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Tribological and physical properties of hybrid reinforced aluminium matrix composites

P.P. Ikubanni [a,*], M. Oki [a], A.A. Adeleke [a], A.A. Adediran [a], O.O. Agboola [a], O. Babayeju [a], N. Egbo [a],
I.M.B. Omiogbemi [b,*]

[a] *Mechanical Engineering Department, College of Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria*
[b] *Mechanical Engineering Department, Air Force Institute of Technology, Kaduna-Nigeria and Ahmadu Bello University, Zaria 800282, Nigeria*

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ABSTRACT

This study considers the physical and tribological properties of hybrid reinforced aluminium matrix composites using Al 6063 alloy and silicon carbide (SiC) and palm kernel shell ash (PKSA) as reinforcements. The reinforcements used were 0, 2, 4, 6, 8, and 10 wt% in the matrix metal at different ratios of the SiC and PKSA using the double stir casting method. Experimental density and porosity of the samples were determined. Taber wear abrasion tester was utilized in the wear test experimentation. The results disclosed that the density of the composite reduced with PKSA increment, while other samples with SiC increment have improved density. The porosity percentage results showed that the double stir casting method used was acceptable as the values were within the permissible limit for cast MMCs. The sliding speed and applied load increment increased the mass loss and wear index for all the samples.

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1. Introduction

Recent developments in advanced engineering materials have brought about the synthesis of metal matrix composites (MMCs) [1,2]. This is because MMCs have found different applications in different industries such as automobile, aerospace, marine, sports, and so on, due to their superior properties, which makes them indispensable. The superior properties are high strength, high modulus of elasticity, and low density [3–5]. For instance, automotive industries such as General Motors, Nissan, and Honda have fully implemented the usage of MMCs in the production of different automobile parts such as piston, valves, and so on [4]. In the production of these MMCs, different matrix materials have been utilized in which Al is the utmost utilized of them all due to its light-weight, good thermal and electrical conductivities as well as high corrosion resistance [3,6].

More so, there is inclusion of reinforcements in the synthesis of MMCs. These reinforcements can be ceramic/synthetic reinforcements such as SiC, Al_2O_3, B_4C, TiC, and so on; agro/industrial wastes ash, or hybrid reinforcements such as hybrid ceramic reinforcement or hybrid reinforcements such as hybrid ceramic reinforcement or hybrid reinforcements of ceramic and agro/industrial wastes ash [1,2,7–9]. The introduction of these reinforcements into the matrix is to enhance the properties of the MMCs synthesized [10,11]. The reinforcement types employed have numerous influences on the wear behaviour of the Al MMCs in which the final properties rest on the characteristics of each of the utilized reinforcement [12]. Various techniques such as stir casting, powder metallurgy, squeeze casting, and so on; have been employed by different researchers in the fabrication of MMCs but the most economical method is the stir casting [4,13,14]. The stir casting route is considered as the best method in the aspect of cost, higher yield materials, complicated shapes production, and less damage [4]. In industries, one of the most frequently encountered problem is wear, which affect the material mainly due to the speed, environmental conditions, and the working load.

The slow, progressive and repeated rubbing action of the material leads to the disintegration of the material. Huge amount of money could be lost due to the repair and replacement of worn-out parts. The ability of MMCs to resist wear depends on the particle size, volume fraction, reinforcement distribution, and shape [5,6].

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* Corresponding authors.
E-mail addresses: ikubanni.peter@lmu.edu.ng (P.P. Ikubanni), omiogbemi1@gmail.com (I.M.B. Omiogbemi).

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Several studies have been done on the investigation of the tribological properties of various MMCs with different reinforcements (monolithic or hybrid). Rao et al. [6] investigated effects of load on the wear and friction of worn surfaces of MMCs using a pin-on-disc type apparatus under a dry condition. TiC particulates were varied between 2 and 10 wt% in the AA7075 matrix as reinforcement. The study reported that higher load led to higher wear rate with lower coefficient of friction (COF) for both the matrix and composites. Halil et al. [3] investigated the mechanical and tribological properties of AMCs produced using Al6061 as matrix, and SiC and B_4C as hybrid reinforcement through the powder metallurgy route. The study observed decline in COF due to load increase, while wear rate declines as sliding distance increased. The tribological behaviours of synthesized Al6061/9% Gr/WC hybrid MMCs was characterized by Ponugoti et al. [11].

