

## Effect Of Addition 4%SiCp On Adhesive Wears Resistance Of Aluminum Alloy (2024-T3)

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### Abstract :

*In this study the effect of silicon carbide particle (SiCp) of 50 $\mu$ m size reinforced to AA 2024-T3 in the percentage of 4% was investigated.*

*Wear specimens were prepared in dimensions of 20mm\*10mm according to ASTM (G99-04) from Native metal, base cast alloy and casting reinforced alloy.*

*Microstructure was examined using optical microscope to examine the structure and hardness test also implemented to show its effect on wear resistance*

*Adhesive wear test was carried out on all alloys at different parameters (sliding time, load and velocity).*

*From the obtained results of wear test it was found that wear rate increased with the increasing of all the studied parameters and the reinforced alloy improved the wear resistance in the percentage of 14% while the cast alloy improved it in the percentage of 10% comparing with the native alloy that is because of the improving in hardness value achieved after adding silicon carbide.*

*A mathematical model has been made depending on the method of least squares which helps in foretelling about the wear rate through the knowledge of time limits taken from the experimental test as a variable with fixing the other variables; also building a model with the same method by which foretelling the rate of adhesive wear through knowing the sliding speed and load.*

*The mathematical (theoretical) results shows a great match in magnitude with wear values attained from experimental test.*

*Key words: Metal matrix composite, adhesive wear resistance, Aluminum alloy 2024-T3*

### % من كاربيد السليكون على مقاومة البلى الالتصاقى لسبيكة الألمنيوم تأثير إضافة 4 2024-T3

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### الخلاصة :

يهدف البحث الى دراسة تأثير إضافة كاربيد السليكون بنسبة 4 % كمادة تقوية وبحجم حبيبي 50 $\mu$ m لسبيكة ألمنيوم 2024-T3.

إذ تم تصنيع عينات اختبار البلى الالتصاقى بإبعاد 20 ملم طول و 10 ملم قطر وفق المواصفة القياسية -ASTMG99- 04 من المعدن الأساس والمعدن بعد سبكه والسبيكة المقواة  
 اجري اختبار الصلادة وفحص البنية المجهرية لكافة مجاميع العينات من السبائك المشار إليها في أعلاه وكذلك إجراء اختبار البلى الالتصاقى عند المتغيرات ( الوقت، الحمل، السرعة) .  
 ومن النتائج التي تم الحصول عليها لمعدل البلى وجد ان عند جميع المتغيرات هناك زيادة في قيم معدل البلى عند زيادة قيم المتغير، وأعطت عينات السبيكة المقواة تحسنا بمقدار 14 % وعينات السبيكة بعد الصب بمقدار 10 % لقيم مقاومة البلى مقارنة مع المعدن الأساس بسبب التحسن الذي حصل في قيم الصلادة عند إضافة كاربيد السيلكون.  
 وكذلك تم بناء نموذج رياضي بالاعتماد على طريقة المربعات الصغرى لحساب معدل البلى ويفيد في التنبأ عن معدل البلى من خلال إعطاء قيم الزمن كمتغير أخذت قيمه من التجارب العملية وبقاء قيم الحمل المسلط وسرعة الانزلاق كثوابت، والتكرار لمعرفة مقدار البلى للمتغيرات الأخرى من حمل مسلط وسرعة انزلاق و أظهرت النتائج المحصلة من الموديل الرياضي تطابقا جيدا مع النتائج العملية

## 1. Introduction :

Now days the most promising materials for advanced and novel industrial requirements include composite materials based on light weight alloy matrix reinforced with ceramic particles or fibers <sup>[1]</sup>.

The physical and mechanical properties of aluminum-based metal matrix composites MMCs have made them attractive materials for automotive and aerospace applications various techniques are employed to manufacture MMCS, which include methods to produce useful engineering shapes and these might be used to produce basic MMC master alloys, such as melt or powder processing alloys The last two methods are the most extensively used, due to the complexity of some of the other processes, and the need for entirely new manufacturing facilities in some other cases. A low-cost technique based on the stirring process has been proposed which can produce composites by conventional aluminum foundry practices, however; the lack of wettability between the molten aluminum and most ceramic particles is the major difficulty of the stirring process, which produces only composites with a low wt. % up to 5% <sup>[2]</sup>.

