Wear Behavior of 2024 Aluminum Alloy Reinforced with SiC Particles

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ABSTRACT

The wear behavior of Aluminum Alloy (AA) 2024 reinforced with SiC particles were investigated at room conditions. Stir casting method was used to prepare the matrix composite of AA 2024 alloy reinforced with different weight percentages of SiC (3, 6, 9, 12 wt%). The wear behavior of both AA 2024 and AA 2024/SiC composite was studied using the reciprocating wear test. Loads of 2.5, 5, 7.5, 10, and 12.5 N were applied with sliding speeds of .0.55, 0.72, 0.88, 1.04 and 1.2 m/sec in dry sliding contact conditions. The microstructure and phase distribution were investigated using Optical Microscope (OM) and Scanning Electron Microscopy (SEM). The results demonstrate the presence of fine dendritic structure with semi-homogeneously distributed SiC particles in the alloy matrix. The micro-hardness increased with increasing SiC percentage. The highest value of hardness of 79.3 HV was found at 12 wt% SiC, from the initial 44 HV of the base alloy. The wear tests showed that the wear rate increased with increasing applied normal contact load at a contact sliding speed of 0.88 m/sec. The wear rate of the as cast material was 18.59 $\times 10^{-8}$ g/cm. Adding the SiC particles decreased the wear rate to 13.78, 9.76, 7.98, and 5.81 $\times 10^{-8}$ g/cm for 3, 6, 9, 12 wt% SiC addition at 12.5 N applied load, respectively. SEM examination of worn surfaces showed that severe and abrasive wear was exhibited at higher loads in the dry case while mild and adhesive wear were observed at lower loads in the lubricated condition.

Keywords-aluminum alloy 2024; SiC; reciprocating wear; casting; micro-hardness; insert

I. INTRODUCTION

Aluminum Matrix Composites (AMCs) are considered as some of the most important engineering materials with higher strength, hardness, elastic modulus, and wear resistance over base alloys [1-3]. Ceramics including carbon, boron, tungsten carbide, titanium carbide silicon carbide and alumina have been used to reinforced aluminum alloys [4-7]. The need to improve the properties of wear resistance because of their its importance in many applications including aerospace, automotive, and electronic industries [2, 8, 9, 18] arises. The addition of SiC particles causes high hardness and high adhesion between the AA matrix and the reinforcement particles resulting to better mechanical properties with significantly increased wear resistance [10-13]. Researchers have studied the wear properties with different wear conditions (speed, load, and time) and different techniques have been studied for the mentioned AAs reinforced by the above reinforcing particles [10-12, 14]. Authors in [15] investigated the effects of 0, 3, 6, and 9 wt% SiC content on the tribological behavior of 2024 AA/SiC produced with the stir metal casting process. The results revealed that the wear resistance of AA/SiC reinforced matrix composites was greater than that of the 2024 AA. The adhesive wear mechanism of the original alloy was adhesive, whereas adding SiC reinforced particles let to change wear mechanism to abrasive. Authors in [16] investigated the effects on the tribological properties of adding BN/SiC nanoparticles to the AA 2024. Authors in [17] studied wear behaviors using pin-on-disc apparatus of the artificial aged AA 2024 and AA 2024 with 20 vol.% SiC composite produced using the Powder Metallurgy (PM) method with 20 N applied load and 0.5 m/s sliding speed for 2500 m sliding distance at temperatures of 20–250 °C. All samples showed a transition mode from mild - severe wear above the critical temperature. Mild wear regime demonstrates high coefficient of friction and wear rate of the composite specimen comparing with the unreinforced alloy.

The present work aims to improve the tribological characteristics of AA 2024-based micro-composites, a linear reciprocating pin on a flat sliding contact with variable reciprocating applied load. AA 2024 composites strengthened with different percentages of SiC particles were tested for wear behavior at different sliding conditions.

II. EXPERIMENTAL PROCEDURE

The material used in this work is AA 2024. Table I presents the chemical composition of the as received alloy and the re-melted and cast alloy. The chemical composition was estimated with a Spectro analytical instrument. Table II lists the physical properties of both AA 2024and Sic particles.

