Effect of Sodium Modifier on the Microstructure and Wear Rate of Al-14 Wt% Si Alloy

Dr. Adnan Ibrahim Mohammed* , Mahdi Muter Hanoon* & Haitham Rzouqi Saleh*

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Abstract

In this study, a demonstration of the effect of Na addition to the microstructure and wear rate of hypereutectic Al-14 wt% Si alloy was carried out. It is found that the addition of Na has an important effect on shifting the eutectic composition of Al-Si alloys from approximately 12 wt% to 14 wt% Si; shifting the unmodified alloy from hypereutectic to eutectic alloys for the modified alloys. The modified alloys have a eutectic composition with fine needle at lower Na content (0.05 wt%). Increasing the percentage of Na to 0.12 wt% resulted in producing a lamellar Si structure compared with acicular structure for unmodified alloy. The wear rate of modified alloys is lower than the hypereutectic alloy. Wear rates observed were in the range of 10^{-9} to 10^{-11} which is fully identified in the mild wear rate regime.

Keywords: Al-Si alloys; Wear rate; Na modifying; Mild wear regime

تأثير التعديل بالصوديوم على البنية المجهرية ومعدل البلى لسبيكة الالمنيوم- 14 % سليكون

الخلاصة:

في هذه الدراسة تم توضيح تأثير إضافة الصوديوم على البنية المجهرية ومعدل البلى لسبيكة الألمنيوم-سليكون فوق الايوتكتيكية ذات نسبة سليكون 14%. لقد وجد بان إضافة الصوديوم له تأثير كبير بإزاحة نقطة الايوتكتيك لسبائك الألمنيوم-سليكون من ما يقارب 12% إلى 14% سليكون بعد التعديل لذلك السبيكة الفوق ايوتكتيكية قبل التعديل تم تحولها إلى سبائك ايوتكتكية بعد التعديل. امتازت ألسبائك المعدلة بتركيب ايوتكتيكى ذات تركيب أبرى ناعم عند محتوى الصوديوم 0.05%. أدت زيادة نسبة الصوديوم المضافة إلى 0.12% إلى الحصول على تركيب طبقي للسليكون مقارنة مع شكل السليكون العدسى للسبيكة الغير معدلة. معدل البلى للسبائك المعدلة اقل من السبيكة قبل التعديل. وان معدل البلى للسبائك بقع ضمن المدى 10^{-9} إلى 01^{-11} سم3/سم والذي يقع بصورة كاملة ضمن مدى معدل البلى الواطئ.

1- Introduction

Silicon is considered the most common element added to Al-alloys; the main characteristics are improved foundry characteristics, especially fluidity and weldability. Aluminum–silicon (Al–Si) alloys have considered as important engineering materials with many advantages such as lightweight, high specific strength and Young's modulus, good heat transfer ability, wear and corrosion resistances [1-3]. Wear resistance of Al–Si alloys is mainly due to the presence of silicon phase in the aluminium matrix. Increasing the silicon content in Al–Si alloys or increasing the refinement of Si phase increases the wear resistance and mechanical properties of the Al-Si system [4-5].

* Production Engineering and Metallurgy Department, University of Technology/ Baghdad

Hypereutectic Al-Si alloys are widely used in the automotive industry, mainly in pistons, cylinders and engine blocks. The presence of small amount of hard primary silicon particles in the eutectic of Al-Si will improve the wear properties. On the other hand, presence of primary silicon resulted in macrosegregation and has low machinability. To solve this problem, modifer elements such as P, Na, Sr and Ca are used to reduce the segregation of Si and as well refine the eutectic of Al-Si. Many studies [6] have been investigated the sliding wear characteristics of Al–Si alloys, in both mild (oxidative) and severe (metallic) wear regime [7].

Many studied being concentrated on determining the wear mechanism; the most important of these mechanism are reported in the literature [7-10] There are only few reports available in open literature [7-18] Mohammed [7], Mohammed and Dwarakadasa [8], Elmadagi and Alpas [9], Erginer [10], Chen and Alpas [11,12], Chen et al. [13], Dienwibel [14], Riahi et al [15], Hutchings [16], Chen [17] and Lasa and Rodriguez-Ibabe [18] have thoroughly investigated the role of silicon content and shape, wear processing parameters and the effect of modifiers on wear rate, debris analysis, worn surface and subsurface damage.