The addition of SiC to Al - 4% Cu refines its structure and improves the yield strength, and the ultimate tensile strength whereas ductility is decreased The wear resistance and friction coefficients are also increased <sup>[3]</sup>.Wear classified to many types such as, adhesive wear which occurs when two surfaces are moving relatively one over the other, and this relative movement is in one direction or a successive movement under the effect of the load so that the pressure on the adjacent projections is big enough to make a load plastic deformation and adhesion. This adhesion will be at a high grade of efficiency and capability in relative to the clean surfaces and the area will be increased during movement at the end there will be some relative wear in the superficial tissues in the weak points of the noticeable <sup>[4]</sup>

Many studies were implemented in this area.

**A.Kok** <sup>[5]</sup> studied the wear behavior and weight fraction of particles up to 30% Al<sub>2</sub>O<sub>3</sub> 2024 aluminum alloy metal finding that the wear resistance of the composites is bigger than that of aluminum alloy and increased with the increasing of Al<sub>2</sub>O<sub>3</sub> particles content and size.

**J.W. Kaczmar** <sup>[6]</sup> studied the wear improvement of aluminum matrix composite materials reinforced with alumina fibers, finding that revealed slightly better resistance under lower pressure.

**V.R. Rajeev** <sup>[7]</sup> studied the effect of normal load and reciprocating velocity on transition from mild to severe wear of A319/15%SiCp, A336/15%SiCp, and A390/15%SiCp composite founding that increase in normal load increases wear rate and depending upon the reciprocating velocity and type of composites.

**S. Mahdavi • F. Akhlaghi** <sup>[8]</sup> studied the effect of size of SiC particles on the dry sliding wear properties of composites with three different sized SiC particles (19, 93, and 146 μm) He found that wear mechanism changed from mostly adhesive and micro-cutting in the Al/10SiC composite containing fine SiC particles to the prominently abrasive and delamination wear by increasing of SiC particle size. While the main wear mechanism for the unreinforced alloy was adhesive wear, all the hybrid composites were worn mainly by abrasion and delamination mechanisms.

This paper aims to study the effect of 4% SiC particles addition to aluminum alloy 2024-T3 on wear resistance and building a mathematical model to predict the values of wear rate to all variables.

## 2. Experimental work

### 2.1 Metal select

Aluminum alloy 2024 T3 according to AISI was select and its chemical analysis is indicated in Table (1) which was conducted by ARL Spectrometer in the specialized institution of engineering industries at industry ministry.

**Table (1) Chemical composition for Aluminum Alloy (2024-T3)**

Element wt%	Al	Ti	Cr	Zn	Si	Fe	Mn	Mg	Cu
measured value	92.6	0	0.05	0.1	0.4	0.3	0.6	1.5	4.4
Standard value	Rem.	0-0.15	0-0.1	0-0.25	0-0.5	0-0.5	0.3-0.9	1.2-1.8	3.8-4.9

To produce Al-Cu-Mg cast and cast composites A liquid metallurgy route has been adopted which includes:

- 1- Melting the base alloy Al2024 T3 in two crucibles to 750 C<sup>0</sup>
- 2- Casting the molten liquid from one crucible in a die of dimensions 12 mm diameter and 150 mm length to produce the base material cast alloy.
- 3- Add to the molten liquid of the other crucible the SiC quantity gradually and stirring manually to form the composite in the percentage of 4%.

## 2.2 Preperation of specimens

Cylindrical specimens for the adhesion wear tests were fabricated with dimensions (10x20mm) according to ASTM (G99-04) specifications.

## 3.2 Categorization

After completing the fabrication of specimens, these specimens were classified and sorted into groups as shown in Table (2).

