STUDY OF TIN ADDING ON DRY SLIDING WEAR PROPERTIES OF
ALUMINUM ALLOYS

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ABSTRACT

The aim of the present research is to study the effect of tin content on wear rate of Al alloys. Mechanism wear behavior was studied by (pin on disc) technique under different conditions of applied loads (100-2500) g, constant sliding speed and time, steel disc hardness is 45 HRC. All alloys were prepared with different percent of tin (3, 7, 13, 23, 33, and 43)\%, also the master alloy (Al-1Cu) was prepared by melting and pouring the molten metal in a metallic mold. Samples of different percentages of tin were investigated under as-cast in order to establish the metallurgical changes and wear. It was found that the tin addition to aluminum alloys decrease the wear rate and improves the wear properties. Also the Al-43% Sn alloy is the best alloy in wear resistant and friction coefficient, this is due to network distribution of Sn phase. The bonding between the tin and matrix was improved at higher tin content. The Al-13% Sn-1% Cu exhibited higher wear rate compare with other alloys tested under the same conditions. In high tin alloys the subsurface region does show plastic deformation having occurred in the direction of sliding. The wear rate of the alloys decrease with increasing Sn content and increases observably with increasing load.

KEYWORDS: Wear Resistance, Subsurface, Al-Sn Alloy, Friction, Wear

INTRODUCTION

Loss of material removal by wear is a universal phenomenon and has attracted the attention of many a scientist, engineer and technologist owing to its importance\textsuperscript{(1)}. In recent years, efforts have been directed towards the study of the actual mechanisms involved in the material removal due to rubbing action at the interfaces. Adhesive wear occurs in a wide variety of plain bearing materials. Al–Sn alloys have a very long history to be used as bearing materials. Successful commercial use of aluminum alloys in plain bearings dates back to about 1940. When low-tin aluminum alloy castings were introduced to replace solid bronze bearings for heavy machinery\textsuperscript{(2)}. Friction and wear are of considerable importance in most of the structural components, particularly in bearing applications. The typical structure of tough matrix with soft tin inclusions in Al-Sn alloy determines the tribological behaviour of the bearing. These alloys provide a good combination of strength and surface properties. The fatigue strength of cold worked and heat treated Al-20%Sn-1%Cu alloy having reticular structure is close to that of Cu-30%Pb alloy with higher seizure resistance\textsuperscript{(3)}. Al-40% Sn alloy is comparable to tin-based white metal but its fatigue strength is superior. High tin-aluminum alloys are used as linings bonded to a steel-backing strip. Aluminum-tin alloys have good mechanical properties with conformability but these are quite costly\textsuperscript{(4,5)}. The chief objective of research in this area is to minimize loss due to wear at all levels. One of the several methods of examining wear is to look at the subsurface effects, because it is known that in ductile materials subsurface deformation influences the wear behavior\textsuperscript{(6)}. In single-phase materials it was difficult to quantify the extent of deformation
while the use of suitable two phase alloys enabled measurement of depth of damage from the structural changes that result. However, because of the fact that in most wear experiments the tendency is to use a range of pressures to study its effect on wear rate, and usually these pressures are rather high. Use of high pressures is clearly derogative in the examination of subsurface effects and results with use of small loads. In a recent study, the topography of the worn surface has been found to display a characteristic appearance related to the wear process and reminiscent of the material removal mechanism.

**EXPERIMENTAL DETAILS**

For each experiment about 400gm of prealloyed Al-1Cu alloy (base alloy) was melted and different percent of tin (3,7,13,23,33 and 43) wt% were added to the melt of master alloys in alumina crucible in an electric resistance furnace at temperature 700ºC. The melt was poured into a metallic mold. The castings were left to cool down in the air.

**Wear Test**

A standard pin-on-disc wear apparatus, which was designed according to ASTM specification F732-82. The wear apparatus consists of motor with constant revolution speed (510 rpm) as shown in Fig.1. Was used to evaluate wear behaviour. Steady state wear rates per unit sliding distance were evaluated from weight loss measurements. A total running time of 30 min was found adequate to generate steady state condition in the bearing pressure range (60.5 - 312.4) kpa and relative interface sliding speed 500 rpm. Wear specimens were machined from ingot and cut according to ASTM specification D2625-83(20 mm) length and 10 mm diameter(7). Cylindrical wear pins were slid against a polished (500 grade emery paper) steel disc of average surface hardness 45HRC. During the wear runs it was observed that within a few minutes the disc surface was coated with fine debris particles. In order to retain actual application conditions, no attempt was made to clear or remove the debris but it was left, in fact, for the entire running time.

