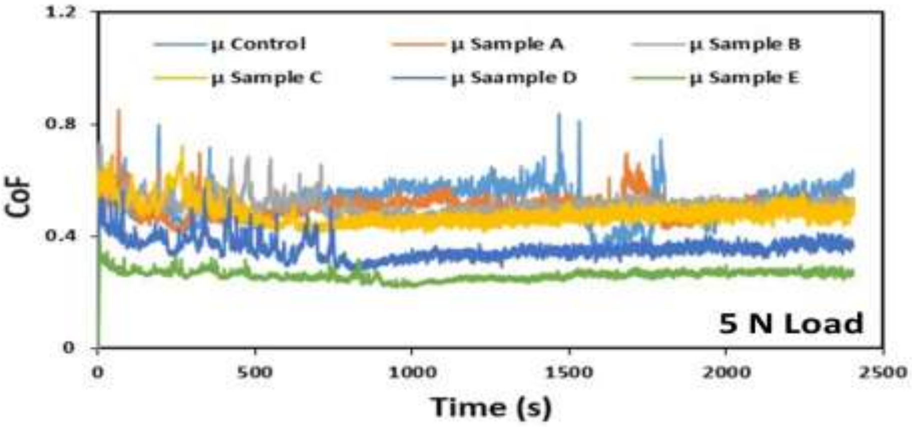

Fig 6: Variation in wear coefficient of friction under 5 N applied Load

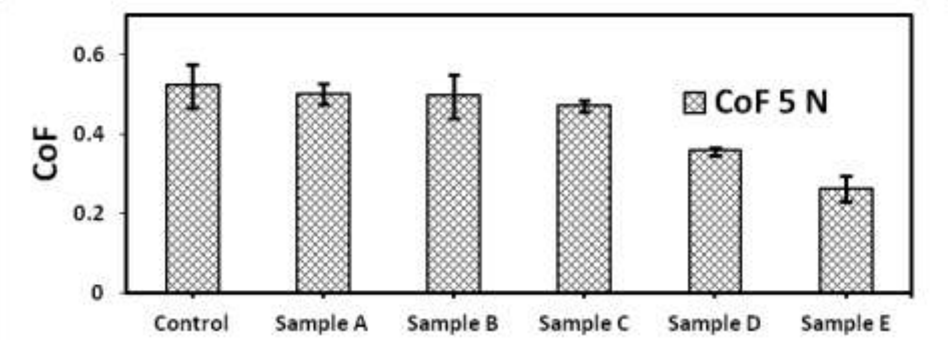

Fig 7: Mean Coefficient of friction under 5N applied Load

Micrograph Studies of the Worn Surface

Figure 7 indicates the micrograph images of the worn surface of Al6063 alloy and reinforced composites with addition of copper nanoparticles under applied load of 5 N. From Figure 7(a), it could be seen that Al alloy shows severe adhesive wear, abrasive wear and aggressive ploughing which resulted in deep grooves. This could be attributed to low hardness value of Al6063 and as a result poor abrasive resistance, while with the addition of graphite and RHA, wear scar on the compacts surface is fairly smooth with no microfracture and cracks, this indicates that abrasive wear level decreases. When CuNP was added, the abrasive wear level decreases further.

Similar observation was also reported by Raju et al., 2018; Leszczyńska et al., 2019[27], and was attributed to the presence of hard phase. However, slight adhesive wear is noticeable on the wear surface of the composites. Generally, increasing CuNP phase in Al6063 hybrid reinforced composites leads to higher hardness and more resistance to wear. So, the wear resistance of composite E was higher than other composites and Al6063 under the same wear test conditions, as shown in Figures 8(a-f).