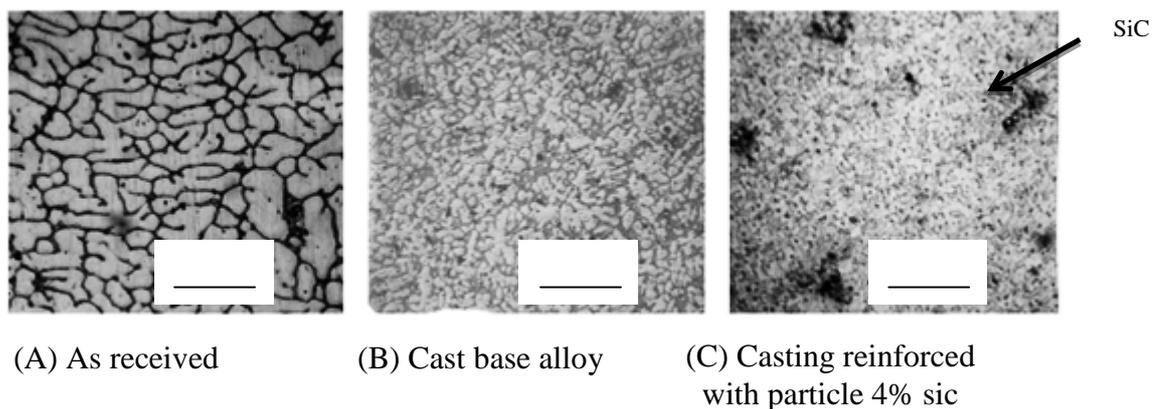
**Table (2) categorization of specimens**

A	As received (native metal)
B	Cast base alloy
C	Casting reinforced with particle 4% SiC (composite)

## 4.2 Microstructure Examination

Microstructure on specimens groups in Table (2), the specimens were prepared as follows:

- 1- The specimens are ground with emery papers of grades 120,350,500,800.
- 2- Polished with a special cloth and Alumina  $Al_2O_3$  solution of size 0. 3.μ.
- 3- Etching the structure by using etching Keller's reagent solution consisting of 95 ml distill water, 2.5 ml  $HNO_3$ , 1.5 ml  $HCl$  and 1 ml  $HF$  and washed after that with water and then dried.
- 4- The optical micrograph of the cast base alloy of Al 2024-T3 and cast composite is indicated in Figure (1) was carried out.



**Fig. (1)The microstructure of all specimens in Table (2)**

## 5.2 Hardness test

Hardness test results which was implemented on all specimens in Table (2) by using Vickers hardness are shown in Table (3)

**Table (3) the hardness test results**

sample	Hardness (Hv) kg/mm <sup>2</sup>
A	87
B	92
C	102

### 6.2 Adhesion wear test

Adhesive wear test was implemented for all specimens by using pin on disc technique as shown in Fig.(2) which includes, fixing the specimen by the bearer in vertical position on steel disc having hardness HRC=54 and rotating at 940 r.p.m, then specify the variables which needed to know its effect on the wear rate like( time, load, sliding speed) ,each parameter include a series of variables when the stage finished we fixed one parameter and change others ,the specimen weight measured before and after test.

The wear rate is calculated from the following equation <sup>[9]</sup>

$$W_r = \frac{\Delta W}{2\pi r t} \dots\dots\dots (1) \text{ [10]}$$

Where

$W_r$ - is wear rate in gm/cm

$2\pi r$ - is the sliding distance (cm)

$t$ - is the time

$\Delta w = w_1 - w_2$



**Fig (2) Apparatuses of adhesive wear test**

### 3. Mathematical Model

After completion of the adhesion wear tests and taking into consideration that the sliding speed is variables which will be effected with other variables like loads and time which were fixed in finding the model which was found after relying on the method of the simplest linear

deviation to show the relation between the basic variables to test wear. The model included the following steps:-

- 1- Writing the general formula for extracting the rate of wear from Eq.(1).
- 2- The Ordinary Least Square (OLS) method is applied in estimating the Eq.(1) through minimizing the total value of the total error squares and the error is the difference between the actual value and the estimated value according to the steps, where it was built a model the simplest linear deviation representing the relation between the dependent variable (wear rate)  $Wr$  and the independent variable (time)  $t$ .

