Investigation on Wear Behavior of Al-Si Eutectic Alloy

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***Abstract*—Samples of aluminum-silicon eutectic alloys were cast via stir casting method to investigate their wear behavior. Three types of samples were prepared. The first solidified under the effect of mechanical vibration (using an amplitude of 0.5 mm and a frequency of 25 Hz); the second has an addition of 0.13 wt% titanium as alloying element; while the third cast with the combined effect of added titanium and mold vibration. Chemical composition test, scanning electron microscope (SEM) analysis, macro-hardness and wear tests were done for the prepared samples. The results showed that at 27 ℃ for 25 minute loading with a load of 20 N, the lowest wear rate of sample prepared with the combined effect of mold vibration and addition of titanium, the biggest wear rate for sample with the effect of vibration, and the wear rate of sample prepared with addition of titanium between them. The wear rate at 100 ℃ is lesser than that at 27 ℃ for all samples at the same conditions.**

Keywords-aluminum-silicon; eutectic; stir casting; grain refiner; mold vibration; wear behavior

I. INTRODUCTION

Alloys of aluminum-silicon are widely used in the automotive and aerospace industries. Such alloys have high combination of castability and mechanical properties, and have a good wear properties. Alloys with the eutectic percentage (12-13wt%Si) are used for parts that required high performance at elevated temperatures specially in automobile and aeronautical industries [1, 2]. The high wear resistance is essential requirement for such applications.

This can be achieved by eliminating the defects of the casting and reducing their grain size. A finer equiaxed structure leads to improve the mechanical behavior of the cast alloy, reduce the porosity, and to the better dispersion of second phase particles [3]. Mold vibration and adding an alloying element as a grain refiner are the most published methods by many researcher to enhance the mechanical properties of Al-Si alloys. Haydar Al-Ethari et.al [4] investigated the effects of mechanical vibrations and squeeze casting on some properties of Al-17 %Si alloy. The results showed that the grain size reduced and the hardness, the tensile strength, and the fatigue life improved. Candrashekharaiahn and Koric [5] studied the effect of titanium on the wear behavior of eutectic Al-Si alloys. The Results indicated an increase in the wear resistance of the eutectic alloy due to the added grain refiner. Jakanur [6] investigated the influence of titanium on the wear of Al(13-20)wt.%Si. The results showed that adding of titanium enhanced the wear performance of such alloys at elevated temperature. Dabb et.al [7] studied the wear behavior of Al-(13-20)wt% Si alloys at elevated temperatures. The results showed that the wear resistance increases as the temperature increases due to the oxide layers formations, which prevents direct contact between the surfaces sliding on each other. Haydar Al-Ethari et.al [8] studied the influence of the mechanical vibration on structural and other properties of Al-Si eutectic alloy. The results showed a significant reduction in the grain size of the dendrite and in the porosity of the samples. In addition, there is an improvement in the hardness, and the tensile properties of these samples.

The present paper is a comparative study to the effects of mechanical molds vibrations; titanium addition; and the combined effect of both of them on the wear behaviors of eutectic Al-Si alloys.

II. EXPERIMENTAL PART

A. *Materials of the Study*

Silicon's bulks (99.9% purity), titanium (99.8% purity), and aluminum wires (99.7% purity) were used to fabricate the samples. Table 1 contains the composition of the aluminum wires.

B. *Preparation of the Samples*

Four types of the alloy were prepared by stir casting. Five samples of each type were prepared to perform each test. The average of the results of each test was recorded. results obtained and used the of these sample to compare between other types of prepared alloys. All types of the prepared samples are illustrated and coded in Table I.

All samples were cast using stir casting method. Electric furnace type (ORH5-F102200) was used to melt the aluminum wire. Short cuts of the wire charged by ceramic crucible to the furnace and heated to 750 ℃. The silicon bulk and titanium powder immersed gradually inside the melt via an envelope of aluminum foil. The melt stirred manually by ceramic rode, and then poured into a steel die preheated to 300 ℃. The die has a cylindrical cavity (20 mm diameter and 150 mm height). In casting with mechanical mold vibration, the die attached to a system providing mechanical vibration up to the complete solidification.