The wear phenomenon and COF were estimated by varying the reinforcement percentage, applied load, sliding distance, and sliding velocity. Other studies conducted on MMCs tribological properties are done by Reddy et al. [4], Velic et al. [12], Dharanikota [15], Dharmalingam et al. [16], Kumar et al. [17], Madhavarao et al. [18], and so on.

The tribological characteristics of MMCs produced with the usage of hybrid reinforcement of ceramic reinforcement such as SiC and agro wastes ash have been done by various researchers. Kumar and Birru [10] investigated the tribological behaviour of MMCs produced using bamboo leaf ash (BLA). The wear test was done using pin-on-disc wear test apparatus. The BLA content increment reduced the wear rate of the composite. Alaneme et al. [13] observed that the trend of the wear rate did not adopt a well-defined pattern. However, the composites which have high alumina content had more wear rate compared to low alumina content composites. In a related study by Alaneme and Sanusi [14], where hybrid reinforcements of Al_2O_3, rice husk ash (RHA), and graphite were used, it was observed that the composites that has no graphite inclusion exhibited greater wear susceptibility compared to those with graphite. However, graphite content increment lowered the composites wear rate. The RHA's effect on wear susceptibility was not consistent; although averagely, there was a proportional relationship between the RHA and wear susceptibility increase.

Based on the available literature search, no study had been done in investigating the tribological characteristics of the hybrid reinforcement usage of SiC and palm kernel shell ash (PKSA) in the synthesis of MMCs from Al6063 matrix. Hence, this study is intended to examine the tribological properties of Al6063 reinforced with SiC and PKSA particulates using Taber type abrasion tester. The main aim is to investigate the consequence of load and speed of rotation on the wear behaviour of the MMCs. The physical properties of the composites were also determined.

2. Materials and method

2.1. Material selection

The as-received Al6063 alloy in form of billet was chosen and utilized as the base metal matrix for the development of the composites. The chemical constituent of the metal matrix (Al6063 alloy) is displayed in Table 1. The hybrid reinforcement selected for the composite production is palm kernel shell ash (PKSA) and silicon carbide (SiC). The PKSA was obtained from the ash processing of palm kernel shell (PKS) at 900 °C after the PKS has been sorted, cleaned, and dried. The chemical composition of the PKSA obtained at 900 °C is presented in Table 2. The PKSA was sieved to particle size of less than 50 μm, while the SiC average particulate size is 30 μm.

2.2. Hybrid composite synthesis

The popular liquid metallurgy route is stir casting method, which was employed in the development of the composites. The composite production was by double stir casting technique in accordance with Alaneme et al. [13]. The charge calculation was done to determine the quantities of SiC, PKSA, and Al6063 required to produce between 0 and 10 wt% reinforcement different mix as presented in Table 3. The hybrid reinforcement particles (SiC and PKSA) were initially preheated at 250 °C to reduce moisture and improve their wettability with the base metal [14]. Using a gas-fired crucible furnace, the Al6063 alloy billets were charged into it and the furnace was heated to a temperature of 750 °C ± 30 °C. The already melted liquid metal was then allowed to cool to a semi-solid state in the furnace at a temperature of about 600 °C. The already preheated reinforcements of PKSA and SiC were poured at this semi-solid state into the Al6063 alloy melt in which the slurry was manually stirred for about 10 min. The semi-solid composites were then superheated to a temperature of about 780 °C ± 30 °C, and was mechanically stirred the second time for about 10 min at a regular speed of 400 rpm. The mechanical stirring was to help in improving the particulates distribution in the molten matrix metal, thereby breaking down the particle agglomerates. The molten composites were the poured into already prepared sand mould for solidification. A typical example of the solidified wear sample is displayed in Fig. 1.

2.3. Density and porosity determination

Both the theoretical and experimental densities were carried out to investigate the impact of the PKSA-SiC varied weight fractions on the densities of the produced composites. The theoretical density of the composites was determined by using the rule of mixture, while the experimental density was obtained by weighing the test sample using a digital weighing balance and then dividing the obtained weight by the volume of the respective test sample.

The percentage porosity of the composites was evaluated using the experimental and theoretical densities using Eq. (1):

$$\%Porosity = \frac{\rho_T - \rho_{Ex}}{\rho_T} \times 100\% \qquad (1)$$

Where ρ_T is theoretical density (in g/cm^3), ρ_{Ex} is experimental density (in g/cm^3)

2.4. Tribological characteristics

Taber Type Abrasion tester (Model No: TSE-A016) was used in the determination of the wear resistance of the composites produced in line with ASTM D4060-14 standard [19]. The samples were machined to dimensions of diameter (100 mm) and thickness (5 mm), as shown in Fig. 2. The surface of the samples was positioned on a turntable platform of the Taber abrasion machine,

Table 1
Chemical composition (%) of the Al6063 matrix.

