THE EFFECT OF NOVEL Ti-Cu INTERMETALLIC COMPOUND COATINGS ON TRIBOLOGICAL PROPERTIES OF COPPER

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ABSTRACT

In order to improve tribological properties of copper, Ti-Cu intermetallic coatings were formed onto the surface of an oxygen free high conductivity (OFHC) copper. Evaluations indicated significant improvements in tribological behavior of the coated samples. Variation of friction coefficient versus sliding distance in the coated and uncoated samples showed the mean value of 0.15 and 0.8, respectively. Study of wear surfaces, wear debris suggested delamination and oxidation wear to be the predominant wear mechanisms in the coated samples, whereas adhesive wear was observed in the uncoated samples.

KEYWORDS: copper, wear, intermetallic coatings, Ti-Cu phases, tribology.

1. INTRODUCTION

The characteristics of copper make this metal suitable for a great variety of metallurgical applications [1-4]. Copper alloys are widely used because of some attractive properties [5-8]. However, the metal has a rather low hardness and is prone to wear and there is an interest to improve its tribological properties through the application of coatings [9]. This could be achieved by developing intermetallic coatings on the surface. Proper wear resistance of these coatings is due to their rather high hardness and chemical absorption of atmospheric gases to the sliding surfaces, which the latter causes the formation of microscopic film on the sliding surfaces [10, 11].

The Cu-Ti binary phase diagram (Fig. 1) shows the possibility of obtaining several intermetallic phases [12, 13].

Fig. 1: Ti-Cu binary phase diagram [12,13].
Ti-Cu intermetallic compound coatings can significantly improve the surface properties [14]. The position of copper and titanium in the electromotive force series indicates that coating of copper with titanium by conventional electroplating is not possible [15]. Thus, coatings must be produced by vapor techniques or by pack cementation method. The purpose of the present work was to study the effect of hard Ti-Cu intermetallic coatings on tribological behavior of copper and the predominant wear mechanisms in the coated and uncoated samples will be discussed.

2. MATERIALS AND EXPERIMENTS

Oxygen free high conductivity (OFHC) copper was used as the substrate material. The pack powder, 5wt.% NH₄Cl, 7wt.% Ti, and balance Al₂O₃ was weighed and mixed thoroughly.

Copper specimens were enclosed in a stainless steel box filled with the powder mixture. Pack cementation process was carried out at 800°C for 6 hrs. The furnace was heated from 25°C to 800°C within 20 minutes. A pin-on-disk wear-testing machine was used and AISI 52100 steel pins (60HRC hardness) were employed as the counterface. Wear tests were carried out under dry conditions and different loads of 30, 60, 90 and 150N.

X-ray diffraction, metallography and electron probe microanalysis (EPMA) were used for phase identification of the coating layers. Wear debris and worn surfaces of the samples were examined by scanning electron microscopy to determine the predominant wear mechanisms and extent of plastic deformation under the surfaces. A Ziess microhardness tester was employed for determination of hardness profile using a load of 50 gr.

3. RESULTS AND DISCUSSION

3.1. Microstructure and microhardness

Figure 2 shows the SEM micrograph of a typical coated sample. The coating consists of an outermost titanium rich layer of 2 µm thick, an intermediate layer of 21 µm thick and an innermost layer of about 7 µm thick. The innermost layer consists of a solid solution of titanium in copper and probably TiCu₄ intermetallic compound. The intermediate layer consists of TiCu and Ti₂Cu phases[1].

![Fig. 2 SEM micrograph of copper coated sample.](image-url)
Figure 3 shows the microhardness profile on the cross section of a coated sample. The microhardness of the innermost layer increases with distance towards the surface. At the end of this layer, it reaches to about 300HV which is three times that of the copper substrate.

The increase in hardness of this layer is due to solid solution strengthening as a result of titanium concentration in copper. The intermediate and outermost layers with a thickness of about 23µm consist of TiCu and Ti₂Cu intermetallic phases and the microhardness is over 800 HV.

