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Electrical Sliding Wear Behaviour of an Aged High Conductivity Cu-Be Alloy

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Abstract: - The wear behaviors of aged high conductivity Cu-Be alloy dry sliding against a steel counterface were investigated on a pin-on-disk wear tester under electric current conditions [3]. The microstructure and the worn surfaces of the aged high conductivity Cu-Be alloy were investigated by scanning electron microscope (SEM) and energy-dispersive spectroscopy (EDS). The results indicated that the aging treatment had an effect on the microstructure, hardness and wear resistance of high conductivity Cu-Be alloy. The hardness values for the alloy reached the peak hardness after an aging treatment at 500 °C for 3 h and over-aging occurred at higher temperature. Both the coefficient of friction and wear loss increased as a small electrical current was applied and decreased as the electrical current density increased. Adhesive wear, abrasive wear and electrical erosion were the dominant mechanisms during the electrical sliding processes. The alloy treated at 500 °C for 3 h exhibited much better wear resistance.

Keywords: electrical erosion, sliding wear, high conductivity cu-be alloy, aging treatment

I. INTRODUCTION

The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper. Cu-base alloys are used for electrical parts such as connectors and lead frames because the electrical conductivity of the alloys is very high. Most of the alloys are usually of the precipitation-strengthened types and are dilutely alloyed with elements of very low solubility to preserve high levels of conductivity. CuBe alloys are one of the precipitation-hardenable Cu-base alloys, and are used as metallic materials with high strength and conductivity. High conductivity Cu-Be alloys span the range from 0.15 to 0.7 wt % Be. Commercial copper-beryllium alloys may also contain a third element addition, either of cobalt or of nickel. This addition to the binary alloy system restricts grain growth during annealing by establishing a dispersion of beryllide particles in the matrix. The addition also enhances the magnitude of the age-hardening response and retards the tendency to overage or soften at extended aging times and higher aging temperatures [1-4]. Copper-beryllium alloys are used in various applications such as electrical and electronic components connectors, bearings, springs, diaphragms, dies, electrodes in resitance welding systems requiring hot hardness, etc. Cu-Be alloys are also used for obtaining non-sparkling characteristics in chemical industry. In these applications, some factors have to be considered, such as the maintenance cost and the wear resistance of the alloy. Therefore, a better understanding of the electrical sliding wear behaviour of the contact material is needed before it can be used [5-6]. Some studies have been reported on the wear behavior of Cu-Cr-Zr and Cu-Ag-Zr alloys under electrical sliding [6, 8 and 9]. The sliding friction and wear behaviors of aged Cu-Be alloy was studied in the presence of electrical current. The results indicated that the aging treatment has affected the microstructure, hardness and wear resistance of Cu-Be alloy [10]. But no previous study has been reported on electrical sliding wear behavior of an aged high conductivity Cu-Be alloy. In the case of Cu and Cu-alloys, however, this topic has not been investigated in detail. Aim of the investigation was to study the sliding friction and wear behavior of a high conductivity high conductivity Cu-Be alloy sliding against a hardened steel disk under electrical current conditions. The effect of aging treatment on the hardness of the alloy and thus, on its wear performance was also studied.