Constituents	Si	Fe	Mn	Mg	Cu	Ti	Zn	Cr	Sn	MnO	Al
%	0.43	0.17	0.04	0.48	0.01	0.02	0.01	0.01	0.01	0.08	Bal.

Table 2
Chemical composition (%) of the PKSA.

Constituents	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3	MnO	LOI
%	0.17	3.14	6.46	66.90	3.78	5.20	5.52	0.53	5.72	0.08	2.50

*LOI- Loss on ignition.

Table 3
Designation of composite samples produced.

Sample designation	Aluminium (wt%)	PKSA (wt%)	SiC (wt%)
A0	100	0	2
A1	98	0	2
A2	96	2	2
A3	94	4	2
A4	92	6	2
A5	90	8	2
A6	98	2	0
A7	94	2	4
A8	92	2	6
A9	90	2	8

Fig. 1. Solidified wear sample.

Fig. 2. Typical example of machined wear sample.

which was then gripped at a constant pressure by two abrasive wheels lowered onto the surface of the sample. The samples were subjected to four different mass (loads) of 250 g, 500 g, 750 g, and 1000 g, and four different rotating speed of the turntable of 250, 500, 750, and 1000 rpm for each sample composition. Due to the rubbing action between the sample and the abrasive wheels during the machine rotation, loose composite debris from the sample was generated. Therefore, the weight before (initial weight) and after (final weight) the test was obtained after 15 min' duration of the abrasion tester was allowed to rotate on the sample.

The wear properties of the composites were then determined as follow in Eqs. (2) and (3). The mass loss was determined using Eq. (2):

$$Massloss = Initialmass(m_i) - Finalmass(m_f) \tag{2}$$

The Taber wear rate index was obtained using the relation as shown in Eq. (3):

$$TaberWearIndex, I = \frac{m_i - m_f}{T} \times 1000 \tag{3}$$

Where $T$is the time of test cycles (minutes), and I is the Taber wear index.

3. Results and discussion

The physical properties of the produced AMC samples were examined and presented in Fig. 3. The density of the synthesized AMCs is displayed in Fig. 3. The experimental density of the unreinforced alloy (Sample A0) was 2.64 g/cm^3 with percentage porosity of 2.063%. Sample A1 has the highest density value of 2.65 g/cm^3. This could be attributed to the hard nature of the 2 wt% SiC reinforcement included in the 98 wt% Al. The gradual reduction in the density of samples A2-A5 could be attributed to the reduction in the wt% of Al and the wt% increase of PKSA, which has lower density compared to Al and SiC. This is in agreement with the study of Prasad et al. [20]. However, the increase in density value for sample A6 could be attributed to the value of wt% Al (98%) and 2 wt% PKSA. The rise in density of sample A6 compared to samples A3 - A5 could be accrued to the much higher Al alloy content and lower PKSA content. The improvement seen in the density of samples A7-A9 could be assigned to the increment in the SiC percentage weight at a constant 2 wt% PKSA. The hard nature of SiC, which strengthens the composites may have resulted in this phenomenon.

The porosity percentage values of the samples were within the permissible limit of less than 4% for cast MMCs [14]. The values were less than 2.5%; hence, the double stir casting route utilized for the production of the composites is said to be reliable.

3.1. Influence of sliding speed and applied load on mass loss

Figs. 4–7 displayed the mass loss against the different sample compositions. The samples were subjected to different loadings of 250, 500, 750, and 1000 g at different speed of 250, 500, 750, and 1000 rpm, respectively. It was observed from the figures that as the speed of rotation increases, the amount of material loss

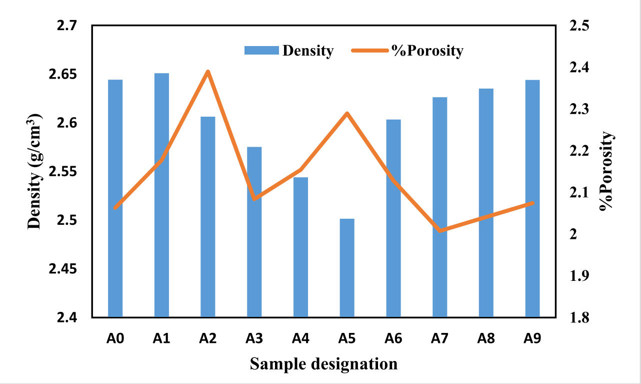

Fig. 3. Density and percentage porosity of the composite samples.

