Wear Characteristics of Al-Based Composite Material

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Abstract

This research studies the wear characteristic of Al- based composite material. Stir casting technique was used to fabricate composite samples of Al-6061 and Al-6061 reinforced with different percentage ages (5%, 10%, 15% weight) of silicon carbide particles (SiC). Abrasive wear behavior of composite was studied by dry sliding pin on disc method. Different parameters were taken into consideration including, applied load, sliding speed, and weight percentage age of silicon carbide particles. Wear test-sliding distance ranged from 1044 m to 3123 m measured over different times (10 min, 20 min, and 30 min). Normal loads range from 10 N to 30 N, at sliding speeds of 1.74m/s. Specific wear rate was calculated considering weight loss calculation which was measured by using digital electronic balance (up to 0.01 g accuracy). The results show that by increasing the sliding speed and the applied load we get the highest wear rate in the aluminum alloy, while with the Al/SiC composite, the wear rate decreases with the increase of SiC percentage age. It was found that hardness increases simultaneously when SiC percentage age increases. The highest hardness in (AL- 15 wt. % SiC) was recorded.

Keywords: Aluminum alloys Composites, Silicon Carbide SiC, wear rate.

خواص المادة المركبة ذات اساس الالمنيوم

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خلاصة

في هذا البحث تمت دراسة خصائص البليان للمادة المركبة ذات اساس الالمنيوم.استخدمت طريقة الخلط والسباكة لصناعة نماذج المادة المركبة للالمنيوم وللالمنيوم المدعم باضافة كاربيد السليكون. تمت دراسة البليان بوجود سطح خشن وذلك خلال دراسة طريقة انزلاق العينة على قرص دوار اكثر صلادة منه. اخذت في هذا الاختبار عدة عوامل بعين الاعتبار منها الحمل المسلط، سرعة الانزلاق، وتاثير اضافة نسب متنوعة من كاربيد السليكون. سرعة انزلاق العينة تتراوح من 1044-3123 متر محسوبة لفترات زمانية متنوعة ومؤثرة(١٠-٣٠ دقيقة). الاحمال العمودية المُسلطة تراوحت من 10-30 نيوتن وبسرعة انزلاق 1.47 متر بالثانية. تم احتساب معدل البليان باعتبار الوزن المفقود والذي يتم قياسه باستخدام ميزان حساس ذو دقة تصل الى(0.01g). اظهرت النتائج ان زيادة سرعة الانزلاق والحمل المُسلط ادت الى زيادة معدل البليان في معدن الالمنيوم. بينما في المادة المركبة معدل البليان يقل بزيادة نسبة كربيد السليكون. لوحظ ان الصلادة تزداد. بزيادة نسبة كربيد السليكون وان اعلى قيمة له كانت عند نسبة 15% كربيد السليكون

الكلمات المفتاحية: سبيكة الالمنيوم ،كاربيد السيلكون SiC ،معدل التاكل .

Introduction

A composite material results from combining two or more materials together in order to give new properties, and, in comparison to its constituents, it has different and better characteristics. The metal matrix composite (MMCs) supported by molecules or fibers represents a group of materials where the hardness and strengthening resistance are combined to the ductility with the toughness of matrix materials. Aluminum has various uses owing to its properties like resisting corrosion, low density, relatively low price, and high strength to weight ratio in addition to its availability in abundance [1].

The MMCs stand for a new type of materials that have attracted scientists and manufacturers recently because of the great potential of use due to their characteristics. As a result, they came to be widely used in scientific, technological, and commercial applications at the expense of the traditional materials in different industries, particularly in planes manufacturing, transportation, electronics, and sport industries [2, 3], so the re-strengthened aluminum alloy matrix composites have become one of the focuses of practical applications as well as research in the structural complexes .Many scientists have concentrated on the improvements achieved through the reinforcements added to the Tribiological applications of MMCs. The impact of adding harder particles in order to enhance MMCs strength in terms of their wear behavior was widely researched. Some scientists proved that the weight loss was significantly reduced after adding some hard materials like (SiC, Al_2O_3) [4]. They found that owing to their highly desired mechanical properties, these alloys can be implemented in high-speed rotating and reciprocating applications such as pistons, connecting rods, brake rotors, and cylinder bores [1]. They also discovered that the mechanical properties of aluminum can be improved by combination with metals like copper, magnesium, and silicon [5]. Researchers are now investigating the effect of adding different materials to aluminum. Naik et al. [3] investigated the development of aluminum 6061with SiC, the composite illustrated that the silicon carbide is used as particulate reinforcement which improved the tribological characteristics, hardness, strength and thermal conductivity.

