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# Effects of sliding velocity and normal load on tribological behavior of aged Al−Sn−Cu alloy

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**Abstract:** The tribological behavior of aged Al−Sn−Cu alloy rubbed in the presence of lubricant over a range of sliding velocities and normal loads was investigated. The results showed that peak-aged (PA) alloy had a better tribological behavior than under-aged (UA) and over-aged (OA) alloys, which could be attributed to the optimized strength−ductility matching and a better hardness under PA condition. Wear rate and friction coefficient showed great sensitivity to applied sliding velocity and normal load. The wear rate and friction coefficient of the alloy exhibited a reduction trend with the increase in sliding velocity. The low wear rate and friction coefficient of alloy at high velocities were due to the effectively protected film and homogeneous Sn on surface. However, an increase in normal load led to an obvious increment in wear rate. The friction coefficient exhibited a fluctuant trend with the increase of normal loads. The seriously destroyed film and abraded Sn resulted in poor tribological behavior at high normal loads. The Sn particles and lubricant film which includes low shear interfacial lubricating layer and oxide tribolayer are the key to the tribological behavior of Al−Sn−Cu alloy.

**Key words:** Al−Sn−Cu alloy; tribological behavior; sliding velocity; normal load; aging

## 1 Introduction

Journal bearings are continuously demanded for better load-carrying capacity and wear resistance property with the development of modern machines to higher output and lower fuel consumption[1]. Al-based alloys containing Pb and Sn are widely used as bearing materials due to their fine load-carrying capacity, wear resistance and compatibility [2,3]. However, the lead-free bearing is the developing tendency of bearing materials due to the environmental health. Therefore, Al−Sn alloys are used in more and more applications as journal bearing materials [4]. With respect to conventional Al−Sn alloys, the further applications in machines are restricted. One of the possible reasons is the poor strength, which cannot satisfy the demand of high load in modern machines [5]. In addition, due to the immiscibility of Al−Sn system, the homogeneous distribution of Sn in Al matrix is not easy to achieve in conventional casting of Al−Sn alloy [6], which results in poor tribological behavior [3]. Considerable efforts have been made to overcome those drawbacks, such as stir cast [2], rapid solidification [7,8], physical vapor deposition [9], electrodeposition [10], severe plastic deformation [11], mechanical alloy [12], alloying addition [7,13,14] and intensive melt shearing [15]. Through optimization of alloying addition, the mechanical properties and wear behavior of alloy could be greatly improved. The addition of Cu has significant influences on microstructure and wear properties of Al−Pb alloys [16]. Similar information was also found by LU et al [17] and BANERJEE et al [18]. LU et al [17] observed the role of Mg addition in wear performance of dual-scale Al−Sn alloys and found that the appropriate addition of Mg could increase wetability and improve distribution of Sn phase, strength and ductility of alloy. BANERJEE et al [18] investigated the influence of Sn on the mechanical properties and age-hardening behavior of Al−Cu−Mg alloys and proved that the hardness and strength of alloy increase with the addition of Sn.

The tribological behavior of alloy is influenced by

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several factors, which include mechanical properties and wear conditions [19]. It is generally recognized that the tribological behavior of alloy has a close relationship with hardness and mechanical properties [20,21]. Previous results [22,23] showed that better mechanical properties of alloy are achievable by thermal aging treatment. Meanwhile, lots of studies have indicated that the tribological behavior has a significant correlation with sliding velocity and normal load [24,25]. As the two important parameters which significantly affect the wear behavior, the effects of load and sliding velocity on wear rate of Al−Si alloys are interdependent especially under severe sliding conditions [24]. The wear resistance of a nanocrystalline Al-based composite at high velocity and low load is improved and it is attributed to the increased tribolayer coverage on the worn surface [25]. It seems that the transfer layer determines the wear behavior of alloy at different sliding velocities and normal loads. An increase in normal load and sliding velocity creates an intermetallic wear-induced layer, which modifies the wear behavior of Cu−0.65%Cr (mass fraction) alloy [26]. The friction coefficient of copper was found to be correlated with the size and distribution of the transfer layer at different sliding velocities [27]. As is well known, the lubricant conditions determine the tribological performance of alloy. Unfortunately, the wear behavior of Al−Sn alloys was almost studied under unlubricated condition [3,5,17,21].