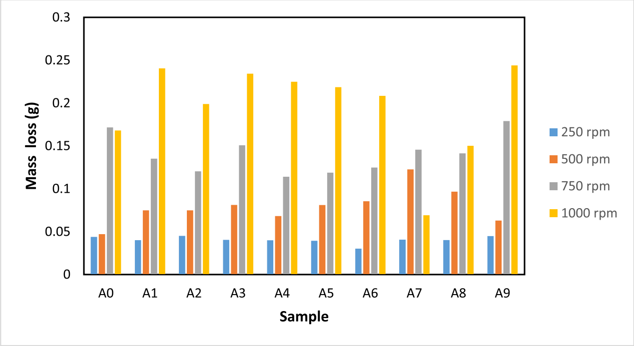

Fig. 4. Mass loss during wear at 250 g load.

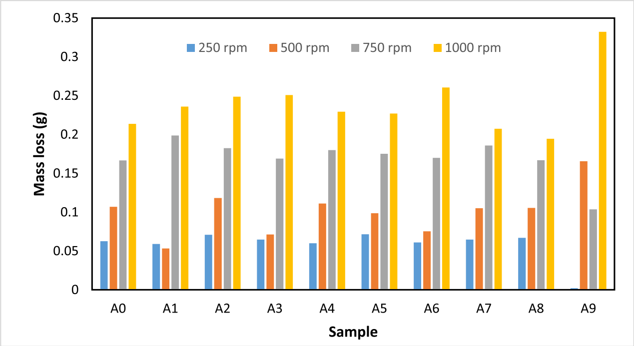

Fig. 5. Mass loss during wear at 500 g load.

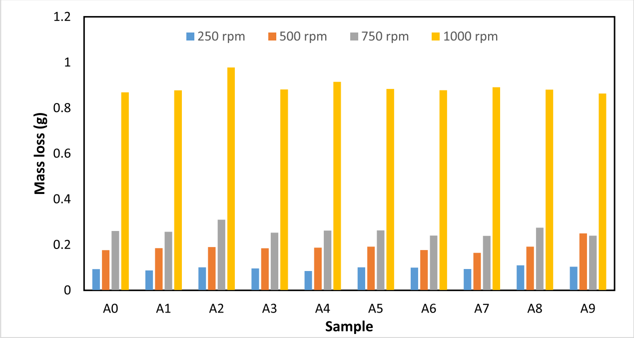

Fig. 6. Mass loss during wear at 750 g load.

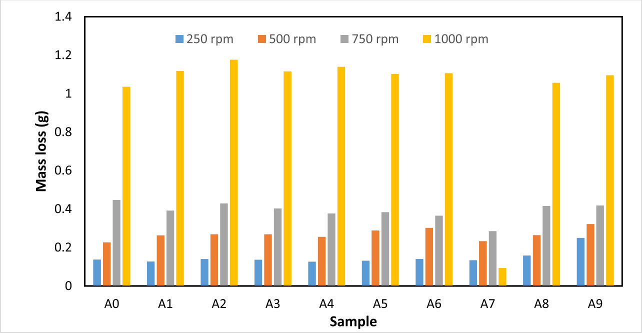

Fig. 7. Mass loss during wear at 1000 g load.

increases. That is, the higher the speed, the higher the material loss. More so, the value of the mass loss varies proportionately with the applied load. This was revealed in the Figs. 4–7. The amount of mass loss becomes more as the applied load increases from all the samples. The increase in load could result into rise in friction, which increase wear and material loss of the composites [21,22]. The surface layers are broken due to the initial rubbing time, hence resulting in cleaned and smoothened surfaces, thereby increasing the contact strength between the surfaces. The further loss of the metal is as a result of surface layer deformation increment based on the adhesion at the surface [19].

3.2. Wear index and impact of sliding speed

The wear index of the samples at various sliding speeds and applied loads are displayed in Figs. 8–11. It was observed that for most of the samples the smaller the sliding speed, the lower the wear index at the different applied load. As the load applied rises, the values for the wear index increases. This is in agreement with the study of Adediran et al. [23]where both the volume loss and wear rate increases as the load increases.