Where:

$$Wr_i = \alpha + \beta t_i + U_i \dots \dots \dots (2) [10]$$

Following is summarizing of OLS steps which basically depend on minimizing the total errors.

$$u_i = (Wr - \alpha - \beta t_i) \dots \dots \dots (3)$$

$$\sum u_i^2 = \sum_{i=1}^n (Wr - \alpha - \beta t_i)^2 \dots \dots \dots (4)$$

Then derive Eq. (4) with respect to  $\alpha$  and  $\beta$

$$\frac{\partial \sum u_i^2}{\partial \alpha} = -2 \sum_{i=1}^n (Wr - \alpha - \beta t_i) \dots \dots \dots (5)$$

$$\frac{\partial \sum u_i^2}{\partial \beta} = -2 \sum_{i=1}^n (Wr - \alpha - \beta t_i) t_i \dots \dots \dots (6)$$

After that the derived equation is equalized to zero, the estimated  $\alpha, \beta$  values are determined as follows:

$$\alpha = \bar{w}_r - \beta \bar{t} \dots \dots \dots (7)$$

$$\beta = \frac{\sum_{i=1}^n W_r t_i - n \bar{w}_r \bar{t}}{\sum_{i=1}^n t_i^2 - n \bar{t}^2} \dots \dots \dots (8)$$

Where

$$\bar{w}_r = \frac{\sum_{i=1}^n W_{ri}}{n} \dots \dots \dots (9)$$

$$\bar{t} = \frac{\sum_{i=1}^n t_i}{n} \dots \dots \dots (10)$$

In the similar way the relationships of wear rate with sliding speed and variables load are derived. Thus the mathematical model of wear rate will be as shown in table (4):

**Table (4) Mathematical Model of wear rate**

Variable	W.r equation	Specimen
Speed	$= 7 \cdot 10^{-7} \text{ Log } V - 6 \cdot 10^{-7}$	A
	$= 1 \cdot 10^{-7} \text{ Log } V - 1 \cdot 10^{-7}$	B
	$= 3 \cdot 10^{-8} \text{ Log } V - 2 \cdot 10^{-9}$	C
Time	$= 1 \cdot 10^{-8} \text{ Log } t + 6 \cdot 10^{-9}$	A
	$= 2 \cdot 10^{-9} \text{ Log } t - 4 \cdot 10^{-9}$	B
	$= 3 \cdot 10^{-12} \text{ Log } t + 3 \cdot 10^{-11}$	C
Load	$= 6 \cdot 10^{-8} \text{ Log } F + 7 \cdot 10^{-8}$	A
	$= 5 \cdot 10^{-8} \text{ Log } F + 5 \cdot 10^{-8}$	B
	$= 3 \cdot 10^{-8} \text{ Log } F + 4 \cdot 10^{-8}$	C

Where V, t, and F are the sliding speed, time and load respectively.

#### 4. Results and discussion

In **Figure.(1)** The matrix structure of the composite shows a smaller grain size than that of A& B samples.

These results may be due to the presence of SiCp, which acts as sites of nucleation during solidification of the melt. The microstructure of this and similar composites shows the absence of voids and a uniform distribution of SiCp in the matrix structure, this is in agreement with researcher in <sup>[3]</sup>.

From the obtained results in Table (3), it was seen that carbide silicon addition at 4 wt % contributed in increasing hardness comparing with specimens (A), (B).

The distribution of SiC particles in a matrix alloy is uniform. Further the micrographs reveal good bond between the matrix alloy and SiC particles. This is due to the presence of Cu in chemical composition of Al-alloy which improves the wettability of ceramics particles with matrix alloy and also increases the retention percentage of SiC particles in matrix <sup>[3]</sup>.

The relationship between wear and other parameters for experimental and mathematical model results are shown in Figures. (3, 4, 5), the Continuous lines refer to the experimental results while the dashed lines to the mathematical model results.