Figure 1 shows the device having a shaft with an eccentricity to provide the mold vibration with an amplitude of 0.5 mm [8, 9]. The electric motor can provide the frequency of 25 Hz in cast all samples.

TABLE I. COMPOSITION OF THE USED ALUMINUM WIRE

Al (Wt.%)	**Mg (Wt.%)**	**Fe (Wt.%)**	**Si (Wt.%)**	**Zn (Wt.%)**	**Ti (Wt.%)**	**Cr (Wt.%)**	**Cu (Wt.%)**	**Other elements (Wt.%)**
99.7	0.1201	0.113	0.022	0.02	0.004	0.003	0.001	0.0169

TABLE II. THE PREPARED ALLOY SAMPLES

Sample`s code	**Mechanical Vibration**		**Titanium addition**
	Frequency (Hz)	***Amplitude (mm)***	
S0	No	No	No
S1	25	0.5	No
S2	No	No	0.13
S3	25	0.5	0.13

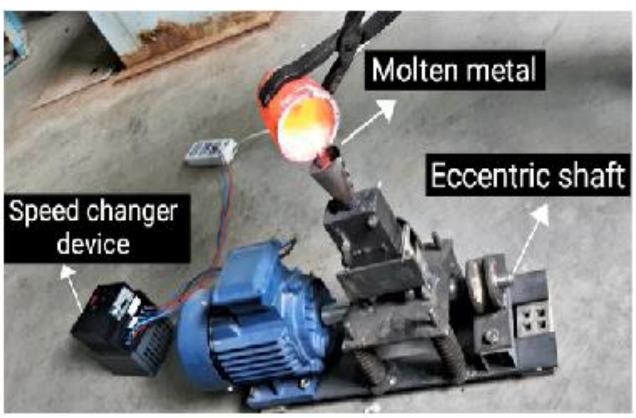

Figure 1. Vibration device [9].

III. TESTS OF THE SAMPLES /RESULTS AND DISCUSSION

A. *Chemical Composition*

XRF-spectrometer analyses ensure the required percentages of silicon and titanium in the prepared samples as shown Table II.

. The silicon weight percentages is in the range (12.1772 to 12.9147), while the weight percentages of titanium in S2 and S3 samples were 0.1398% and 0.1321% respectively.

B. *Scanning Electron Microscope (SEM) Analysis*

Suitable grinding were performed to the specimens of 20 mm diam. and 10mm in height by using SiC paper grits as (180.0 - 220- 400 - 600 -800 - 1000 -1200 -1500 -2000 and 2500 grits) and then polished by diamond of 0.2 μm. Keller’s reagents (95mL H_2O, 2.5 mL HNO_3, 1.5 mL HCl, 1.0 mL HF) based on ASTM (E407-07) [10] used to the specimens. SEM type (TESCAN S8000) was used. Figure 2a shows the SEM image of aluminum silicon eutectic alloys of sample (S0). The microstructure of the sample contain a large size of dendrite grains of aluminum. It contains large plats or needles of eutectic silicon inside the form of large plats with sharped sides and end, this morphology of silicon is general termed as acicular silicon. As the coarse plats or needles of silicon area brittle, the eutectic alloy shows slow ductility and low tensile strength. A finer eutectic silicon flake & refined α-Al dendrites broken as small islands due to mechanical vibration can noticed in figure 2b which shows the SEM image of sample (S1). This effect of mechanical vibration improve the mechanical properties. Figure 2c and 2d show the SEM of samples (S2) and (S3). The coarse eutectic of aluminum silicon plates in sample (S0) is converted into globular particles by titanium and mechanical mold vibration. The grain size of dendrite became smaller compared with that of sample (S0), therefore, there will be an enhancement in mechanical properties.