4. Conclusion

The physico-tribological properties of the synthesized hybrid reinforced AMCs were investigated in this study. The results revealed that:

i. the increase in PKSA reinforcement in samples A2-A5 at constant 2 wt% SiC reduces the experimental density value.
ii. the increase in SiC in samples A7-A9 at constant 2 wt% PKSA increase the density of the composites but below the unreinforced samples.
iii. as the applied load and sliding speed increases, the mass loss and the Taber wear index increase.
iv. This implies that the produced AMCs could be utilized in areas where friction orcontact between it and other materials are low.

CRediT authorship contribution statement

P.P. Ikubanni: Conceptualization, Supervision, Validation. **M. Oki:** Investigation, Validation. **A.A. Adeleke:** Software, Data curation, Investigation, Validation. **A.A. Adediran:** Data curation, Visualization, Validation. **O.O. Agboola:** Data curation, Visualization, Validation. **O. Babayeju:** Reviewing, Visualization, Validation. **N. Egbo:** Writing - review & editing, Visualization, Validation. **I.M.B. Omiogbemi:** Writing - review & editing, Visualization.

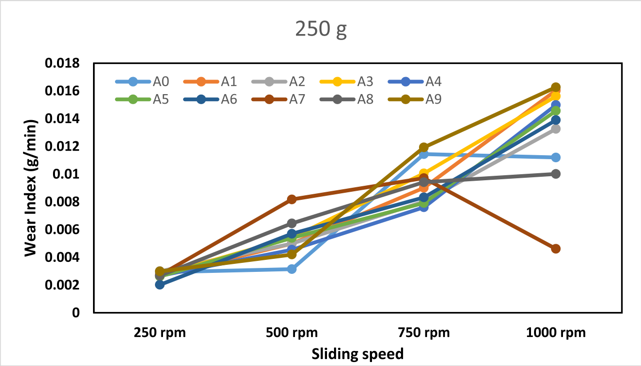

Fig. 8. Wear rate vs. sliding speed at 250 g load.

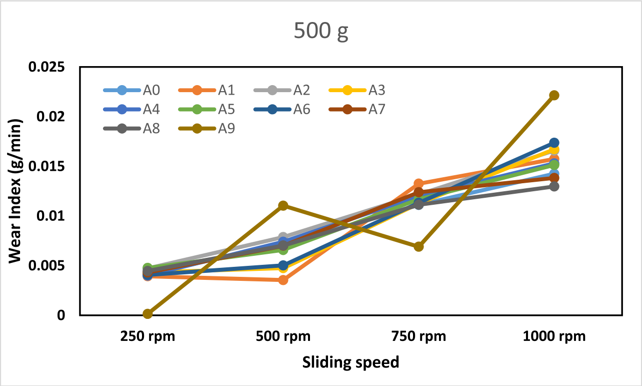

Fig. 9. Wear rate vs. sliding speed at 500 g load.

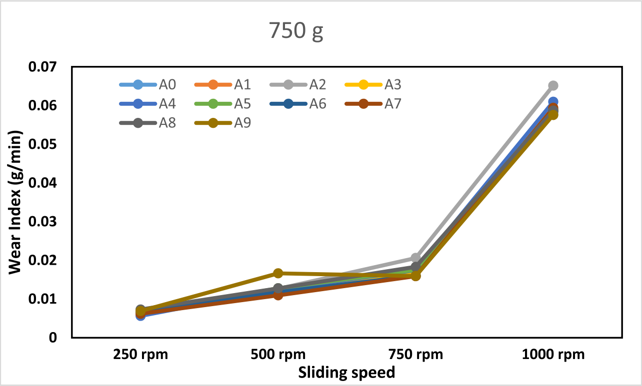

Fig. 10. Wear rate vs. sliding speed at 750 g load.

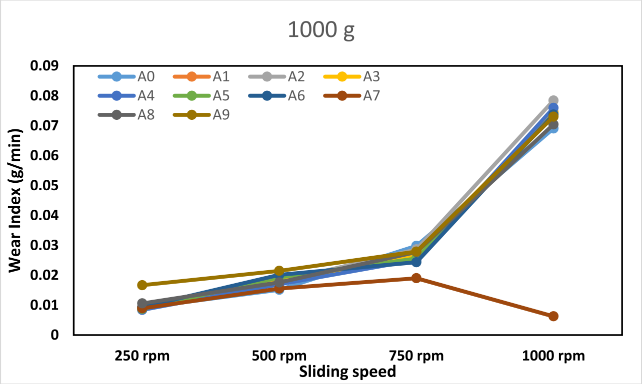

Fig. 11. Wear rate vs. sliding speed at 1000 g load.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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