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The effect of sliding speed and amount of loading on friction and wear behavior of Cu–0.65 wt.%Cr alloy

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ABSTRACT

Friction and wear behavior of a peak aged Cu–0.65 wt.%Cr alloy was investigated. The friction and wear experiments were run under ambient conditions with a pin-on-disk tribometer. Experiments were performed using various applied normal loads and sliding velocities. The tribological behavior of the studied alloy was discussed in terms of friction coefficient, wear loss and wear mechanism.

Friction coefficient and wear loss have shown large sensitivity to the applied normal load and the sliding velocity. At the sliding velocity of 0.3 m/s weight loss increased from 6.9 to 51 mg by increasing the normal load from 20 to 40 N. At higher sliding velocity minimum weight loss is achieved at 60 N normal load. So it can be seen that with increasing normal load wear rate decreases due to the formation of a continuous tribofilm which consists of Fe–Cu intermetallic. Varying of friction coefficients in different conditions of normal load and sliding velocity is correlated to the wear behavior.

The analysis of worn surfaces by XRD and SEM showed that an increase in normal load and sliding velocity creates an intermetallic wear-induced layer, which modifies the wear behavior of the alloy. The XRD result indicates that new phase of $Cu_{9.9}Fe_{0.1}$ is generated on worn surfaces of the pin specimens during the wear tests. There is a significant correlation between the micrograph of worn surfaces and the wear rate of specimens.

1. Introduction

The copper–chromium age-hardening alloy system has several interesting and apparently unique characteristics. Previous studies by transmission electron microscopy (TEM) showed that during the aging treatment of these alloys, very fine and coherent Cr-rich precipitates appear at the early stages. They change and grow into incoherent body-centered cubic (bcc) Cr precipitates with increasing time and temperature [1,2]. The strengthening mechanism usually proposed in this case was that of dislocation pinning by the stress fields around the coherent precipitates. Therefore, the precipitation-hardened Cu–Cr–Zr alloy has attracted considerable interest recently because of its superior combination of high mechanical strength, high thermal-electrical conductivity and lower cost [3]. The influence of aging or combination of heat treatment and cold deformation parameters on the microstructure and properties of copper–chromium alloys has been intensively studied [1,2,4]. So these alloys attract much attention because of strength and electrical conductivity modifiability. In some applications of Cu–Cr alloy, factors such as wear resistance must be taken into account. Qi et al. [3] and Tu et al. [5] investigated the wearing behavior of Cu–Cr–Zr alloy against a brass disk. They concluded that the peak aged Cu–Cr–Zr alloy exhibited a high Vickers hardness as a result of a fine scale precipitate dispersion. In addition adhesive wear, abrasive wear and arc erosion were the dominant wear mechanisms under unlubricated condition. Friction coefficient tended to decrease with increase of normal load. They showed that the wear rate of the Cu–Cr–Zr alloy increased with the increase of the normal load and electrical current. But there was no report to evaluate room temperature wear behavior of Cu–Cr alloy against steel.

In this work an attempt has been made to study the tribological behavior of peak aged Cu–0.65 wt.%Cr alloy, sliding against a steel disk under unlubricated conditions. The effects of sliding speed and normal load on its friction and wear performance were investigated. Moreover, the morphology, composition and structure of worn surfaces of the specimens were analyzed by SEM, EDX and XRD.

2. Experimental procedure

A copper alloy with the composition of Cu–0.65 wt.%Cr was prepared in a vacuum induction furnace. The ingots were homogenized at 1050 °C for 30 min and then hot extruded into a rod of 15 mm diameter. This rod was machined into a cube with

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a size of 10 mm × 10 mm × 10 mm. The cube samples were solution treated in air atmosphere at 1000 °C for 45 min and then quenched in cold water. Subsequently, all the specimens were aged at 500 °C for times from 1 to 4 h in an electric furnace and subsequently cooled in air. Finally, samples with a size of 5 mm × 5 mm × 10 mm for wear test were machined from the solution and aged cubes.

Hardness measurement was carried out on cubes using a Vickers hardness testing machine at 30 kg. Friction and wear tests were performed on a pin-on-disk wear tester in air, with the Cu–0.65 wt.%Cr alloy pin rubbing against a 52100 steel disk with a hardness of 60 HRC under unlubricated conditions. The steel disk was 40 mm in diameter and 5 mm in thickness. The wear test was carried out at sliding speeds of 0.3, 0.5 and 0.7 m/s respectively, under nominal loads of 20, 40 and 60 N for a sliding distance of 1000 m. The weight losses of the specimens after wear test were measured by weighing the specimens. Before the wear test, the specimens were polished with 800 grit emery paper and cleaned ultrasonically. The morphology, composition and structure of worn surfaces of the specimens were analyzed with MV2300 CamScan type scanning electron microscope (SEM) coupled with an energy dispersive X-ray analyzer (EDX) and Philip's Xpert pro type X-ray diffractometer (XRD).

3. Results and discussion

3.1. Effect of aging treatment on hardness

Fig. 1 shows the variation of Vickers hardness of Cu–0.65 wt.%Cr alloy as a function of aging time at 500 °C. It is obvious that aging at 500 °C increases hardness with time until it reaches to a peak after 1 h, then the hardness decreases as time elapses.