Hasan–et al. [6, 7] investigated the wear properties in Al-SiC particulate complexes and the Al- Si piston alloy, using liquid metallurgy method employing 2124 Al alloy as the base component with 10 and 20 % SiC particulates by weight. The abrasive wear investigated by pin on disc method. The test results showed that the SiC particulate phase is elicited in order to lessen the wear rate (expressed in terms of gm/m, mm^3 /m etc.) significantly in the complexes. The volumetric wear rate (mm^3 /m) in 20 % SiC composite is lessened by 62-66% for 400 emery sliding in accordance to the base alloy. In the case of 10% SiC composite the corresponding reduction in the wear rate is 15-25%. Mishra et al. [8] investigated the tribological conduct of Al-6061 / SiC metal matrix composite by using Taguchi's techniques. The results showed that increasing SiC (10% and 15%) lifts the wear resistance of complexes by make-up a protecting layer between pin and counter face. In both complexes, sliding distance and applied load have the highest effect on wear rate. Similarly, applied load is the only factor which largely impacts the coefficient of friction in both complexes. Mahdavi and Akhlaghi [9] concentrated on the impact of SiC substance on the processing, compaction behavior and characteristics of l6061/SiC/Gr hybrid complexes. The results showed that hardness grows with the increase in SiC content. Singh et al. [10] investigated a two-body abrasive wear conduct of aluminum alloy–sillimanite particle reinforced composite. The wear rate results displayed that wear rate of the composite and the matrix alloy was lifted with increasing applied load and abrasive size; wear resistance (inverse of wear rate) of the composite was finer than that of matrix alloy for superior size abrasives, however the trend opposite of coarser size abrasives. Through coarser abrasives, composite undergoes higher wear rate from the alloy after a significant applied load, wear rate decreases with the increase in sliding distance. This happens because of the abrasive molecules' work hardening of wear surface, clogging, attrition and shelling. Singh [11] presented the mechanical and tribological conduct of Al matrix alloys supported with SiC and Gr particulate up to 10%. Parametric studies show that the hardness tensile strength of Al-SiC alloy is more than the Al-Gr composite resulting from high hardness of SiC particulates. As graphite being self-solid lubricant, the excess percentage age of strengthening Gr leads to decrease in wear characteristics. In this paper the results depict that either increasing the load or sliding distance or both enumerates to increase in wear. The wear is also influenced by the hardness and the tensile strength of the composite. Radhika [12] presented the investigation on the tribological conduct of aluminum composite (Al-Si10Mg) plus graphite (3%) and alumina (9%) as strengthening which is produced by stirring casting process. The wear resistance is increased by the incorporation of graphite as a primary restrenghthening and the involvement of alumina as another support, in addition it has a significant influence on the wear conduct. Sliding distance has the highest effect at the wear rate come after an applied load and sliding velocity. Ibrahem [13] investigated the influence of SiC support with 6061-T6 alloy and prepared the composite by melting the alloy in vortex with 4% and 10% weight fractions of SiC strengthening. In this paper, it was found that wear resistance ameliorate during the carbide addition, compared with the base alloy.

The effect of SiC addition contributed to the increased hardness of the alloy and ameliorates the wear resistance. Asif [14] investigated the impact of strengthening with silicon carbide molecules and solid lubricants like graphite/antimony Tri sulphide (Sb^2S^3) with 20%; the result shows that the wear rate of hybrid composite is smaller than the binary composite's one. In a recent study the effect of different percentage age of silicon carbide particles (SiC) (5%, 10% and 15% weight) on wear characteristic of Al based composite material was investigated.

Experimental Work

Materials

Al 6061 with different percentages of SiC, (5%, 10%. 15%) were investigated.

Specimens Preparation

Specimens for wear test and properties were prepared by casting method; the ingots of aluminum 6061 were divided into little pieces and melted at 700°C in a graphite crucible of high electric furnace (max 1200°C). After removing the dross, the incorporation of SiC into the aluminum 6061 is melted by making a whirlpool in the alloy with manual stirring. After thoroughly blending SiC molecules with various percentages at any time, composite pattern was cast in permanent disc mold. The mold was manufactured from high stainless steel and designed according to international standard ASTM G99-95, the dimensions of the testing specimens were, 30 mm in diameter, and 10 mm in height, the density of the resulted composite is shown in Table (1).

