ANTISEIZURE CHARACTERISTICS OF LEADED ALUMINUM ALLOYS UNDER DRY SLIDING CONDITIONS

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ABSTRACT

Aluminum-Silicon alloys, with soft lubricant metal, are considered to be one of the important tribological alloys which resist seizure. The effect of different lead percentages (1-20%Pb) that added to the modified eutectic Al-12%Si alloy on the wear rate and resistance was studied by sliding these alloys under dry sliding conditions on a carbon steel disc at different sliding distances (2.24-40.37 km). The results showed that the wear rate was decreased and wear resistance increased with increasing lead percentage of Al-12%Si alloy. Furthermore, wear rate was increased linearly with increasing sliding distance.

الخلاصة

تعد سبائك الالمنيوم–سليكون المحتوية على معدن مزيت من السبائك الترايبولوجية المهمة المقاومة للالتصاق. يهدف هذا البحث الى دراسة تاثير اضافة الرصاص بنسب مختلفة (1-20%Pb) على معدل ومقاومة البلى لسبيكة Al-12%Si الايوتكتيكية المحورة تحت تاثير الانزلاق الجاف على قرص من الفولاذ الكربوني عند مسافات انزلاقية مختلفة (2.24-40.37 km). اوضحت النتائج انخفاض معدل البلى وزيادة مقاومة البلى مع زيادة نسبة الرصاص لسبيكة Al-12%Si. علاوة على ذلك فان معدل البلى يزداد بصورة خطية مع زيادة مسافة الانزلاق.

KEYWORDS:
Aluminum Alloys, Antiseizure Characteristics, Sliding Conditions

INTRODUCTION

Aluminum based alloys; especially eutectic aluminum-silicon alloys are regarded to be one of the most important tribological alloys due mainly to the presence of silicon **(Lee 1998 and Yasmin 2004)**. Silicon is the second most abundant impurity of aluminum. It imparts fluidity in casting, weldability and high mechanical properties **(Mondolfo 1976)**. These properties incited many researchers in order to approach the convenient application. Therefore, replacement of cast iron by aluminum based alloys in manufacturing automobile pistons is the start point in the early ninetieth century **(Sarkar 1980)**. Lead is technically and economically the best qualified metal for use as a soft phase alloying addition to aluminum based alloys. Leaded aluminum alloys are characterized by low wear rate, antifriction and antiseizure characteristics suitable for a variety of bearing applications **(Tiwari 1987)**. **(Rudrakshi et al. 2004)** found that the wear properties of spray formed Al-Si-Pb alloy were improved to be greater than that of Al-Si alloy as a result of microstructural features of spray formed alloy and the nature of the worn out surfaces. **(While Hao et al. 2005)** showed that the main reason of decreasing wear in the hot extruded Al-4Si-20Pb alloy attributed to the constituents of lubricating film that created between the mating surfaces. They indicated that this film is composed of mixture of Fe_2O_3, Pb_4SiO_6 and a small amount of Fe_2O_3 at room temperature, and $Pb_4Al_{12}(SiO_3)_7$, SiO_2, Al_2O_3 and a small amount of Fe_2O_3 at high temperature. The same result is concluded by **(An et al. 2006)** when irradiated Al-Si-Pb alloys with high current pulsed electron beam in which the different constituents of lubricating film is the main reason of decreasing wear.

In this work, some light will be thrown to study the effect of lead addition on wear rate and resistance of modified eutectic Al-12%Si alloy.