TABLE III. CHEMICAL COMPOSITION OF THE PREPARED ALLOYS

Alloy sample code	Al wt.%	Si wt.%	Fe wt.%	Mg wt.%	Zn wt.%	Ti wt.%	Cu wt.%	Cr wt.%	Other Elements wt.%
S0	86.4934	12.8071	0.3684	0.1499	0.0516	0.001	0.001	0.001	0.1266
S1	86.7562	12.9147	0.003	0.0688	0.0293	0.001	0.002	0.002	0.2230
S2	87.401	12.0142	0.2948	0.0887	0.0298	0.1398	0.0051	0.002	0.0346
S3	87.1132	12.1772	0.1718	0.0821	0.0344	0.1321	0.0011	0.001	0.2871

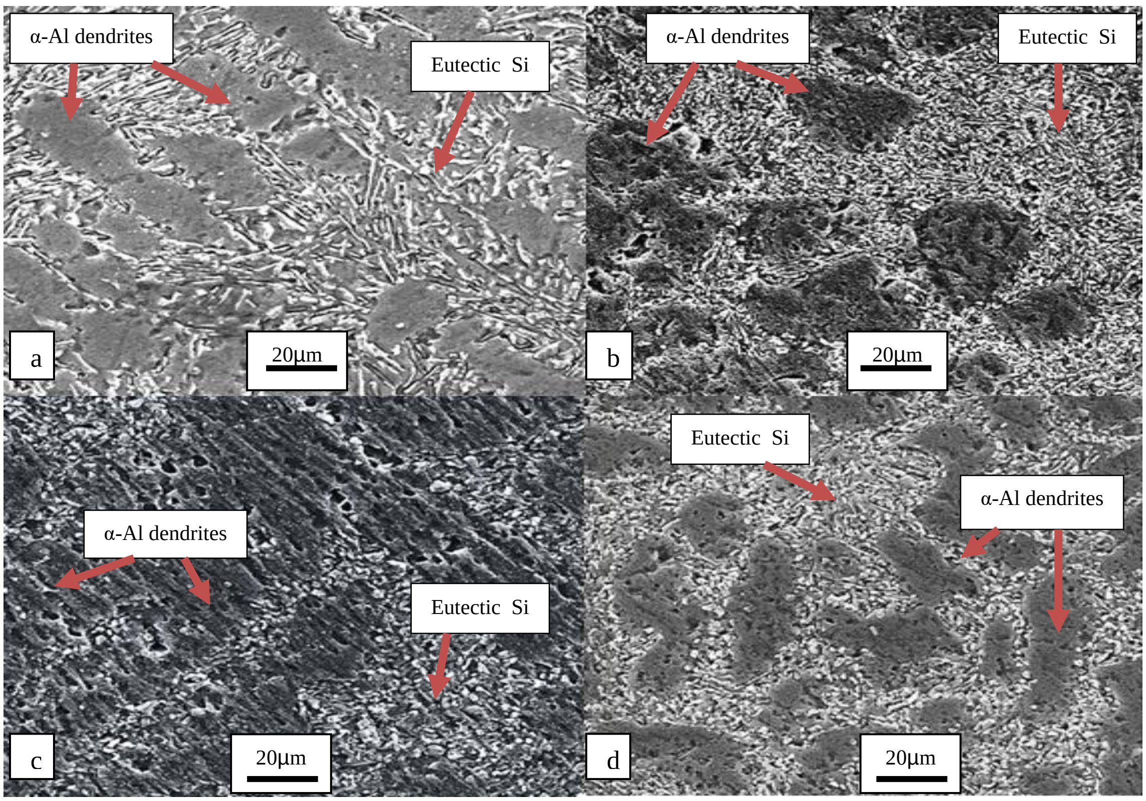

Figure 2. SEM image of samples: a)S0 b)S1 c)S2 d)S3.