3.2. Tribological Behavior

Wear resistant of coated and uncoated samples were studied at different loads. Weight loss for the coated specimens was negligible at 30N load, whereas in the uncoated copper weight loss was observed from the beginning of wear testing. As sliding continued, the weight loss in uncoated samples gradually increased and a steady linear rate of weight loss was observed. By increasing the applied load to 60 N (Figure 4), the weight loss of the coated samples still was too low to measure until at sliding distance of 800m, where abrasion of the coating began at an increasing weight loss. The weight loss of uncoated samples at 60N load was somehow similar to that at 30N, except that a higher wear rate was observed at 60N load. Increasing the wear resistance of coated samples is due to the presence of Ti-Cu intermetallic compound coatings. The higher hardness of these coatings compared with copper substrate is one reason for this improvement. In addition, formation of the titanium oxide (TiO₂), on the surface of the as-coated sample could effectively reduce the wear volume [11]. Oxidation of titanium during the coating process and the inherent non-stoichiometric properties of intermetallic-type coatings may cause the formation of surface titanium oxide, the formation of which could efficiently reduce the wear volume [10].
In the case of uncoated samples, the weight change at the beginning of wear test was very low. By increasing the sliding distance, the rate of wear increased. In pure metals, the presence of oxide film on the surface acts as a solid lubricant and also as electrical insulator, which have an important effect on separating the interacting surfaces. By increasing the applied load or as the sliding continues, the oxide film penetrates into the metal surface and adhesion occurs at the interface [11].

Variation of friction coefficient vs. sliding distance in coated samples at a load of 30N shows a relatively constant value of 0.15 (Fig. 5a). By increasing the applied load to 60N, the amplitude of friction coefficient increased (Fig. 5b), but the mean value was still significantly lower than that of uncoated samples which is around 0.8.

Lower coefficient of friction in coated samples can be explained by the formation of Ti-Cu intermetallic compound coatings having higher hardness and a low friction inherent characteristic. The effect of higher hardness is to reduce the amount of transferred load to subsurface, causing the applied load withstood mainly by the coating. Therefore, the plastic deformation of the subsurface layers decreased, thereby the contact area between the sample and the counterface was reduced. As a result, sliding took place only on very limited asperities at the contact surface. On the other hand, the presence of titanium oxide on the surface of the as coated sample played an important role in reducing the coefficient of friction. Such an oxide film acts as a nonmetallic layer formed on hard Ti-Cu intermetallic coating, which can still reduce the coefficient of friction [11, 21]. Such conditions prevent adhesion of steel pin to the coating, thus reducing adhesive wear mechanism.
Worn surface of a coated sample tested at 60N in figure 6a indicates plate-like debris that are pulled out from the surface as a result of delamination wear. SEM micrograph of the particles shows the presence of plate like debris (Fig. 6b) and EDS analyses from large particles indicated that they mainly consist of copper and titanium. The observation of plate-like debris indicates that delamination was predominated during wear of coating material. However, fine particles were also observed within the plate-like debris, which according to EDS analyses, they were mainly copper, titanium and oxygen. These results indicate that oxidation wear has happened during wear testing of the coated samples.
SEM examination of counterface pin after sliding against coated sample showed evidence of plastic deformation on the surface (Fig. 7). This observation is related to the influence of hard intermetallic coatings on the counterface surface. As the wear test continued, the coating failure happened and the contact between counterface and copper substrate results in adhesion and material transfer by adhesive wear (Figures 7a, 7b). The situation was proved by X-ray dot mapping of the adhered particles on the pin surface (Fig. 7c). This is due to the fact that adhesive wear is the predominant wear mechanism for uncoated copper.
Fig. 8 Wear subsurface of coated sample after wear test under 60N load.
a) Presence of microscopic cracks under the surface, b) Formation of plate-like debris.

SEM micrograph was taken from coated sample in figure 8 shows the subsurface layers. The presence of deformation and microscopic cracks are obvious under the wear surface (Fig. 8a). The directions of microscopic cracks are parallel to the direction of wear path, i.e. perpendicular to the direction of the applied load. As the wear test continued, microscopic cracks joined together to form plate-like debris (Fig. 8b). The presence of such cracks under the surface emphasized that delamination is the dominant wear mechanism in coated specimens.

4. CONCLUSIONS

1-Pack cementation technique can be used to develop titanium-copper intermetallic phases on copper substrate. This is best achieved by an optimised pack composition at 800°C and for duration of 6 hours.

2-Formation of Ti-Cu intermetallic compounds on the surface of copper by pack cementation technique, improves the tribological behavior of copper. This is obtained by reducing the coefficient of friction to about 0.15 and increasing the wear resistance during pin-on-disk testing against steel pin.

3-Ti-Cu intermetallic coatings significantly increase the surface hardness of copper. The Ti-Cu intermetallic coating at optimum condition produced microhardness value as high as 800HV.

4-The predominant wear mechanism in coated samples is delamination and oxidation wear, whereas in uncoated copper adhesive wear is the controlling mechanism.
REFERENCES