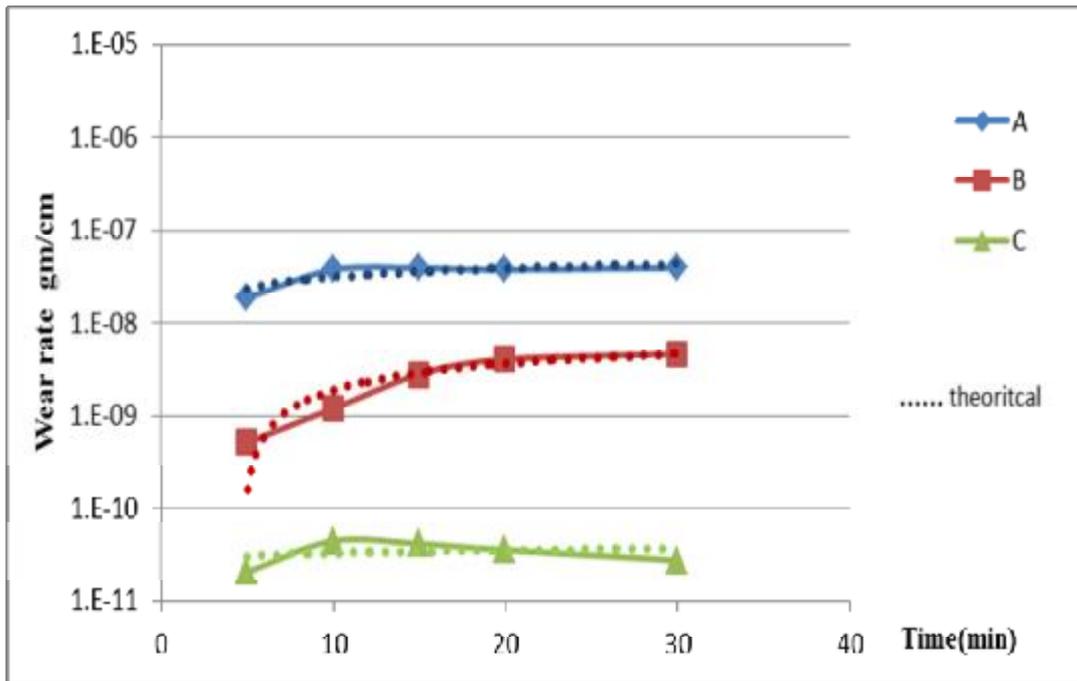


Fig.(3) The relationship between sliding time and wear rate at constant parameters 1.5 kg load and sliding speed 5.5 m/sec

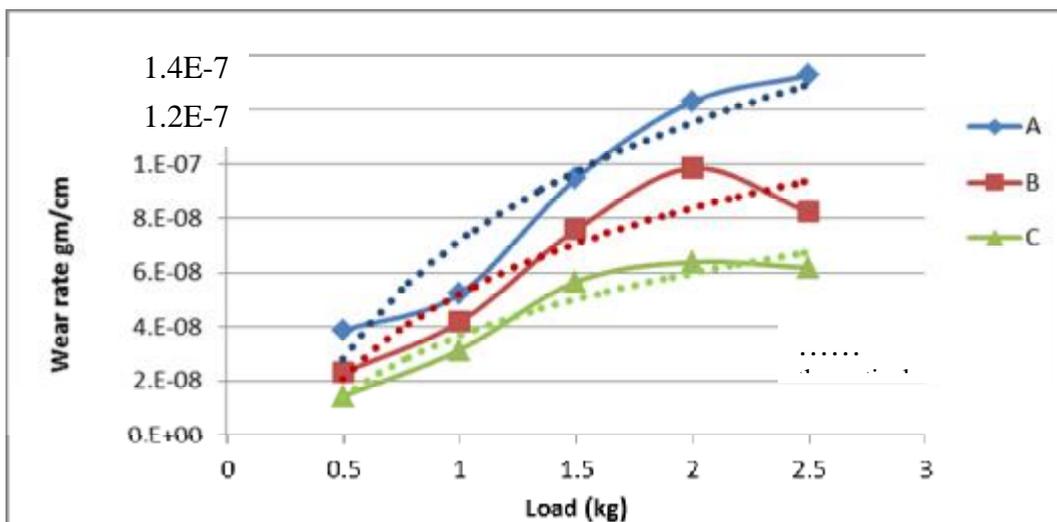
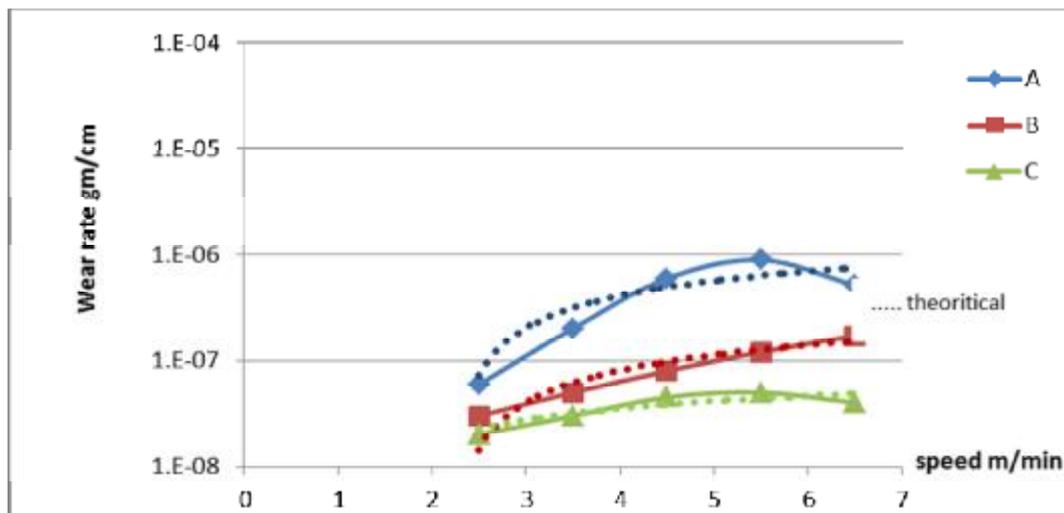