They were found that the minimum wear rate is observed near eutectic alloy. The wear process is governed by fragmentation of silicon phase in the subsurface region which obtained by plastic deformation. The extent of this depth of damage is complex and affected by all the dependent and independent parameters. The accepted mechanism is consisted of many steps; firstly starts with initial damage in the worn surface followed by fragmentation of Si particles and finally removal of debris.

It is found that some authors have found that the modification by Sr and Na leads to increase the absorption of hydrogen by melt to produce hydrogen compounds [19-21]. Garet et al [19] have reported that NaH is present in the Na modified Al-Si alloys. This compound was suggested to be composed during solidification to release hydrogen. Iwahori et al [20] have found that the rate of vacuum degassing of Na modified melts decreased the hydrogen content noticeably compared with Sr addition. This is because the hydrogen adsorbed into the oxide more strongly by addition of Sr. On the other hand, Gruzleski [21] has shown that the Sr modifier does not increase the susceptibility of melt to adsorb hydrogen by formation of hydrogen containing compounds.

2- Materials and Experimental Procedures

As-cast Al-14% Si master alloy was selected as a base alloy which was prepared from remelting of Al-14% Si master alloy in an electrical furnace. It is melted at a temperature of 830 oC for 15 minutes for homogenization. The melt was treated with different amount of Na of 0.05 and 0.12 wt% to study the morphology changes, shifting of eutectic composition and wear rate. The modified alloys were kept for 5 minutes before pouring. The cooling rate of solidification was determined to be approximately 50 ^{o}C/s.

The counterface steel ring used for wear test was made of AlSI 1050 steel with a composition of 0.5% C, 0.3% Mn, 0.03%P and 0.03% S and the balance is Fe. The outside diameter of the disc was 300 mm and its thickness was 10 mm. The hardness of the disc was checked to be 350 HV.

Following the casting of the alloys, samples for microstructural characterization and microhardness measurements were made. The samples were ground to 1000 grit finish with SiC and finally polished with alumina colloidal paste using standard micrographic procedures. The etching solution used was 0.5 vol.% HF in distilled water. The microstructures were characterized through digital optical microscopy (OM). The approximate volume fraction of porosity was determined through quantitative image analysis from the microstructures. A computerized vicker hardness machine was used to measure the hardness of the samples.

The wear samples of Al-Si alloys were prepared from the cylindrical ingot to produce pins with 10 mm diameter and 25 mm long. The upper surface of the samples (pins) which is prier to counterface disc was ground with 400 grit SiC grinding paper. The weight applied of each test was added as a dead weight in the range of 2 to 11.25 N. During the wear test, the sample was pressed in the holder position perpendicular to the counterface disc. The disc is rotated at 1500 rpm. The wear loss was measured using an electrical balance with a sensitivity of + 0.1 mg, the wear rate expressed in Cm^3/cm was determined from the wear loss using the following formula:

$$\text{Wear rate} = \Delta W/2\pi\rho dnt. \qquad .....(1)$$

where ΔW is the weight wear loss (g), d is the sliding distance diameter (25 cm), ρ is the alloy density (2.67 cm^3/cm), N is the revolution of the disc (1500 rpm) and t is the test time (30 minutes).

3- Results and Discussion

Modification with Na has been found to be an essential for Al-14 wt% Si due to the elimination of Si segregation and refining the eutectic Al-Si. It is also noticed that the modified alloys have a different microstructure which yields better mechanical properties (Table 1). It is found that with an increasing the percentage of Na, the porosity was increased in the alloys (Fig. 1) This is due to the increment of the viscosity of the liquid [12] which will not allow the liquid to flow between the dendrite to compensate for shrinkage with decreasing the modification temperature. The other reason for micro porosity during modification is due to the inclusions present in the Na modified melt which will react with haydrogen released during solidification to form hydrogen compounds. It was found that both the modified alloys were changed from hypereutectic to eutectic alloys with fine microstructure of the eutectic (Fig. 1) Increasing the percentage of Na resulted in changing the Si morphology from acicular structure to fine fibers (at low Na addition) to lamellar morphology (at high Na addition).

Figure 2 shows the change in the volumetric wear rates with applied load. The wear rates wee very mild at low loads and increased gradually until material experienced a transition from very mild to mild wear as indicated by the sharp increase in the slope of the curves. The mild wear manifested itself by massive surface damage and large scale aluminum transfer to the counterface accompanied by the generation of coarse debris particles. It is a typically in the shape of plates with a dark oxide appearance. These features were readily identifiable during the test by the naked eye which faciliting the observation of the wear transition. In the very mild wear regime, volume loss due to wear increased linearly with the bearing load indicating that wear progressed under the steady-state conditions. Above the transition load, wear rates were also linear. Within a certain load range, wear was initially very mild but became mild when the tests were run for a sufficiently long time. Representative volumetric wear loss versus bearing load plots show the linear relationship between the wear rate and bearing load in the very mild and mild wear regimes for the tests performed under a constant sliding speed.