II. EXPERIMENTAL DETAILS

A high conductivity Cu-Be alloy was supplied by Arslan Metal Inc. Table 1 shows the chemical composition of the Cu -Be pin material. Prior to ageing process, all specimens were turned to a diameter of 10 mm and cut to a length of 15 mm. Samples of Cu-Be alloys were solution treated at 900 °C for 2 h, and quenched in the water at 20°C, then aged for 1, 2 and 3 h, at temperatures of 410, 440, 470, 500 and 530 °C, respectively, in an electric resistance furnace and subsequently cooled in air. JEOL JSM-6390LV scanning electron microscope (with energy dispersive spectrum (EDS)) was employed in making the microstructure measurements. Vickers hardness tests were performed using a 10 kg load. Five observations (on average) were reported in each case. For sliding tests, a pin-on-disk wear machine was modified as shown in Fig. 1 in order to transfer electrical current across the sliding interface. A D.C. power supply was connected across the specimen and the disk insulated from the drive system. The power supply worked in a constant current output mode where the current range was 0 to 30 A. But the drop in voltage couldn't be measured. Wear tests were carried out at a sliding speed of 0,98 m s-1, 2000 m distance and, a normal load of 20 N, which corresponded to a normal pressure of 0.254 MPa. Sliding friction and wear tests were performed on the pin-on-disk wear tester in ambient air, with the Cu-Be alloy pin rubbing against a steel (Ck 45 material). The disks with a diameter of 180 mm and a thickness of 15 mm were manufactured and they were heated up to 900°C and hardened by water quenching which provided a hardness of 53 HRc. Following the hardening process, surface of the disk was grinded for 0.2 μm (Ra) in order to obtain a smooth surface which is free from scratches. Prior to wear testing, 3 specimens were prepared for each condition. All the specimen surfaces were polished with 1000 grit emery paper, cleaned with alcohol and dried. Mass losses of the pin specimens were measured with an analytical balance at preset time intervals throughout the tests. The temperature rise in the specimen was measured by a thermocouple inserted as close to the interface as possible. The worn surfaces of the specimens were examined by scanning electron microscopy (SEM). Three observations (on average) were reported in each case. To calculate of friction coefficient, a 50 N load cell connected to the wearing device. Obtained data were averaged out and the friction coefficient was calculated.

Table 1 Chemical Compositions of Cu-Be Alloy pin (wt%)

	Cu	Be	Co	Ni	Fe	Others
Cu-Be alloy %	97,2	0,37	2,1	0,14	0,03	0,16

III. RESULTS AND DISCUSSION

3.1. Effect of Aging Treatment on The Microstructure and Hardness

The alloy pins were solution annealed at 900 °C for 2 h, quenched rapidly to room temperature, and precipitation hardened at various temperatures and times. Fig. 2 shows the effect of aging temperature on the Vickers hardness of the Cu-Be alloy. It is evident from Fig. 2 that the value of hardness increases obviously after aging treatment compared with the hardness 85 HV of the alloy without aging. The value of the hardness for the Cu-Be alloy initially increased with increasing aging temperature and reached the peak hardness (212 HV) at 500 °C for 3 h. With further increasing the aging temperature, the decrease in hardness indicated that overaging occurred, and the fine precipitates were replaced by the coarse and incoherent particulate within the alloy matrix. These are favorable for Orowan strengthening mechanism [6, 7].

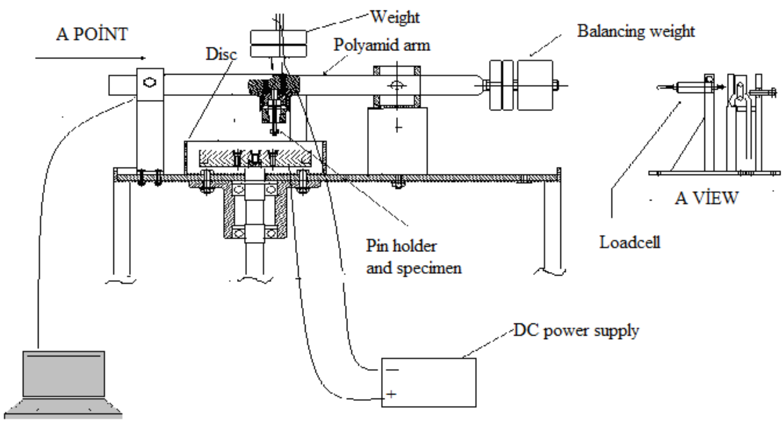


Figure 1 Schematic of The Pin-On-Disk Wear Machine for Electrical Sliding Tests [10]