Table 1: Density of composite

Density	ρ (g /mm^3)
AL6061	0.0027
AL-SIC5%	0.00275
AL-SIC10%	0.00278
AL-SIC15%	0.00281

Wear Test

The abrasive wear technique was used to measure the specific wear rate and the sliding speed with various applied loads ranging from 10 to 30 N. The wear test measurement was carried out by using a pin-on-disc abrasion wear tester device (model: NUS-1). Emery papers of abrasive sizes were fixed on a wheel (diameter 60 mm, thickness 12 mm) to perform as an abrasive media. At the sliding speed of 1.74m/s the tests are performed on a sliding distance from 1044 m to 3123 m at different times (10 min, 20 min and 30 min) and the material of disc is EN 36 steel. Dry sliding wear tests were performed at room temperature, the samples were prepared by using the cut from the cast specimens (12 mm diameters and 15mm length), and each sample was cleaned thoroughly before and after wear tests, polished samples of (40×35×4) mm in size. The weight loss of each specimen was identified by weighing the specimen before and after the experiment. The specific wear rate was calculated from the weight loss data which was measured by using the digital electronic balance (up to 0.01 g accuracy). During the test, the sample is squeezed against a revolving EN32 steel disc (hardness of 65HRC) by applying load that acts as counter-weight and balances the pin. The following equations were used in the account:

N mot r = n_1, note: $n_1 > n_2$

Where N: motor angular velocity

$i = \frac{n1}{n2} \Rightarrow 3.424 = \frac{950}{n2}$ Where i: reduction ratio

$\therefore n2 = n\ disc = 277.4\ rpm$

$$v = \omega * r = \frac{2\pi * n}{60} * r = \frac{2\pi * 277.4}{60} * 0.06$$

$v = 1.74\ m/s\ (sliding\ velocity)$

$Sliding\ distance\ = velocity * time$

With different times (10 min, 20 min and 30 min) and the material of disc is EN 36 steel with hardness of 385 Hv. Specific wear can be counted according to the following equation. $W_s = \frac{\Delta m}{\rho \cdot t \cdot v \cdot F}$

Where (W_s) is the specific wear rate, Δm: weight loss, ρ: density, t: time, F: load.

Hardness Test

Hardness may be identified as the resistance to deformation, and for metal characteristic is a measure of their resistance to permanent or plastic deformation. The Brinell method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then vanished. The resulting impression is measured across at least two diameters usually at right angles to each other and these results averaged (d). A chart is then used to convert the averaged diameter measurement to a Brinell hardness number. Test forces range from 500 to 3000kgf. The hardness technique is used to determine Brinell hardness, identified in ASTM E10. The hardness measurements are set by using (i-sensys-LBP2900B Brinell device) with digital readout system, applied load 500 Kg, ball of fixed diameter equal to 10mm, and total load time normally (10-15) s. Brinell hardness can be calculated according to the following equation.

$$HB = \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})}$$ Since: - F= 500 Kg and D=10mm.

The Brinell number, which normally ranges from 50 BHN to 750 BHN for metals, will increase as the sample gets harder.

Results and Discussion

Abrasive Wear

The effect of specific wear rate on the AI 6061 with percentage age of SiC (Al-6061- 5 wt. % Sic), (Al-6061- 10 wt. % Sic) and (Al-6061- 15 wt. % Sic) can be determined by the abrasive wear technique. For loads ranging from 10 to 30 N and sliding speed of (1, 74) m/s, we can perform tribological tests. The performed sliding distance tests are about 3000mm and the material of disc is EN 36 steel with hardness of 385 Hv. Table (2) and figure (1) below illustrate certain wear rates with load for AI 6061 and with (Al6061- 5 wt. % Sic), (Al6061-10 wt.% Sic) and (Al6061-15 wt.% Sic). As it was proved that with increase in SiC percentage age, the wear of composites increases directly proportional with the applied load because of the hardness imparted due to SiC addition. The highest wear takes place in aluminum alloy, while, with Al/ SiC composite, the wear decreases inversely with the increase in SiC percentage age.