Fig.(4) The relationship between load and wear rate at constant parameters 10min and sliding speed 5.5m/sec



**Fig. (5) The effect of sliding speed on wear rate at time 10 min and load 1.5 kg**

In **Figure(3)** it was seen that all specimens give an increase in wear rate with increasing in sliding time because increasing in time will cause an increase the period of contact between tips of the surface ,but specimen ( C ) gives the lowest value because SiC causes an increase in hardness which contributed in this improvement, **Figure (4)** shows the effect of load on wear rate for all specimens, it was seen an increasing in wear rate as increasing in load since the adhesive process of the two tips surfaces depends on applied load, if the load is low the contact appears in upper bit and this was very thin during sliding process that causes a thin layer from oxide works as a protective surface film which limits the touching between the two sliding surfaces and prevent the direct metallic connection between the surfaces tips thus the required force to cut and separate the occurred connection between the two surfaces tips less than the force between the metal atoms itself and that will cause a decrease in wear rate ,on the other hand an increasing in applied load this will break the oxide film because of its brittleness for its shoots out the friction sliding surfaces for both the discs and specimen during the sliding process which causes a strong metal contact between them make the required force to shear its contact tips more than the force between the metal atoms itself ,it was seen that specimen (C) gives the lowest wear rate value for the same above reason.

The effect of sliding speed on wear rate is shown in **Figure.(5)** All specimens give an increasing in wear rate as increasing the sliding speed, this is due to the fact that duration of rubbing is the same for all sliding speed, while the length of rubbing is more in case of higher speed.

The dashed lines in **Figures (3, 4, and 5)** shows the mathematical (theoretical) model results which give a convergence in magnitudes of wear rate results attained from experimental experiments.

## 5. Conclusions

- 1- The hardness of composites is higher in a percentage of 12% than that for cast (Al-Cu-Mg)
- 2- The addition of SiCp in 4% greatly improves the wear of the composite in a percentage of 14% comparing with the native alloy while the cast alloy improve the wear in 10% comparing with the native alloy.
- 3- Make a mathematical model which foretells the rate of adhesion wear through the knowledge of the time period, sliding speed and loads, these models are for experiments, which means that the wear value depends on the specified parameters magnitudes taken from the experiments.
- 4- The mathematical model equations show a convergence in results with the experimental one.

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