In precipitation hardening, second-phase particles act in two distinct ways to retard the motion of dislocations. The particles may either be cut by the dislocations or resist cutting and the dislocations are forced to bypass them. A critical parameter of the dispersion of the particles is the particle spacing λ. A simple expression for the linear mean free path is:

$$\lambda = \frac{4(1-f)r}{3f} \quad (1)$$

where f is the volume fraction of the spherical particles of radius r. When the particles are small and soft, dislocations can cut and deform the particles. λ is the function of aging time and the temperature [3,6]. The alloy hardness is dependent on both the aging time and the temperature, but the latter has a more significant influence on hardness [7]. According to previous studies during the age hardening of copper–chromium alloy system, very fine and coherent Cr-rich precipitates appear in the early stage. They change and grow into incoherent bcc Cr precipitates with increasing time and temperature [1–4]. On the other hand, growth leads to the increase of the interparticle spacing. Large interparticle spacing between precipitates weakens their role as obstacles to the dislocation motion, thus contributing to a decrease in hardness [8].

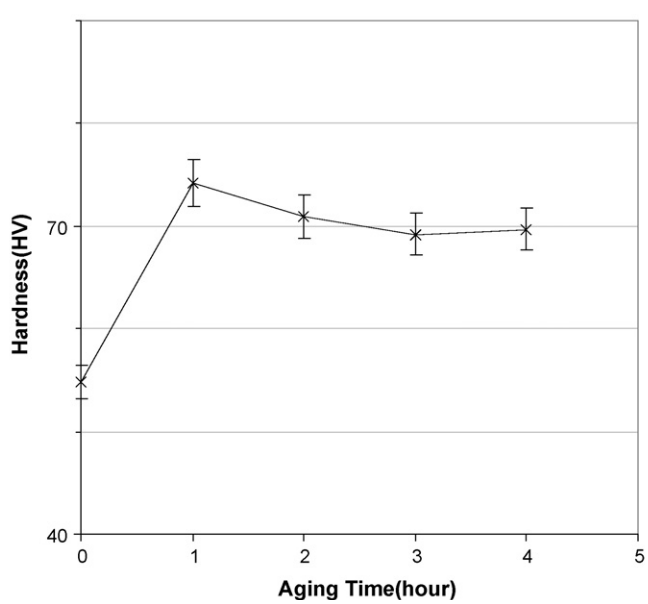

Fig. 1. The hardness of the Cu–0.65 wt.%Cr alloy as a function of aging time at 500 °C.

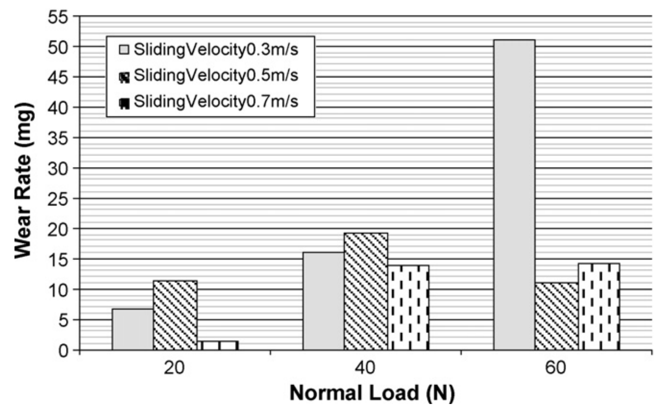

Fig. 2. Variation of wear rate of the aged Cu–0.65 wt.%Cr alloy as a function of the normal load and sliding velocity.

It is clear that the hardness of the specimens reach the peak hardness after aging for 1 h, so an alloy having this aging condition was selected for the wear test.

3.2. Friction and wear behavior of peak aged Cu–0.65 wt.%Cr alloy

3.2.1. Load, speed dependence and microscopic study of worn surface

The wear rate of the peaked aged alloy with the variation of sliding velocity and normal load is presented in Fig. 2. It is noticed that the samples exhibit an incremental, and then reductional trend in wear rate with the increase in sliding velocity at 20 and 40 N normal loads. The increase in wear rate as a function of the sliding speed from 0.3 to 0.5 m/s can be attributed to temperature rise resulting in a reduction in hardness. So, with the reduction of hardness, according to Archard equation, the wear rate will increase [9]. An increase in sliding velocity from 0.5 to 0.7 m/s decreases the wear rate. Since oxide formation plays a crucial role in the wearing process, any factor changing the rate of oxidation of the sliding surfaces will influence the wear rate. Temperature is the most important variable affecting oxidation rate. The temperature at the sliding interface will depend both on the ambient temperature and on the frictional power dissipation, the latter in turn depending on the sliding velocity and load [10,11]. An increase in temperature, oxide formation is accelerated due to increasing of sliding velocity. This oxide layer prevents direct metallic contact between the Cu–0.65 wt.%Cr alloy and the steel counterpart so that the wear rate is decreased. In addition, during wear an intermetallic wear-induced layer develops on the surface of pin (see Section 3.3). So due to the excessive hardness of intermetallics, the wear rate will decrease according to Archard equation.

Fig. 3a–i shows the worn surfaces of Cu–0.65 wt.%Cr pin at various normal loads and sliding speeds. It can be seen in Fig. 3a, b, d and e that with the increase of sliding velocity from 0.3 to 0.5 m/s at 20 and 40 N of normal load tribolayer is detached from the surface, but at the velocity of 0.7 m/s (Fig. 3g and h) a compact and continuous intermetallic wear-induced layer with an oxide layer is developed on the surface and decreases the direct contact between the pin and the disk.

According to Fig. 2 the wear rate of Cu–0.65 wt.%Cr pin at 60 N normal load and 0.3 m/s sliding velocity is very high. Fig. 3c shows deep grooves in the worn surface of this specimen. So due to high normal load the surface of pin is severely abraded and the wear rate of this sample is very high. With the increase of sliding velocity to