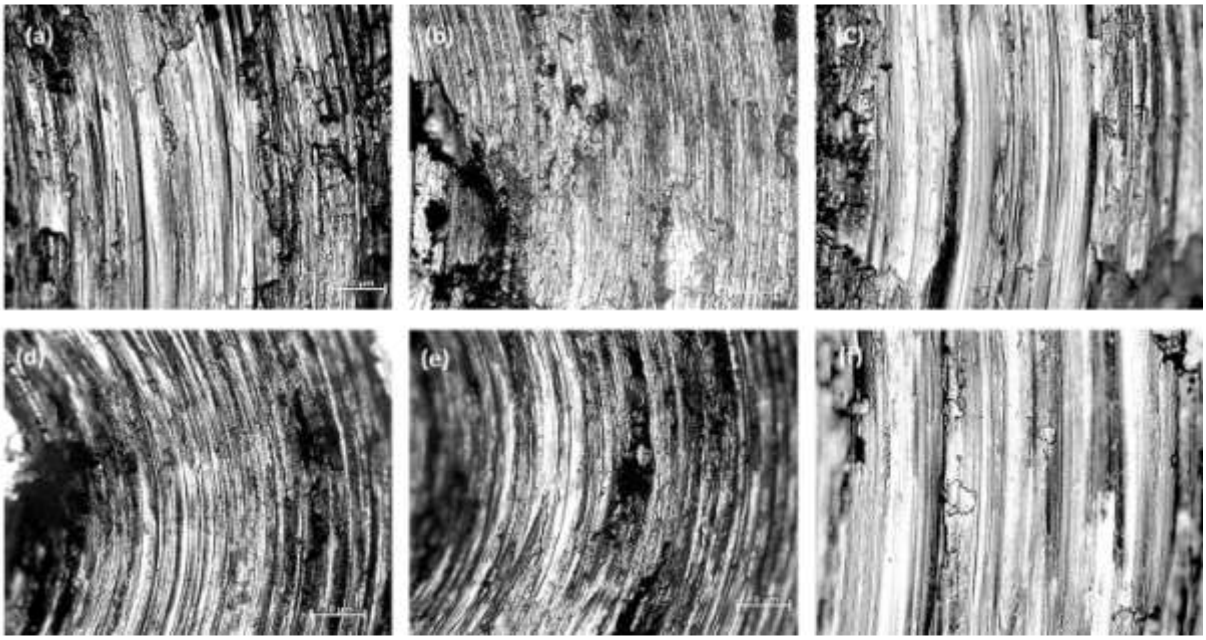

Figure 8(a-f): Micrograph images of the worn surface of Al6063 alloy and reinforced composites

IV. CONCLUSION

Wear behaviour of aluminium and aluminium hybrid reinforced composites fabricated by stir casting coupled with spin casting technique has been investigated. The addition of CuNP to sample B to E was observed to be responsible for decrease in weight and volume loss which resulted to decrease in wear rate of fabricated composites. Composite with 4 wt. % CuNP recorded the lowest wear rate and COF with values of 2.09826E-07 m^3/m and 0.262µ, respectively. As the density of the hybrid reinforced composite increases with addition of CuNP, porosity reduces and wear resistance increases.

REFERENCES

[1]. Surappa, M. K. (2003). Aluminum Matrix Composites: Challenges and Opportunities, Sadhana, 28(1-2), 319-334.

[2]. Lee, J.M., Lee, S.K., Hong, S.J. and Kwon, Y.N. (2012). Microstructures and thermal properties of A356/SiCp composites fabricated by liquid pressing method. Materials and Design, (37), 313-316.

[3] Alidokht, S.A., Abdollah-Zadeh, A., Soleymani, S. and Assadi, H. (2011). Microstructure and tribological performance of an aluminium alloy based hybrid composite produced by friction stir processing. Materials and Design, 32(5), pp. 2727-2733.

[4] Zheng, R., Yang, H., Liu, T., Ameyama, K. and Ma, C. (2014). Microstructure and mechanical properties of aluminum alloy matrix composites reinforced with Fe-based metallic glass particles. Materials and Design, 53, pp. 512-518.

[5] Wang, Z., Tan, J., Sun, B.A., Scudino, S., Prashanth, K.G., Zhang, W.W., Li, Y.Y. and Eckert, J. (2014). Fabrication and mechanical properties of Al-based metal matrix composites reinforced with Mg65Cu20Zn5Y10 metallic glass particles. Materials Science and Engineering: A, 600, pp.53-58.

[6] Rana, R.S., Purohit, R. and Das, S., 2012. Review of recent studies in Al matrix composites. Int. J. Sci. Eng. Res, 3(6), pp. 1-16.

[7] Narula, C.K., Allison, J.E., Bauer, D.R. and Gandhi, H.S. (1996). Advanced materials for automobiles. Chemtech, 26 (11).

[8] Maruyama, B., 1998. Progress and promise in aluminum metal matrix composites. AMPTIAC Newsletter, 2(3), 1-8.

[9] Anandkumar, R., Almeida, A. and Vilar, R. (2012). Microstructure and sliding wear resistance of an Al–12 wt.% Si/TiC laser clad coating. Wear, 282, pp. 31-39.