At the end of the wear run the wear pin was transferred to the specimen chamber of JSM 6400 scanning electron Microscope to study the structure of the worn surface. The pin was then subjected to 5°oblique sectioning and polishing to observe the subsurface structure. Examination of the subsurface damage was carried out for both the etched and unetched conditions in the optical microscope as well as the scanning electron microscope.

![Figure 1: The Pin-On-Disc Wear Apparatus](image)

Before starting a new wear experiment the disc surface was cleaned, ground with 600 grade Sic emery paper, cleaned and degreased so that the starting conditions for every wear run were exactly identical.
Weight method was used to determine the wear rate of specimens. The specimens were weighted before and after the wear test by sensitive balance type (Metter AE200) with accuracy 0.0001 gm. The weight loss ($\Delta W$) was divided by the sliding distance and the wear rate was obtained by using equation as follows (8):

$$\text{Volume wear rate} = \frac{\Delta W}{S_D}$$

$$S_D = 2\pi d \rho n t$$

$$\Delta W = W_2 - W_1$$

$$\text{Volume wear rate} = \frac{\Delta W/2\pi d \rho n t}{S_D}$$

where:

- $S_D$ = linear sliding speed (m/sec.)
- $d$ = sliding circle diameter (cm)
- $t$ = sliding time (min)
- $n$ = steel disc speed (r.p.m)
- $\rho$ = density of material g/cm$^3$
- Hardness of steel disc = 45 HRC
- Diameter of specimen = 10 mm
- Length of specimen = 20 mm

**RESULTS AND DISCUSSIONS**

**Load-Wear Rate Relationship**

The variation in the adhesive wear rates of the binary AL-Sn alloys is plotted in Fig.2 as a function of the bearing pressure in the range (60.5-312.4) kpa. The variation shown in Fig.2 is typical of the behavior of all Al alloys. The wear rate increased linearly in three distinct regions in almost all cases. These three regions have been referred to as the low pressure region (mild wear) and the high pressure region (severe wear) which are separated by a transition region (transition wear). A similar behavior had been observed in pure aluminum (9). The wear rates observed in the low pressure region did not show much variation with varying alloy composition or sliding speed. Wear in this region is interpreted as reflecting the fracture of the oxide layer at the wear interface, especially since the load levels involved are insufficient to cause deep penetration and deformation in the metal below the oxide. Also, as was shown by Razavizadeh and Eyre (10), the temperature levels reached at the interface are not high enough to cause the extent of oxidation necessary for the observed amount of debris. Thus, in the low pressure region, wear is primarily controlled by the fracture and removal of the oxide debris particles and in the low pressure region, deformation in the subsurface regions was not observed. The effect of increasing the pressure is to accelerate the fracture of the oxide and thus cause increased wear. As the surface oxide is removed, the fresh metal exposed is further oxidized. The appearance of the transition wear suggests a change in the mechanism of material removal during the dry unlubricated sliding contact of aluminum with steel. From the observed results it can be said that the change in the mechanism occurs at a bearing pressure sufficient to cause a low wear rate. The slope of the linear plots of wear rate vs. pressure in the high pressure region varied considerably with alloy composition. This region was characterized by the formation of metallic debris particles present along with the fine oxide debris.
results are in agreement with those of other researchers \((11)\). It can therefore be said that in this region wear is occurring both by oxide removal and metal failure at the interface. As the bearing pressure increases, the amount of metallic debris also increases, leading to increased depths of subsurface damage.

![Figure 2: The Effect of Applied loads on Wear rate of Different Alloys at Rotation Speed 510 r.p.m, Sliding Time: 30 min, Disc Hardness: 45HRC, Radial Distance: 5 cm](image)

**Effect of Tin Content**

The effect of tin content on the wear rate of aluminum is shown in Fig. 3. As has been observed by other investigators \((3,4)\), the adhesive wear rate in aluminum is reduced by the addition of tin to reach a maximum value at about 13\% Sn. Further addition of tin decreases the wear rate. Therefore the wear behavior of Al-Sn alloys is mild wear (oxidative wear) at low loads and when the load increases the wear rate increases and transforms to metallic wear at high loads.