The alloying elements (Co and Ni) are normally in solution in the liquid metal. Because of their strong affinity for beryllium, they combine with it and seperate during solidification as particles. The β phase is a BeCu2 compound, and the equilibrium γ phase in copper-beryllium alloys is BeCu. But, the β phase is not observed in the high-conductivity copper-berylliums with less than 0.7 wt% Be. During the age hardening process, microscopic, beryllium-rich particles are formed in the metal matrix [5]. Microstructure shows supersaturated solution of beryllium and cobalt in copper (Fig. 3a). The cobalt-beryllide phase is uniformly distributed, and metastable hardening precipitates are not resolved. The EDS spectrum (Fig. 3b) indicates that the coarse particle pointed as 1 in Fig. 3a is cobalt-rich beryllides. In the high conductivity alloys, most of the beryllium is partitioned to beryllide intermetallics. Coarse beryllides formed during solidification limit grain growth during annealing, while fine beryllides formed during precipitation hardening impart strength. From the EDS analysis in Fig. 3a pointed as 2, it is concluded that the structure consists of α phase and a uniform distribution of the beryllide phase [Fig. 3c]. This conclusion agrees well with recent experimental examinations of the alloy [3, 5].

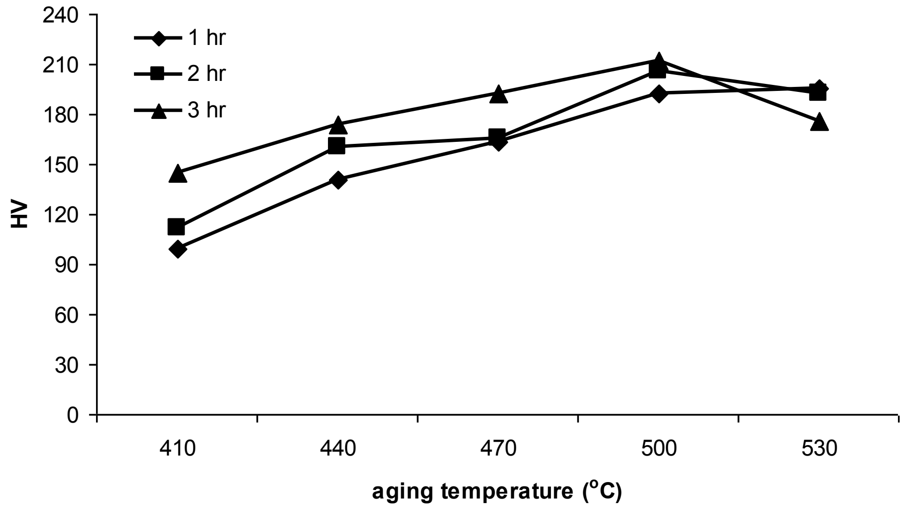
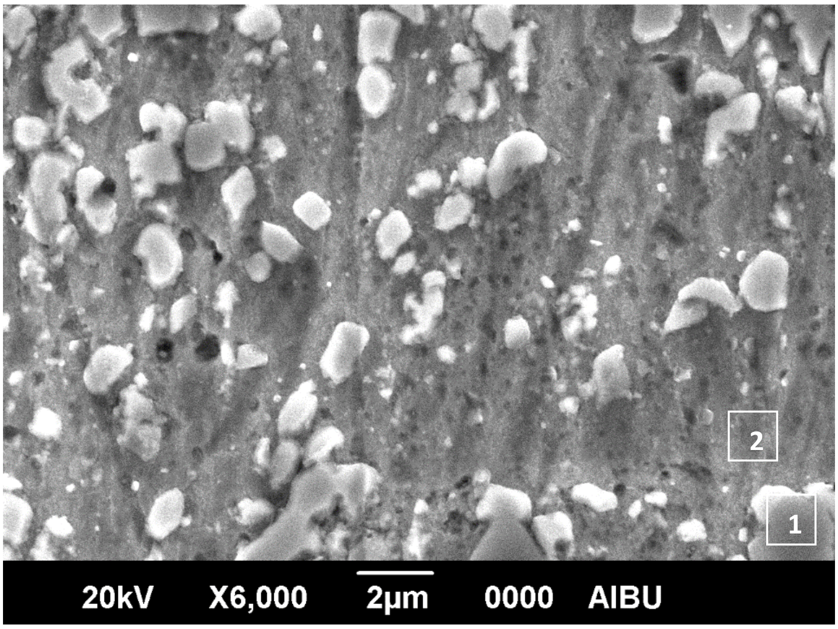
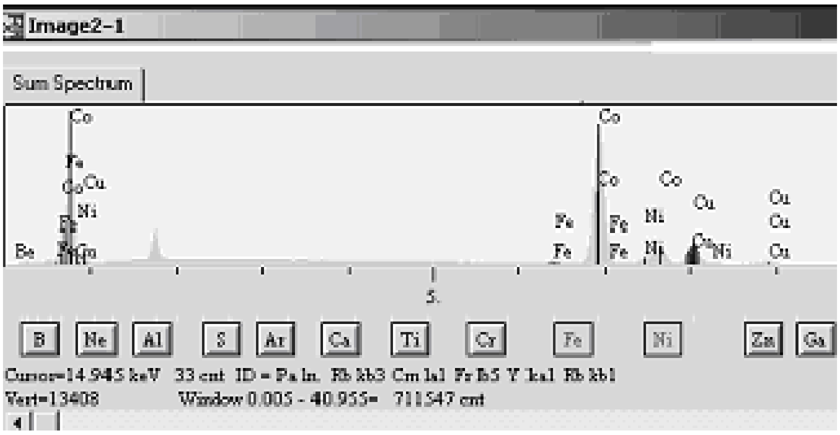