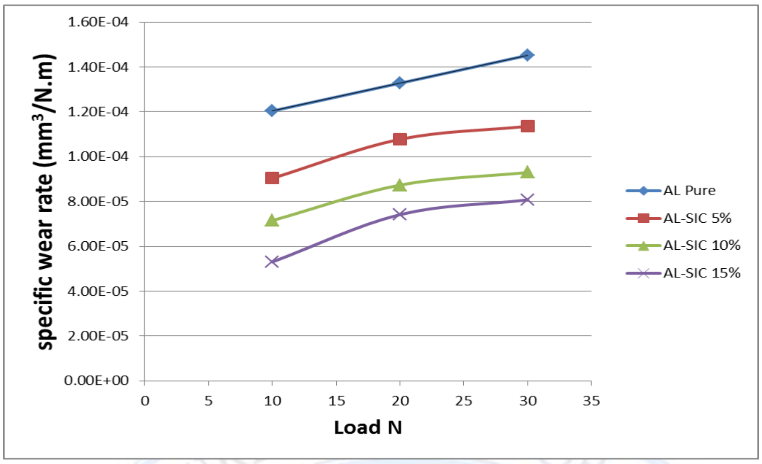

Figure 1: Specific wear rate with load for (AI6061), (AI-6061- 5 wt. % Sic), (AL-6061- 10 wt. % Sic) and (AL-6061- 15 wt. % Sic)

Table 2: specific wear rate with applied load for (AI-6061), (Al-6061- 5 wt. % Sic), (Al-6061- 10 wt. % Sic) and (Al-6061- 15wt. % Sic).

	Ws= Δm/(ρ.t.v.Fn) (mm³/N.m)	Δm (g)	ρ (g /mm³)	t (s)	V(m/s)	F(N)
Al-6061						
1	1.20E-04	0.0034	0.0027	600	1.742955	10
2	1.33E-04	0.0075	0.0027	600	1.742955	20
3	1.45E-04	0.0123	0.0027	600	1.742955	30
AI-SIC 5%						
1	9.04E-05	0.0026	0.00275	600	1.742955	10
2	1.08E-04	0.0062	0.00275	600	1.742955	20
3	1.14E-04	0.0098	0.00275	600	1.742955	30
	AI-SIC 10%					
1	7.15E-05	0.00208	0.00278	600	1.742955	10
2	8.74E-05	0.00508	0.00278	600	1.742955	20
3	9.30E-05	0.00811	0.00278	600	1.742955	30
	AI-SIC 15%					
1	5.31E-05	0.00156	0.00281	600	1.742955	10
2	7.42E-05	0.00436	0.00281	600	1.742955	20
3	8.08E-05	0.00712	0.00281	600	1.742955	30

Table (3) and Figure (2) below illustrate specific wear rates with sliding distance for AL 6061 and with (Al6061- 5 wt. % Sic), (Al6061- 10 wt. % Sic) and (Al6061- 15 wt. % Sic). It was proved that with the increase in SiC percentage age, the wear of composite increases with the increase in sliding distance. The highest wear occurs in aluminum alloy, while with Al/SiC composite, the wear decreases with the increase in SiC percentage age.

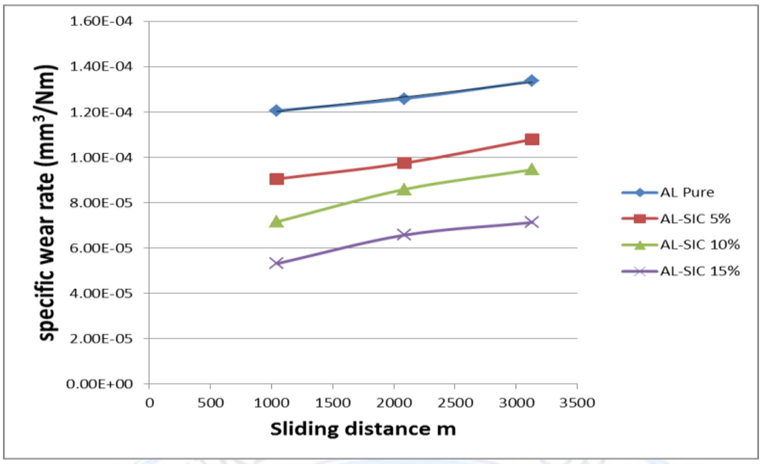

Figure 2: Specific wear rate with sliding distance for (Al, Al- 5-15 wt. % Sic),

Table 3: Specific wear rate with sliding distance for (AI 6061), (Al6061- 5 wt. % Sic), (Al6061-10 wt. % Sic) and (Al6061- 15 wt. % Sic), at (10N) load