![Figure 3: The Effect of Tin Content on the Adhesive Wear Rate of AL-Sn Alloys at Rotation Speed 510 r.p.m, Sliding Time: 30 min, Disc Hardness: 45HRC, Radial Distance: 5 cm](image)
Worn Surface Results

There are two main types of wear, abrasive wear and adhesive wear. The present work studies the former one. Interest in the study of worn surface topography has registered a steep increase since the availability of the scanning electron microscope in which the specimen could be examined with no further preparation and with a very large depth of field. In an earlier study it was shown that the use of a two phase material lends itself to easy and direct identification of the extent of subsurface damage\(^{(12,13}^{\text{and } 14})\). In this study, it was realized that use of the two phase alloys also gives the facility of studying the characteristics of the wear surface topography. Thus it becomes clear that to study the wear mechanism it is also necessary to choose proper values of pressure and speed, and suitable disc materials and the test materials.

In ductile materials it is known that the subsurface layers undergo plastic deformation. The wear surface is expected to show typical wear track patterns. In the case of the metal, aluminum, the surface presents a very confusing picture, as shown in Fig.4(a). Addition of tin changes the topography so that it can be more easily analysed, as can be seen from Figures 4(b) and 4(c). Purçek\(^{(15)}\), Purcek et al\(^{(16)}\), Savaskan et al\(^{(17)}\) and Cuvalc and Bas\(^{(18)}\) observed micro fractures in Zn based bearings. They have observed big wear tracks in bronze bearings. Rapoport et al\(^{(19)}\), Gronostajski et al and Turk et al\(^{(20)}\) have observed homogen and small wear tracks in bronze bearings. In this study, similar wear tracks were observed and the worn or damaged surfaces contain grooves, also some plastic deformation, together with presences of fine oxides debris particles. All the surfaces shown in Figure 4 are worn under similar conditions.

![Figure 4: Scanning Electron Images of Freshly Worn Surfaces of (a) AL-7% Sn Alloy, (b) AL-33% Sn Alloy and (c) AL-44% Sn Alloy, Load, 1400g, Arrows Indicate Sliding Direction](image)

The effect of increasing the bearing pressure on the surface structure is shown in Figure 5. Although deformation in the surface layer is more obvious, the number of cracks appearing on the surface and the number of fracture islands increase, cracks become shallower.
Structure of the Subsurface Region

Microstructural examination carried out on oblique sections revealed the nature and depth of subsurface deformation caused by the sliding process\(^9\). The oblique sections shown in Figure 7 reveal the presence of deep "V" grooves at the intersection of wear surface and polishing plane (the line of intersection between the dark areas on the left and the bright areas on the right is the line of the intersection in each case). The depth of these grooves is indicative of both the amount of deformation and the average size of the debris particles. As the amount of tin is increased, the depth of the grooves decreases. The ductile matrix and soft phase (tin phase) undergoes severe plastic deformation and increasing in plastic strains (Figure 8).
Figure 8: Microstructures in the Subsurface Region of AL-33%Sn Alloy (Bearing Load, 1400 g, Rotational Speed 510 r.p.m, Disc Hardness, 45HRC, Sliding Time, 30 Min and Radial Distance, 5cm) Showing the Deformation Zones of Subsurface Damage, Arrows Indicate Sliding Direction

Figure 9: Shows the Melting of Tin Phase in Regions near from the Worn Surface Due to Increasing the Temperature of Surface Interface (Flash Temperature) Under Low and High Bearing Pressures

Figure 9: Microstructure in the Oblique Sections of AL-43%Sn Alloy (a) at load 100 gm and (b) at 2500 gm

CONCLUSIONS

- The wear behavior of aluminum-Sn alloys changes from mild wear (oxidative wear) at low loads to metallic wear at high loads.
- The A1-12 % Sn alloy shows the highest wear resistance in comparison with other alloys.
- The wear rate increases with increasing bearing load.
- In all AL-Sn alloys wear is characterized by a region of subsurface deformation which in the tin phase is uniformly distributed in matrix of aluminum. The subsurface region does reveal of plastic flow in direction of sliding.

REFERENCES

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