Figure 2 Variation of Hardness of the Cu-Be with Aging Temperature



(a)



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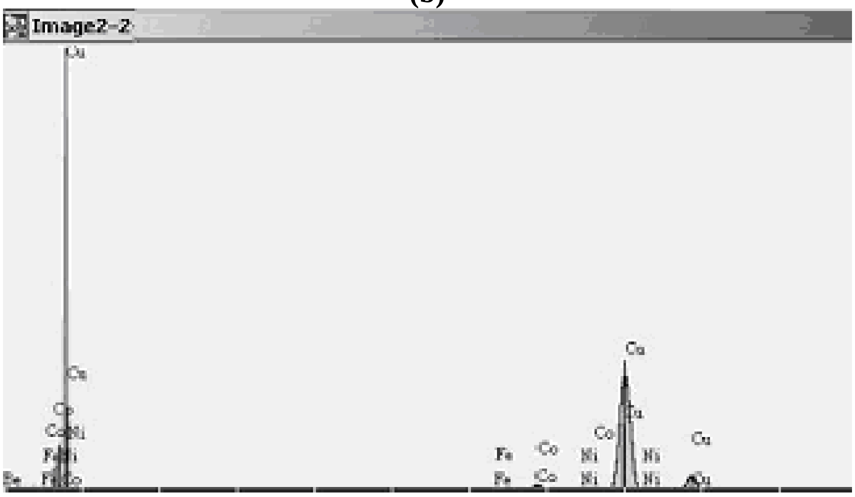


(c)

Figure 3 (a) SEM Images of the Cu-Be Alloys, Precipitation Hardened at 500 ^{O}C for 3 h, Etchant (Ammonium Persulfate-Hydroxide) (b) EDS Spectrum from Point 1 in (a), (c) EDS Spectrum from Point 2 In (a).

3.2. Sliding Wear and Friction Coefficient Under Electrical Current

Fig. 4 shows the variation of wear loss of Cu-Be alloy as a function of the aging temperature at electrical current of 30 A. It can be seen that the wear loss of the alloy initially decreases with aging temperature. After reaching the minimum wear loss at 500 °C, the wear loss increases with further increasing aging temperature. The hardness plays an important role in the wear properties of the alloy. Comparison of the data in Fig 4 with those in Fig. 2 shows that the wear loss of the alloy is approximately in inverse ratio with the hardness and minimum wear rate corresponds to the maximum hardness.