The stir casting method using vortex technique was adopted. The base alloy was melted in an electric furnace with a top slot by using a graphite crucible at 700 ˚C. After fully melting, reinforcing material SiC was added, with particle size distribution of 50-75 µm. In this casting process, the aluminum alloy was first superheated to slightly above its melting temperature to produce a vortex using a stainless - steel mechanical stirrer. SiC particles were wrapped with aluminum foil and preheated to 300 ˚C. The particles were then slowly added to the melted alloy, and the mixing was continued for about 8 minutes at a stirring speed of about 500 rpm. Figure 1 shows a schematic diagram of the process.

TABLE I. CHEMICAL COMPOSITION OF THE AA 2024

Element	Before melting	After casting
Si	0.134	0.101
Fe	0.252	0.241
Cu	4.870	4.798
Mn	0.664	0.551
Mg	1.300	0.976
Cr	0.017	0.010
Zn	0.103	0.111
Ni	0.011	——
Ti	0.017	——
Al	Rem.	0.101

TABLE II. PROPERTIES OF AA 2024 AND SiC

Property	AA 2024	SiC
Density ($g.cm^{-3}$)	2.78	2.51
Young's modulus(GPa)	73	450
Melting point (°C)	630	2445
Thermal conductivity (W/m K)	121	28

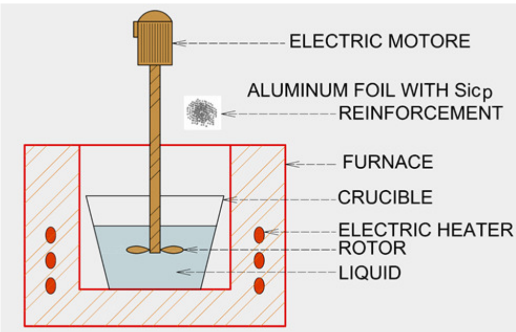

Fig. 1. Schematic diagram of the stir casting process.

The melted metal was then poured into a preheated 250 ˚C cast iron mold with cavity dimensions of 12 mm diameter and 80 mm length. Cast specimens of the base and the reinforced alloy composites were machined to 10 mm in diameter and 20 mm height for wear test as illustrated in Figure 2.

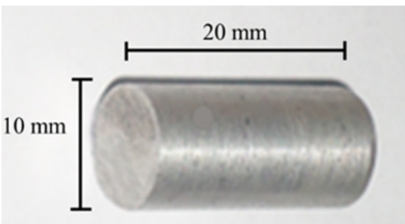

Fig. 2. Wear test samples of 20mm length and 10mm diameter.

The specimens were faced ground using SiC emery papers with grades of 200, 400 and 600. Figure 3 shows the microstructure of the as cast alloy. The structure is one of dendritic structure mode due to the solidification in a metallic mold.

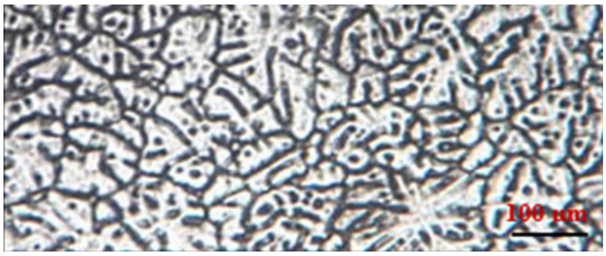

Fig. 3. Micro-structure of the as cast AA 2024.

III. RESULTS AND DISCUSSION

Figure 4 shows the distribution of SiC particles within a cut-off specimen of the alloy.