Wear rates of Al-14 wt% Si alloy and modified alloys increased with increasing the bearing loads. The wear rate is higher for unmodified alloy. This implies that improvement of wear resistance of modified alloys is related to the changing of Si particles present in the eutectic. It suggests that the needle and lamellar shapes provide a better wear resistance than acicular shaped Si particles which is formed in the unmodified alloy. Also increasing the hardness for the modified alloys (42 HV for 0.05 wt% Na and 38 HV for 0.12 wt% Na) which might be another factor responsible for better wear resistance compared with unmodified alloy with 33 Hv. In addition to the wear rates data, worn surface and debris formation demonstrated that modified alloys deeply fallen in the mild wear regime.

Conclusions

1- Addition of sodium to Al-14 wt% Si changed considerably the morphology of Si from acicular to fine needle at low Na addition to lamellar at high Na addition.
2- The percentage of porosity increased with increasing the Na addition.
3- The unmodified alloy with hypereutectic composition has changed to eutectic structure for modified alloys.
4- Addition of Na has a considerable improvement in wear resistance compared with unmodified Al-14 wt% Si alloy.

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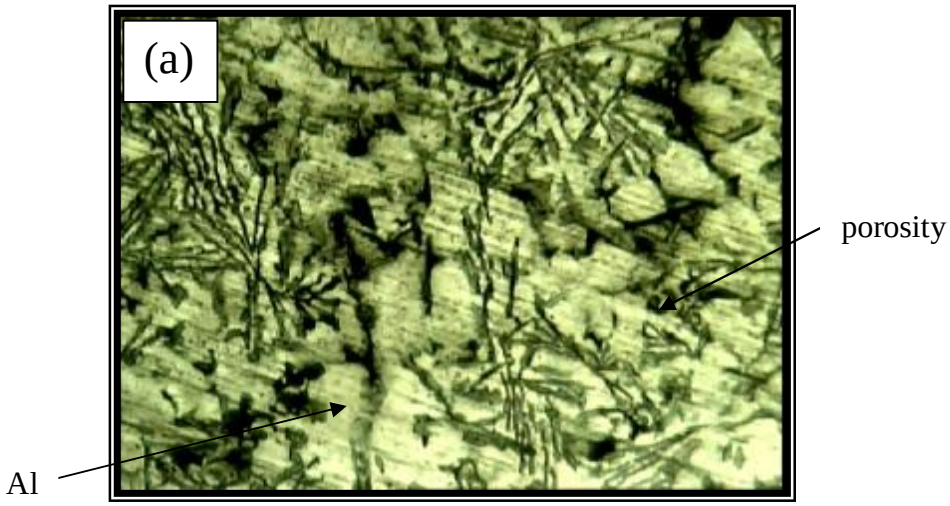
Table (1) The hardness of Al-Si alloys studied.

Alloy	HV
Al-14 wt% Si	33
Al-14 wt% Si-0.05 wt% Na	42
Al-14 wt% Si-0.12 wt% Na	38

Table (2) the chemical composition of Al-Si alloys

Alloy	% Si	% Fe	% Cu	% Mn	% Na	% Pb	% Al
Al-14 wt% Si	14	0.284	0.02	0.172	___	0.013	Reminder
Al-14 wt% Si-0.05 wt% Na	14	0.284	0.02	0.172	0.05	0.013	Reminder
Al-14 wt% Si-0.12 wt% Na	14	0.284	0.02	0.172	0.12	0.013	Reminder