In this work, the hardness and strength of Al−Sn alloy have been improved by the addition of Cu. It was found that the hardness of alloy increased from HV 30 to HV 70 after the addition of Cu. Homogenization treatment and hot extrusion were carried out on Al−Sn−Cu alloy in order to improve the homogeneous distribution of Sn in Al matrix. The tribological behavior of the alloy was studied under lubricating condition which is close to the real applications [28]. The objective of the current work is two-fold: firstly, to observe the tribological performance of Al−Sn−Cu alloy under different aging treatment; secondly, to focus on exploring the effects of sliding velocity and normal load on tribological behavior of alloy under lubricating condition.

## 2 Experimental

The studied alloy was prepared by direct water-cooling casting and the nominal composition of the alloy is given in Table 1. To improve the homogeneous distribution of Sn in Al matrix, the Al−Sn−Cu alloy was homogenized at 480 °C for 19 h and then hot-extruded by 25 MN extruding machine at the extrusion temperature of 380 °C and extrusion ratio of 20. The samples were solution-treated in air atmosphere at 490 °C for 1 h and then quenched in cold water. Subsequently, all the samples were aged at 190 °C for 1, 2, 4, 6 and 12 h, respectively.

**Table 1** Nominal composition of Al−Sn−Cu alloy (mass fraction, %)

| Sn | Cu | Fe | Si | Zn | Al |
|---|---|---|---|---|---|
| 3.61 | 3.48 | 0.09−0.10 | 0.06−0.07 | 0.02−0.03 | Bal. |

Hardness measurement was carried out on samples by a microvickers hardness testing machine at a load of 200 g. Tensile test was implemented on the MTS−810 type electrohydraulic servo-controlled material testing machine at a rate of 2 mm/min. The precipitates were observed by transmission electron microscopy (TEM) using a Tecnai $G^2$20S-TWIN transmission electron microscope. Friction and wear tests were performed on the UMT−3 wear tester in ambient environment for 30 min. The samples were machined into a cuboid with dimensions of 25 mm × 25 mm × 20 mm. The wear test was performed under lubricating condition which is close to the real applications and the lubrication was accomplished by using CD15W/40 diesel engine oil. The grinding ring has a size of *d*9.5 mm × 9.5 mm and hardness of HRC 62. The wear test was carried out at sliding speeds of 0.04, 0.08 and 0.12 m/s, respectively, under normal loads of 50, 100 and 150 N.

The samples were polished, and then ultrasonically cleaned in absolute ethanol and dried before wear test. The friction coefficient varying with the sliding duration was continuously recorded by a computer connected with the wear tester. The wear volume ($\Delta V$) was calculated as the following relationship [29]:

$$\Delta V = B\left[\pi\frac{r^2}{180}\sin^{-1}\left(\frac{b}{2r}\right)-\frac{b}{2\sqrt{\left(r^2-\frac{b^2}{4}\right)}}\right] \tag{1}$$

In the present study, the wear volume was simplified from Eq. (1) and characterized by

$$\Delta V = \frac{Bb^3}{12r} \tag{2}$$

where $B$ is the length of the wear track, $r$ is the radius of the grinding ring, $b$ is the width of the wear track. Wear rate was calculated by dividing the wear volume by sliding distance (30 min × (0.04−0.12) m/s). The worn morphology and microstructure were observed by scanning electron microscopy (SEM) using a FEI Quanta−200 scanning electron microscope. Moreover, cross-sectional samples perpendicular to the worn surface were cut, ground and polished for SEM