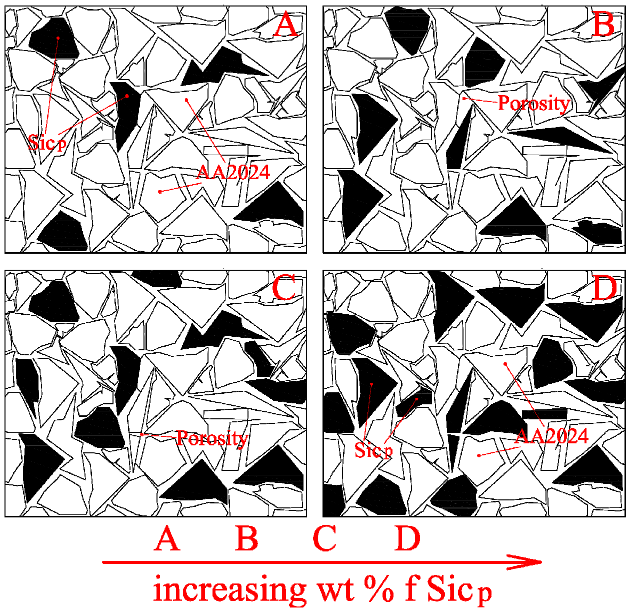

Fig. 4. Microstructure of AA 2024/SiC for (A) 3, (B) 6, (C) 9, and (D) 12 SiC wt%.

Figures 5(A), (B), (D) show the microstructure of the alloy after the addition of SiC, which changed the dendritic structure to a fine structure due to dendrite fragmentation by inoculation and SiC particle distribution. With 3 and 6 % wt SiC addition, the micro-structure reveals a homogeneous distribution of the SiC particles. Increasing the SiC percentage to 9-12 wt% led to the emergence of several particles of different shapes and sizes combined inside the composite material. A few pores also appeared with this increment (Figure 5 (C), (D)).

The Vicker's hardness test was used to measure micro-hardness with 300 g and 15 s dwell time. A reciprocating pin on flat wear test device was used for wear testing. The wear tests were run at different sliding speeds and applied loads of 2.5, 5, 7.5, 10, and 12.5 N at room temperature for 25 minutes sliding contact time for all wear tests. Cylindrical pins 10 mm in diameter and 20 mm in height were prepared from the base alloy and the cast composite ingots. The specimens were loaded through a normal specimen holder against a horizontal reciprocating flat surface. The flat surface was made of carbon steel with 160 mm length and 70 mm width.

The wear rate was calculated by the weighing method according to the standard ASTM G133 pin on flat surface. The effect of SiC particle addition to the AA 2024 on the Vickers micro-hardness of the resulted composite structure is represented in Figure 6, where an increase in hardness of 79.3 HV was obtained by increasing SiC% content up to 12%, while the initial AA 2024 hardness was 44HV. Microhardness increased by increasing the weight % of the SiC particles due to their high hardness [19].

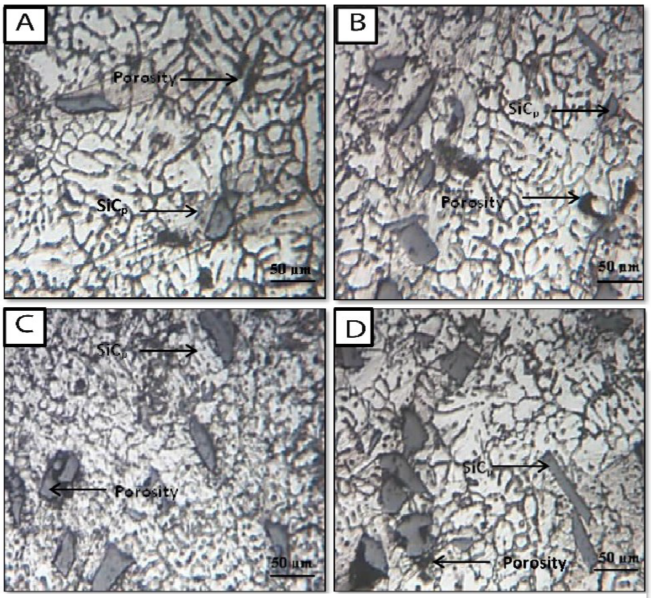

Fig. 5. Schematic diagram of the microstructure of the distribution of SiC particles within cut-off specimens.