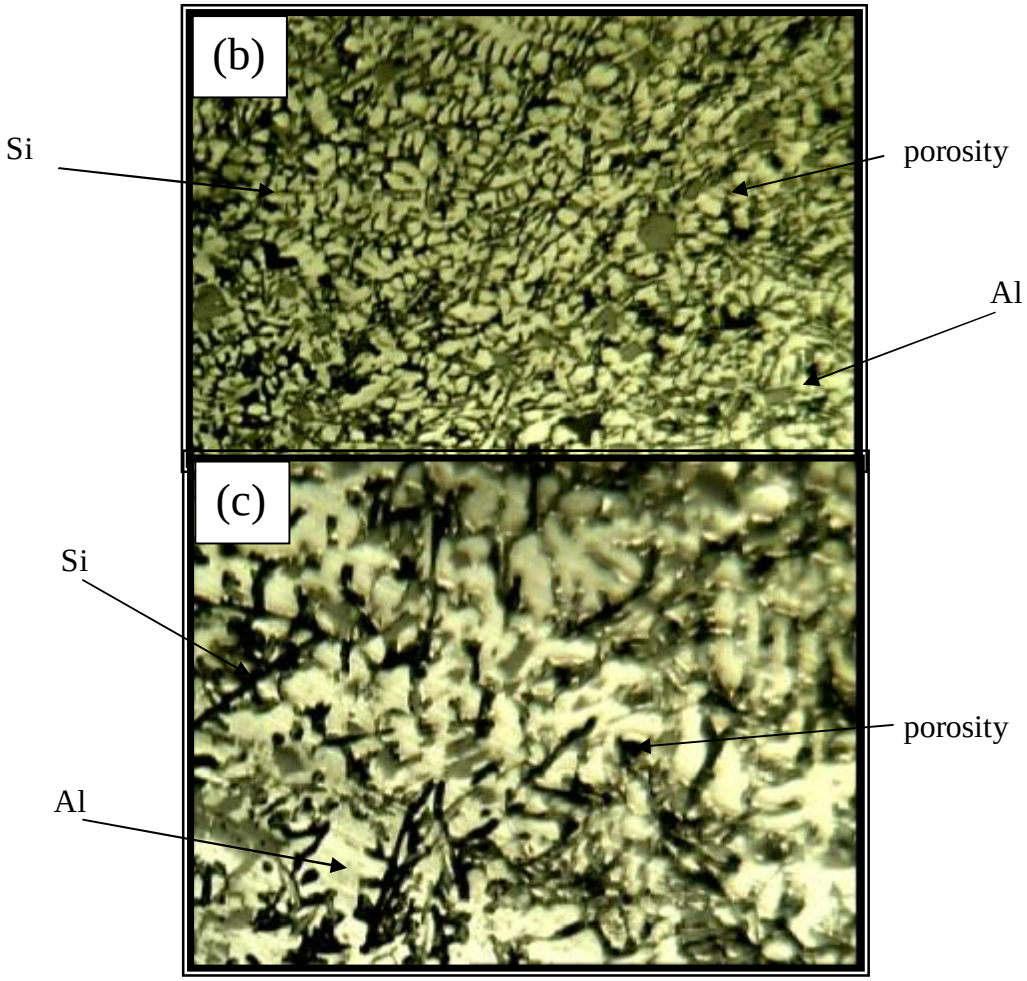


Figure (1) microstructure of as cast (a) Al-14% Si, (b) Al-14% Si-0.05% Na and (c) Al-14% Si-0.12% Na. X400.

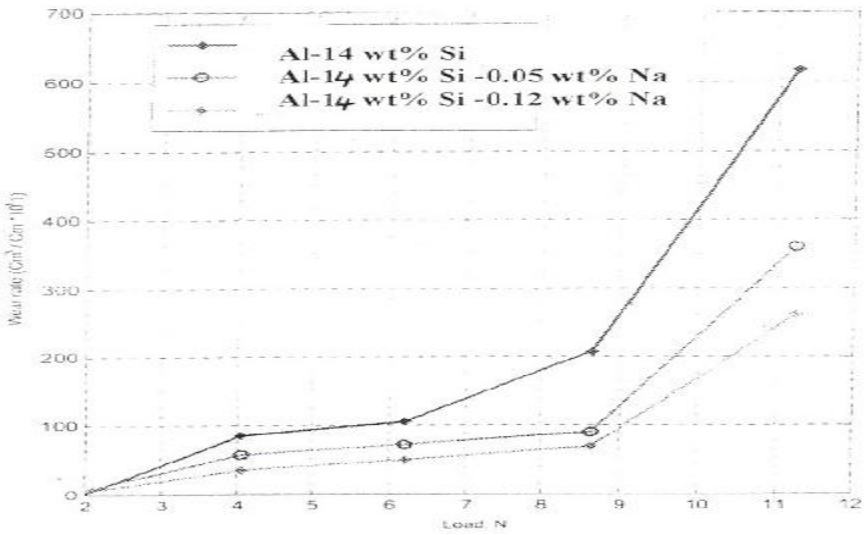


Fig 2. Wear rate- bearing load relationship for Al-Si alloys.