[10] Shabani, M.O. and Mazahery, A. (2013). The synthesis of the particulates Al matrix composites by the compocasting method. Ceramics International, 39(2), pp. 1351-1358.

[11] Anandkumar, R., Almeida, A., Colaço, R., Vilar, R., Ocelik, V. and De Hosson, J.T.M. (2007). Microstructure and wear studies of laser clad Al-Si/SiC (p) composite coatings. Surface and Coatings Technology, 201(24), pp. 9497-9505.

[12] Gingu, O., Mangra, M. and Orban, R.L., 1999. In-situ production of Al/SiC$_p$ composite by laser deposition technology. Journal of Materials Processing Technology, 89, pp. 187-190.

[13] Torralba, J.D., Da Costa, C.E. and Velasco, F. (2003). P/M aluminum matrix composites: an overview. Journal of Materials Processing Technology, 133(1-2), pp. 203-206.

[14] Mazahery, A. and Shabani, M.O. (2012). Study on microstructure and abrasive wear behavior of sintered Al matrix composites. Ceramics International, 38(5), pp.4263-4269.

[15] Lancaster, L., Lung, M.H. and Sujan, D. (2013) Utilization of agro-industrial waste in metal matrix composites: towards sustainability. In Proceedings of World Academy of Science, Engineering and Technology (No. 73, p. 1136). World Academy of Science, Engineering and Technology (WASET).

[16] Arora, G. and Sharma, S. (2017). A review on monolithic and hybrid metal–matrix composites reinforced with industrial-agro wastes. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 39(11), pp. 4819-4835.

[17] Hoover, N.N., Auten, B.J. and Chandler, B.D. (2006). Tuning supported catalyst reactivity with dendrimer-templated Pt− Cu nanoparticles. The Journal of Physical Chemistry B, 110(17), pp. 8606-8612.

[18] Niu, Y. and Crooks, R. M. (2003). Preparation of dendrimer-encapsulated metal nanoparticles using organic solvents. Chemistry of Materials, 15, pp. 3463-3467.

[19] Eastman, J.A., Choi, S.U.S., Li, S., Yu, W. and Thompson, L.J. (2001). Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. Applied physics letters, 78(6), pp.718-720.

[20] Talabi, H.K., Adewuyi, B.O., Olaniran, O. and Babatunde, T.F. (2019). Mechanical and wear behaviour of Al6063 reinforced with snail shell and copper nanoparticles. Annals of the Faculty of Engineering Hunedoara, 17(4), pp. 81-85.

[21] Choi Y, Lee C., Hwang Y., Park M., Lee J., Choi C., Jun M. (2009). Tribological behaviour of copper nanoparticles as additives in oil. Current Applied Physics, 9, pp. 124–127.

[22] Alaneme, K. K., Aluko, A. O. (2012). Production and age hardening behaviour of borax pre mixed SiC reinforced Al-Mg-Si alloy composites developed by double stir casting technique, The West Indian Journal of Engineering, 34 (1-2), pp. 80–85.

[23] ASTM G99-05. Standard test method for wear testing with a pin-on-disk apparatus, ASTM International, West Conshohocken, PA, 2016,

[24] Baradeswaran, A., Perumal, A.E. (2014). Wear and Mechanical Characteristics of Al 7075/graphite Composites, Composite Part B: Engineering, Vol. 56, pp. 472-476.

[25] Wang, X.L., Yin, Y.L., Zhang, G.N., Wang, W.Y. and Zhao, K.K. (2013). Study on antiwear and repairing performances about mass of nano-copper lubricating additives to 45 Steel. Physics Procedia, 50, pp. 466-472.

[26] Raju, P.V.K., Rajesh, S., Rao, J.B. and Bhargava, N.R.M.R. (2018). Tribological behavior of Al-Cu alloys and innovative Al-Cu metal matrix composite fabricated using stir-casting technique. Materials Today: Proceedings, 5(1), pp.885-896.

[27] Leszczyńska-Madej, B., Madej, M. and Wąsik, A. (2019). The effect of Cu addition on wear mechanisms and tribological properties of aluminium matrix composites reinforced with SiC. Journal of Composite Materials, 53 (22), pp. 3073-3083.

Talabi Henry K, ET.Al "Wear behaviour of Al6063 Alloy Based Reinforced with Graphite-Rice Husk Ash-Copper Nanopaticles". *American Journal of Engineering Research (AJER)*, vol. 9(03), 2020, pp. 186-192.