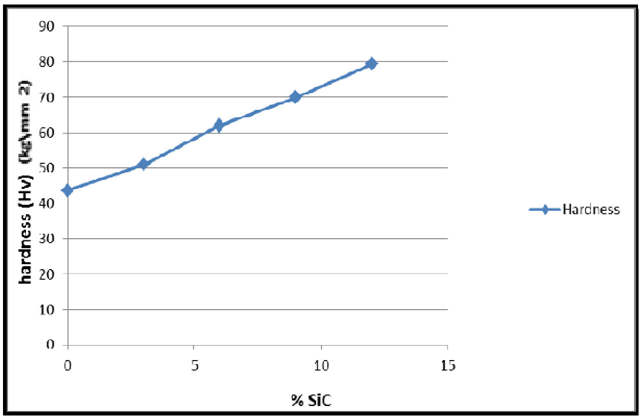

Fig. 6. Microhardness of composite AA 2024-SiC.

Figure 7 presents the wear rate of the as cast AA 2024 with metal matrix composites with different addition percentages of SiC particles and different applied loads. As cast alloy shows higher wear rate than the composite materials at all loads due its lower hardness. As the weight percentages of SiC particles increases up to 12 %wt, the wear rate decreases. With increasing applied load, the wear rate increases for all base alloy and composites. Figure 8 shows the effect of SiC particle addition on the wear rate in dry sliding conditions. It can be seen that increasing the wt% of SiC resulted in drastic decrease in wear rate at 2.5 N load, where the wear mechanism was abrasive and no adhesion was noticed. Similar results were reported in [15-16]. Increasing the load up to 12.5 N led to an increase in wear rate due to the transition to adhesive from abrasive wear and the higher heat generation. This can be related to the increasing effect of simultaneously decreasing the applied load and increasing the wt% of SiC particles to reduce wear rate which confirms previous work conclusions [17].

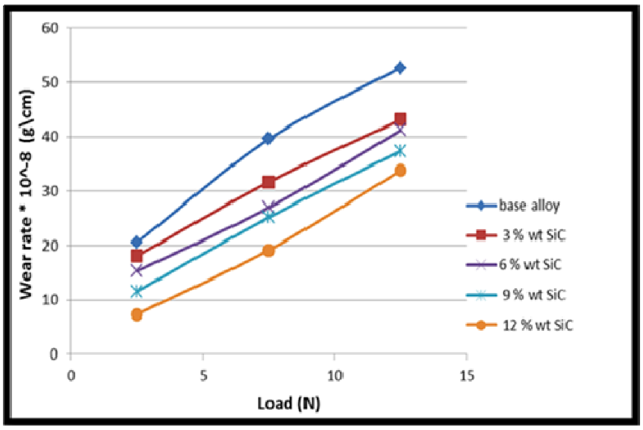

Fig. 7. Wear rate of the as casting and reinforced materials at different applied loads.

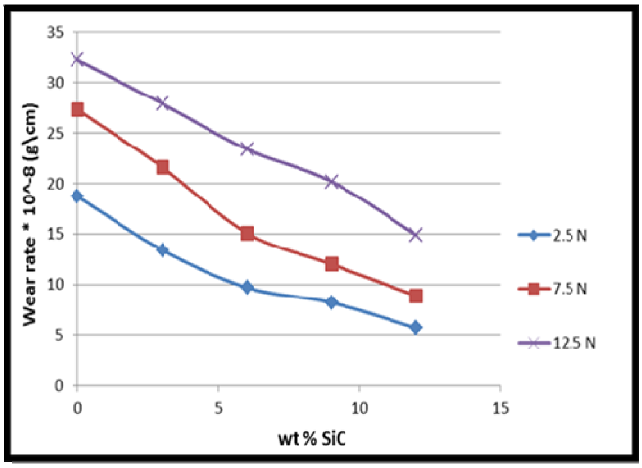

Fig. 8. Relationship between wear rate and SiC percentage in dry reciprocating sliding contact.