N0.	Ws= m/(ρ.t.v.Fn) (mm^3/N.m)	Δm (g)	ρ (g /mm3)	t (s)	V(m/s)	sliding distance (m)
AI6061						
1	1.21E-04	0.0034	0.0027	600	1.74	1044
2	1.26E-04	0.0071	0.0027	1200	1.74	2088
3	1.34E-04	0.0113	0.0027	1800	1.74	3132
AI-SIC5%						
1	9.06E-05	0.0026	0.00275	600	1.74	1044
2	9.75E-05	0.0056	0.00275	1200	1.74	2088
3	1.08E-04	0.0093	0.00275	1800	1.74	3132
AI-SIC10%						
1	7.17E-05	0.00208	0.00278	600	1.74	1044
2	8.60E-05	0.00499	0.00278	1200	1.74	2088
3	9.46E-05	0.00824	0.00278	1800	1.74	3132
AI-SIC15%						
1	5.32E-05	0.00156	0.00281	600	1.74	1044
2	6.58E-05	0.00386	0.00281	1200	1.74	2088
3	7.14E-05	0.00628	0.00281	1800	1.74	3132

Table (4) and Figure (3) below illustrate the hardness of Brinell for (AL 6061), (Al6061- 5 wt. % Sic), (Al6061- 10 wt.% Sic) and (Al6061- 15 wt.% Sic). It was found that hardness increases simultaneously when the SiC percentage age increases. The highest hardness takes place in (AL- 15 wt. % SiC); with Al/SiC composite, the hardness decreases with the decreases of SiC percentage age, the lower value of hardness takes place in pure (AL 6061). It is obvious that the wear rate trend is inversely proportional to the hardness, and SiC percentage age causes an increase in hardness while on the other hand causes an obvious decrease in wear rate. That is why SiC is commonly added in order to enhance the wear rate characteristics.

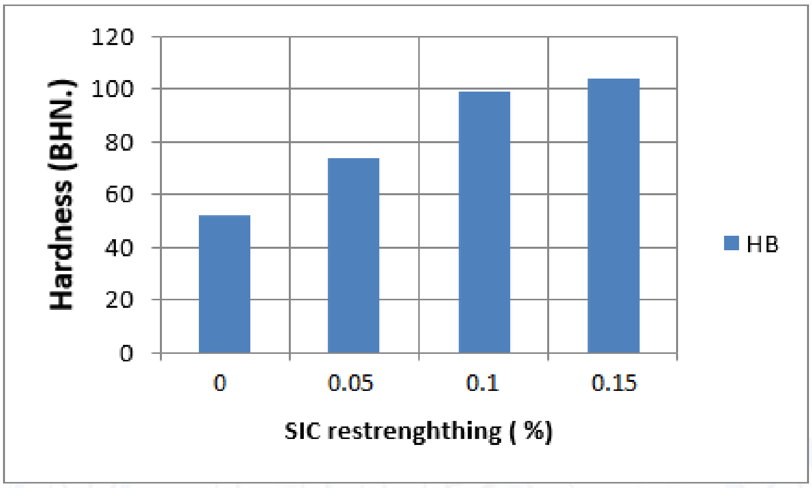

Figure 3: The hardness (BHN) of AI, AI- 5-15 wt. % Sic

Table 4: Brinell hardness for (AI 6061), (Al6061- 5 wt. % Sic), (Al6061- 10 wt. % SiC) and (Al6061- 15 wt. % SiC

NO.	Type	Brinell Hardness	Load(kg)	D(mm)	d (mm)
1	AL	52HBS500	500	10	3.415
2	AL-SIC 5%	52HBS500	500	10	2.885
3	AL-SIC 10%	52HBS500	500	10	2.513
4	AL-SIC 15%	52HBS500	500	10	2.445

Conclusions

The combined results of specific wear rates and hardness for (AI 6061), (Al6061- 5-15 wt. % Sic) show that:

1. The highest wear occurs in aluminum alloy, while, with Al/ SiC wt% complexes, the wear decreases with the increase in SiC percentage age.
2. The wear of complexes increases with the increase in applied load.
3. The wear of complexes increases with the increase in sliding distance.
4. The Brinell Hardness increases with the increase in SiC percentage age.
5. The lower value of hardness occurs in (Al 6061).

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