MATERIALS AND METHODS

Leaded aluminum alloys were prepared using commercial high purity aluminum, lead and Al-18%Si master alloy as starting materials. The master alloy of Al-18%Si was previously prepared by adding high purity silicon as chunks to the molten of commercial high purity aluminum using gas fired furnace under the pressure effect via graphite block in a graphite crucible to prevent any floatation of silicon on the molten surface of aluminum. The molten of Al-18%Si alloy was casted in a metallic mould to produce ingot of Al-18%Si master alloy. A specified amount of commercial high purity aluminum was added to the molten of Al-18%Si master alloy to obtain Al-12%Si alloy. Lead was added separately in different amounts, that corresponding to 1-20%Pb, to the diluted Al-18%Si master alloy with aluminum to produce different types of leaded Al-12%Si alloys. The addition of lead was carried out using vortex method as a result of no solubility and miscibility between lead and eutectic Al-12%Si alloy. In this method, lead was added as chips to the molten of diluted Al-18%Si master alloy with aluminum in a graphite crucible using graphite fan to prevent any reaction. The inclination angle of vortex mixing and speed of mixer rotation were 30° and 1256 rpm respectively. All leaded alloys were mixed at 650 $^{\circ}$C for 10 min individually to obtain homogenous distribution of lead inside the molten of Al-12%Si alloy. The pouring temperature for each alloy was fixed at the same temperature of vortex mixing in which each alloy was poured into a cooled carbon steel mould to obtain chilled ingots of Al-Si-Pb alloys. All casted ingots have the dimensions of 100 mm length and 15 mm diameter. Chemical composition of pure aluminum, master alloy and prepared Al-Si-Pb alloys is tabulated in table I. The ingots of Al-Si-Pb alloys were cut and turned to produce specimens suitable for microstructural and wear study. For microstructural study, each alloy specimen was cold mounted and then ground using different SiC emery papers. Primary polishing was carried out using slurry of alumina while final polishing was achieved using diamond paste. All microstructural study specimens were etched using 1%Vol. HF etching solution.

Pin on disc type wear testing apparatus with 450 Hv carbon steel disc was used in this work in order to determine antiseizure characteristics of Al-Si-Pb alloys. Wear test specimens that previously prepared have the dimensions of 10 mm length and 5 mm diameter. The sliding circle diameter and bearing pressure were fixed at 14 cm and 63.6 kPa respectively. A wide range of running periods was used ranging from 10 min to 3 hr in order to produce different sliding distances (2.24-40.37 km).

RESULTS AND DISCUSSION

Fig. 1 shows the microstructure of modified eutectic Al-Si alloys. It is clear from this figure that two phases are presented in the matrix of Al-Si-Pb alloys. These phases are eutectic and lead, while one phase presented in the matrix of Al-12%Si alloy which is eutectic. Fig. 1 also shows the potent effect of chilling on producing modification of eutectic silicon in the matrix of leaded alloys, in which fibrous eutectic silicon associated with aluminum dendrites can be recognized in the matrix for each alloy. This modification in eutectic silicon morphology from angular and flake as in ordinary conditions to the fibrous as in this work has a crucial role on increasing the mechanical and tribological properties of eutectic Al-Si alloys as mentioned elsewhere **(Subramanian 1991, Fatahalla 1999 and Liao 2002)**. It is explicit to know that lead decreasing the hardness of Al-Si alloys in a magnitude dependent on its percentage in the matrix. This decreasing in hardness value does not mean decreasing in wear properties of Al-Si alloys. This can be demonstrated by showing the relationship between sliding distance and wear rate as shown in **Fig. 2**. It is clear from this figure that the wear rate was increased linearly with increasing sliding distance for each alloy. In the other side, the wear rate was decreased with increasing lead percentage at any sliding distance. Plastic deformation always associated with wear in the subsurface region of the base matrix of Al-Si alloys. The deformation of aluminum phase results in fragmentation of silicon phase into fine particles distributed in the subsurface region **(Pramila Bai 1984)**. In this work, no fragmentation was occurred as a result of potent effect of modification that occurred in eutectic silicon morphology as explained above. The aluminum and silicon phases in the eutectic of Al-Si alloys behave independently on each other during dry sliding in which the silicon phase resists the applied bearing pressure while the aluminum phase accommodates the plastic deformation in the matrix. The presence of lead in the matrix of modified Al-12%Si alloy results in decreasing the wear rate as explained above. This is because the lead acts as a lubricant and reduces wear between mating surfaces as a result of its extrusion during dry sliding of leaded aluminum alloys on carbon steel disc and forming a trib-layer of low shear strength spreads over modified eutectic Al-12%Si alloy substrate. The smearing of lead prevents adhesion between the mating surfaces in areas dependent on lead location in the matrix of modified eutectic Al-12%Si alloy. Therefore, wear rate will be decreased and in the same time seizure resistance will be increased. This result can be demonstrated precisely from the relationship between lead percentage and wear resistance, as shown in **Fig. 3**, in which the wear resistance increases with increasing lead percentage. From curve fitting programme, the wear resistance (W_R) changes with lead percentage (L_p) according to the following formula:

$$W_R=-0.021L_p^2+1.267L_p+35.83 \qquad (1)$$

This illuminates the importance of lead addition; especially the adhesive compatibility of slided metals **(Norton 1998)** indicated clearly the low metallurgical compatibility between lead and iron where iron can be considered as a counterface material. This makes Al-Si-Pb alloys a suitable choice for bearing applications. The relationship between wear rate (W_r) and hardness (Hv) is shown in **Fig. 4** in which the wear rate decreases with decreasing hardness, i.e. increasing lead percentage, according to the following formula obtained from curve fitting programme

$$W_r=0.002Hv^2-0.2Hv+6.250 \qquad (2)$$

CONCLUSIONS

Rapid cooling of leaded eutectic Al-12%Si alloys in a metallic mould could produce modification of eutectic silicon morphology in the matrix of these alloys. The presence of accompanied lead that added using vortex method with modified eutectic silicon led clearly to remarkable changes in the antiseizure characteristics of leaded alloys. These changes can be summarized by decreasing wear rate and increasing wear resistance with increasing lead percentage, i.e. decreasing hardness.

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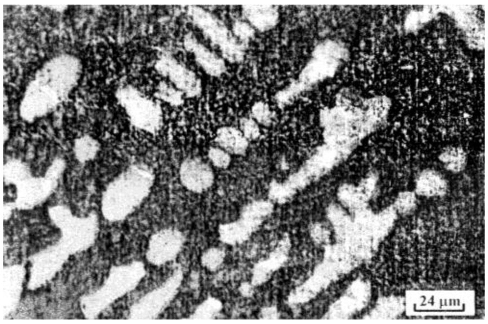
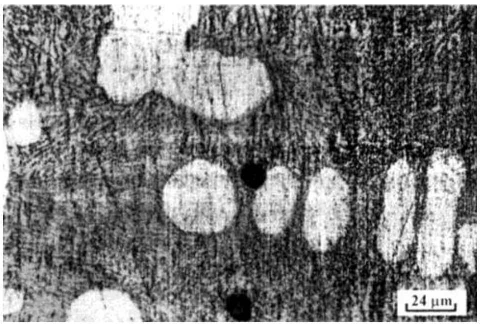
Elements	Si	Fe	Cu	Pb	Mn	Ti	Al
Al	0.11	0.11	0.008	0.001	0.007	0.005	Rem.
Al-18%Si	18.2	0.31	0.09	0.001	0.02	0.009	Rem.
Al-12%Si	12.4	0.24	0.03	0.001	0.01	0.007	Rem.
Al-12%Si-1%Pb	11.9	0.24	0.03	1	0.01	0.007	Rem.
Al-12%Si-6%Pb	12.7	0.24	0.03	6	0.01	0.007	Rem.
Al-12%Si-12%Pb	12.1	0.24	0.03	12	0.01	0.07	Rem.
Al-12%Si-20%Pb	12.4	0.24	0.03	20	0.01	0.07	Rem.

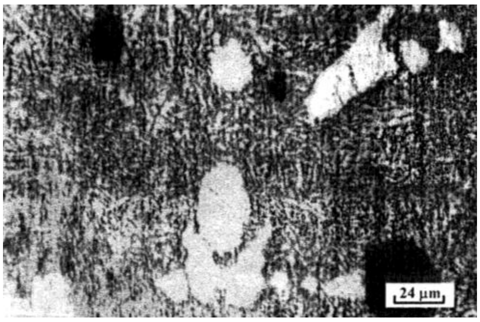
TableI Chemical composition of pure aluminum, master alloy and prepared Al-Si-Pb alloys.



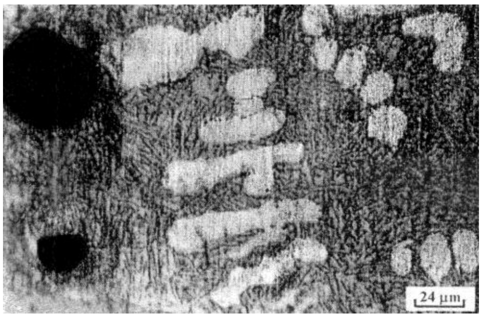
Al-12%Si



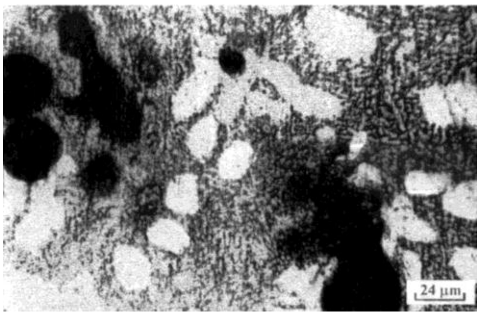
Al-12%Si-1%Pb



Al-12%Si-6%Pb



Al-12%Si-12%Pb



Al-12%Si-20%Pb

Fig. 1 Microstructure of as-cast leaded modified eutectic aluminum-silicon alloys.