A Scanning Electron Microscope (SEM) was employed to study the effect of the applied load on the surface topography of the worn surfaces of the samples at contact load of 10 N and 2.5 N with the addition of 6 wt% SiC, at reciprocating sliding speed of 0.88 m/sec for a contacting period of 25 min. Figure 9 shows the effect of different loads in the dry condition. It is noted that for the higher load, the surface suffered severe wear due to the formation of deep grooves as a result of the ploughing action of the SiC particles. Cracks were revealed on the worn surface and the abrasive wear nature can be noted a little debris separated from the surface of the alloy leading to lowered wear resistance.[15, 20]. Applying lower load caused less severe wear and the wear lines tracks were shallow. X-Ray Defraction was used to investigate the phases of the structures of the samples. A SEM was employed to study the effect of the applied load on the topography of the worn surfaces of the samples for both dry and wet sliding condition. Increasing wear resistance for wet sliding samples and decreasing plastic deformation were noticed. The wear effect generally increased with increased applied load [12]. Figure 10 shows scratches and debris on the surface of the worn specimen.

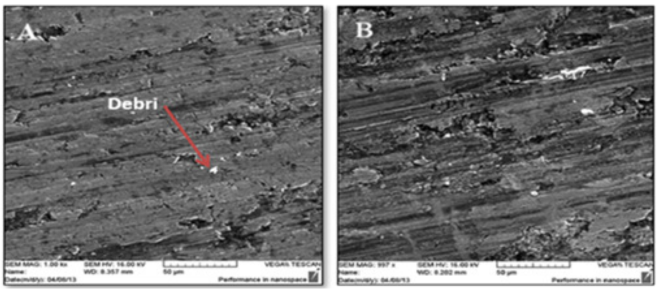

Fig. 9. SEM of worn surfaces at reciprocating sliding contact speed of 0.88 m/sec, 6 wt% SiC, and contact period of 25 min. (A) 2.5 N, dry case, (B) 10 N, dry case.

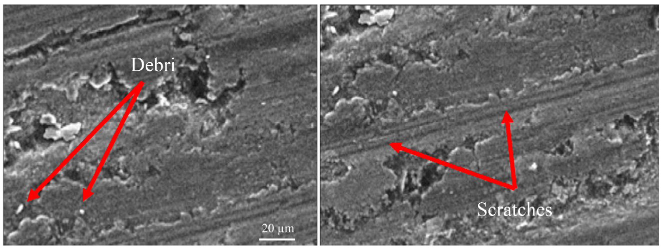

Fig. 10. SEM of the worn specimen.

IV. CONCLUSION

The Aluminum alloys have a wide range of industrial applications, thus it is necessary to find ways to enhance their mechanical properties. The aim of this study is to increase wear resistance and hardness of the AA 2024 alloy by adding different wt % of SiC particles. Tests were conducted for stir casted samples for both cases, i.e. with and without the addition of SiC particles. Wear test was conducted using a reciprocating piston flat test device. Microstructure was examined by an optical microscope. Hardness was measured by the Vicker's macrohardness device with 0.4 k.g load. The influence of the addition of different weight percentages of SiC (3, 6, 9, and 12 wt%) on the dry sliding tribological properties of the AA 2024 was investigated using reciprocating wear, in addition to microhardness and microstructure. The following conclusions are derived from the results of this study:

- The hardness of the AA 2024-SiC composite increased with the increase of SiC particles. The highest hardness was found at 12 wt% SiC addition.
- Increasing of the applied load caused an increase in wear rate while increasing of the SiC content caused a decrease in wear rate.
- In dry sliding contact, the applied load on the contact surface had a combined effect with the sliding contact speed on the wear rate.
- The interaction between the applied load, the wt.% of SiC, and the sliding contact speed on the wear rate was more than that of the interaction between wt.% of SiC with the same sliding speed.
- SEM images showed high abrasive severe wear in dry sliding contact.
- AA 2024 has a low hardness with poor wear property. Adding hard ceramic SiC particles improved its wear resistance.

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