C. Macro-hardness Test

The specimens were ground and polished suitably before the test. The test was performed based on ASTM (E10-15a)[11] via Wilson hardness tester type (UH-250) using a ball indenter with 2.5 mm diameter and a loading of 31.25 kg for 10 seconds. For each specimen, the average of three values considered as the Brinell hardness.

The recorded Brinell hardness of 55, 67, 72, and 82 kg/mm^2 for the S0, S1, S2, and S3 alloy samples respectively. Clearly, the combination of vibration and titanium has the greatest effect toward enhancement of the Brinell hardness. Titanium restricts the growth of dendrite grains and forms the intermetallic compound Al_3Ti, which causes the increase of the hardness of the alloy [12]. The effect of the vibration toward reducing the dendrite grain size leads and consequently refining the microstructure, leads to an increase in hardness.

D. Wear Test

Pin-on-disk test technique was used for investigating the wear. The rotating disk is made of steel with a hardness of 2850 HVs, while the pin represented by the specimen. Specimens of 20mm diam., and a height of 10 mm were prepared based on ASTM (G99-104) [13]. Cleaning the specimen and then drying in vacuum furnace at 100 ℃ for 30 minutes were performed. The specimen weighed via electric balance model (M 254A) with $\pm$ 0.0001 accuracy before and after the test to calculate the loss of its weight. Then, the weight loss converted to volume loss according to the following equations:

$$\text{Volume loss } (mm^3) = \frac{\text{weight loss } (g)}{\text{density}(g/mm^3)} \quad (1)$$

where: weight loss = weight before the test – weight after the test

$$\text{Wear rate } (mm^3/min) = \frac{\text{Volume loss } (mm^3)}{\text{Time } (min)} \quad (2)$$

The dry test was performed at 27 ℃ and at 100 ℃ based on a loading by 20 N for 25 minutes. Figure 3 shows the results of the wear test for the prepared samples. The wear rate decreases with the temperature due to the oxide film formation on sliding surface, which prevent the direct contact of the sliding surfaces [14].

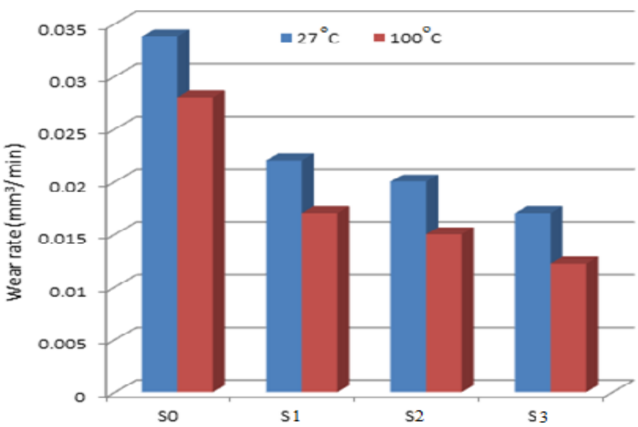

Figure 3. Wear rate of the prepared samples under a load of 20 N for 25 minutes.

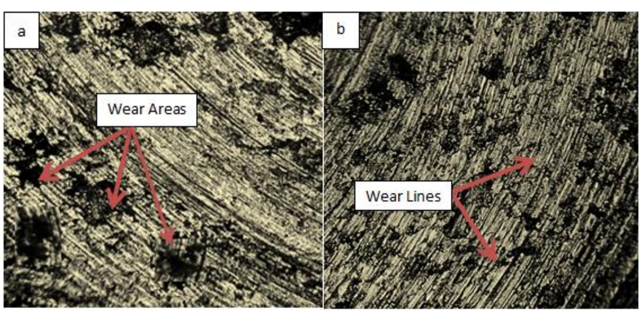

Figure 4. Microstructure for S0 alloy magnification at 100X after wear test under a load of 20 N for 25 minute: a) at 27 ℃ b) at 100 ℃.