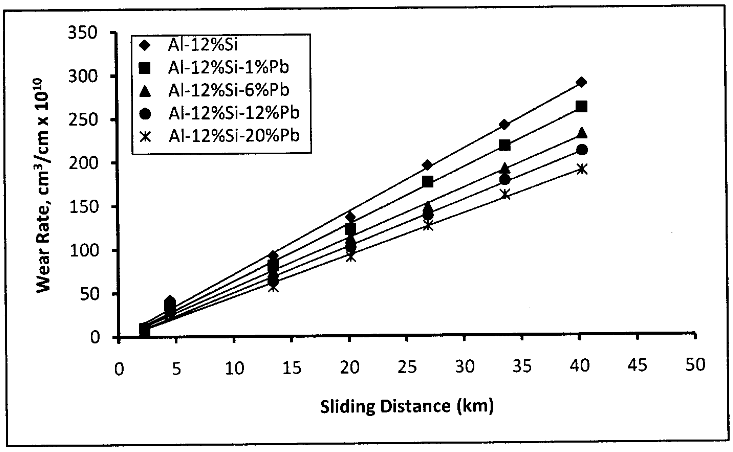


Fig. 2 The relationship between sliding distance and wear rate of Al-Si-Pb alloys.

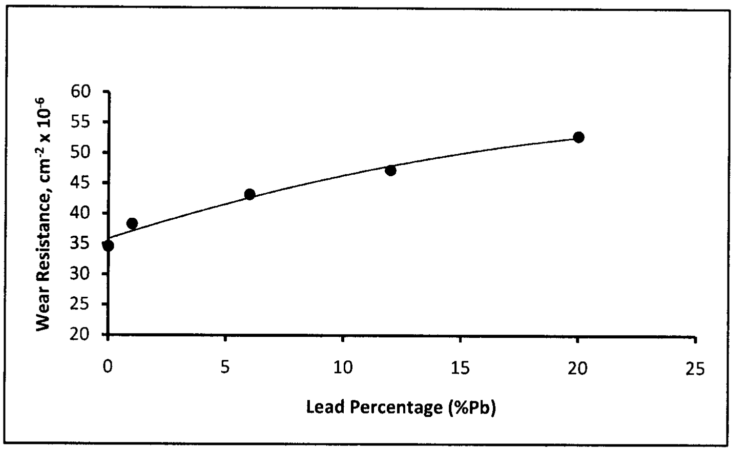


Fig. 3 The relationship between lead percentage and wear resistance of Al-12%Si alloy. Sliding distance, 40.37 km.

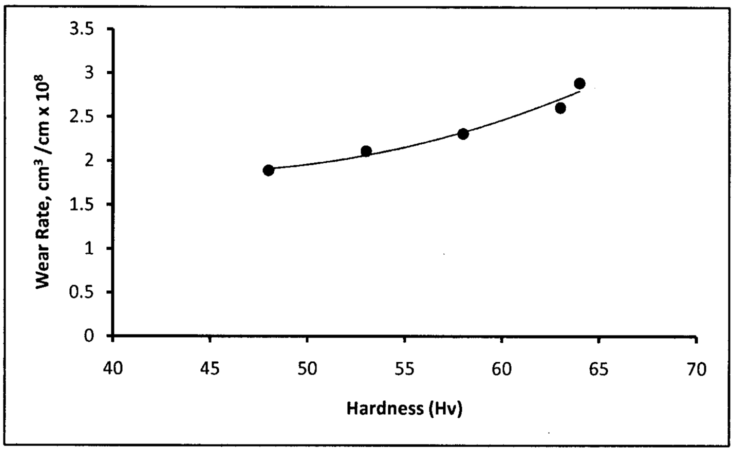


Fig. 4 The relationship between hardness and wear rate of Al-Si-Pb alloys. Sliding distance, 40.37 km.