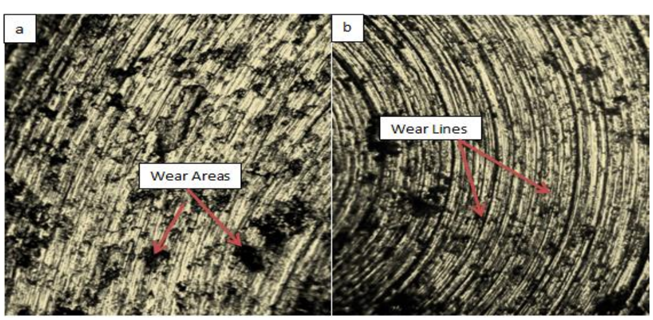

Figure 5. Microstructure for S1alloy magnification at 100X after wear test under a load of 20 N for 25 minute: a) at 27 ℃ b) at 100 ℃.

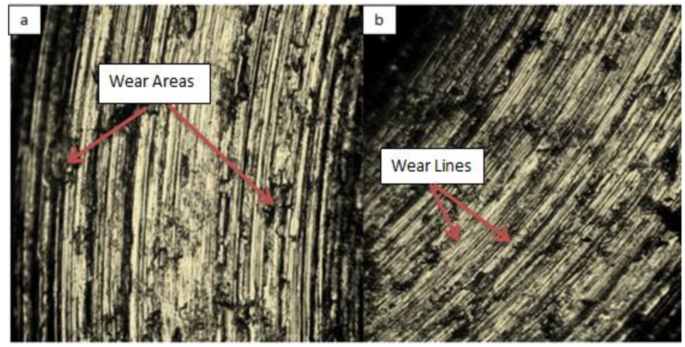

Figure 6. Microstructure for S2 alloy magnification at 100X after wear test under load of 20 N for 25 minute: a) at 27 ℃ b) at 100 ℃.

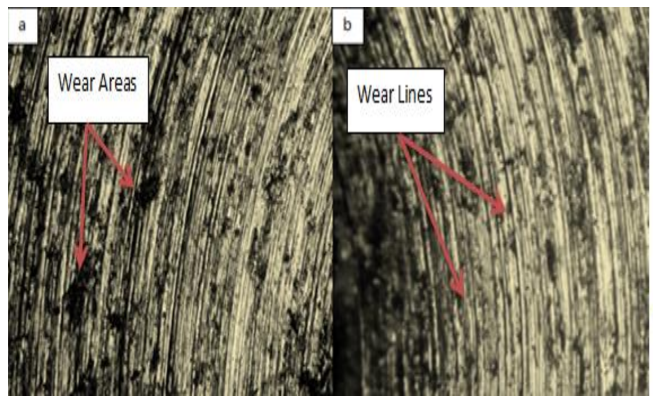

Figure 7. Microstructure for S3 alloy magnification at 100X after wear test under a load of 20 N for 25 minute: a) at 27 ℃ b) at 100 ℃.

IV. CONCLUSIONS

The influence of mechanical mold vibration, an addition of titanium, and a combination of them on wear behavior at 27 ℃ and 100 ℃ temperatures of Al-Si eutectic alloy was investigated. Due to the results the following can concluded:-

- The addition of titanium and /or the mechanical mold vibration converted the coarse eutectic of aluminum silicon plates into globular particles. This refines the grain size of dendrite and leads to an enhancement in wear behavior of the alloy.
- The wear rate of all samples decreased at 100 ℃ compared with 27 ℃. At 100 ℃ with a loading of 20 N for 25minutes the wear rate of the sample that prepared without vibration and without addition of titanium decreased by 17%, with mechanical mold vibration by 23%, with addition of titanium 25%, while by the combined effect of them by 28%.

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