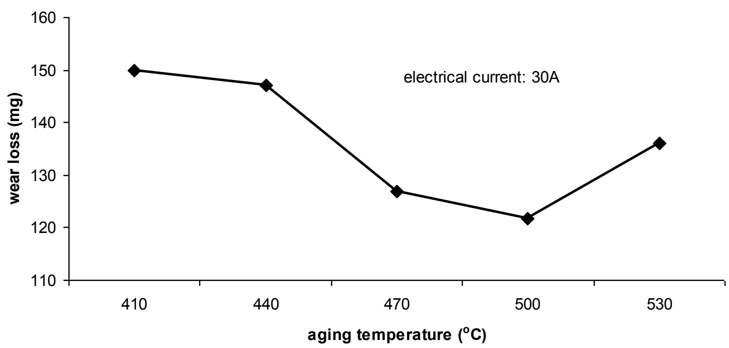


Figure 4 Effect of Aging Temperature On Wear Loss of the Cu-Be Under Electrical Sliding Conditions

In order to evaluate the wear resistance of the Cu-Be alloy after appropriate aging treatment, the specimen after aging at 500 °C 3 h was chosen. Fig. 5 and Fig. 6 show the variation of the wear loss and friction coefficient of the Cu-Be alloy pin with electrical current. The test wear performed under an applied load of 20 N and at a sliding of 0.98 ms-1. It is shown clearly from the graphs that the wear loss and the friction coefficient of the Cu-Be alloy both initially increase with the increasing electrical current but then decrease with further increase in electrical current. At electrical current of 20 A, the wear loss reaches a maximum. Under the electrical sliding, the wear of the contact pin includes the mechanical wear and electrical wear. The initial increase in wear loss and the friction coefficient with electrical current may be due to the micro welding of asperities on the contacting surface. Because, when the electrical current increases, the temperature will rise, and so the oxidation rate increase. This resulted in developing a thicker oxide film on the surfaces so that adhesion was considerably reduced. Consequently, both wear loss and the friction coefficient decreased with higher levels of current density. Similar results were also reported by Liu et al [11] for a Cu-Nb composite pin and a hardened tool steel disk in ambient atmosphere. But Tu et al reported that the wear rate of the Cu-Cr-Zr alloys dry sliding against a brass counterface increased with increasing electrical current [6]. Paulmier et al indicated that the friction coefficient of a sliding contact of steel XC48 pin/graphite disk (sliding speed, 1 m/s in ambient atmosphere) was 0.35 under electrical current of 40 A whereas it is 0.15 under non-electrical sliding [12].

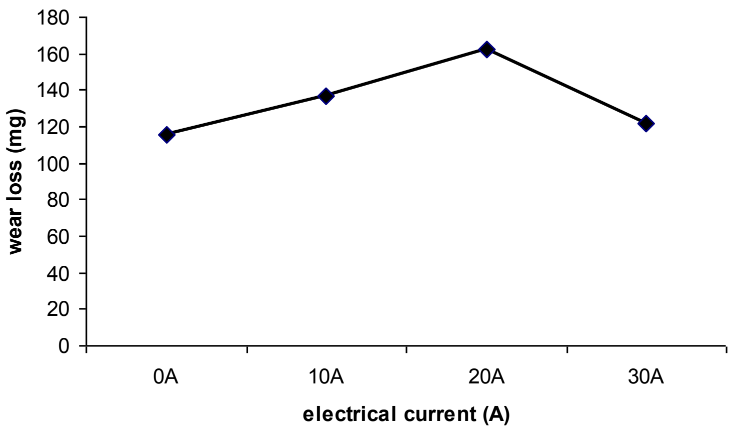


Figure 5 Variation of Wear Loss with Electrical Current (After Aging 500 ^{O}C for 3 h).

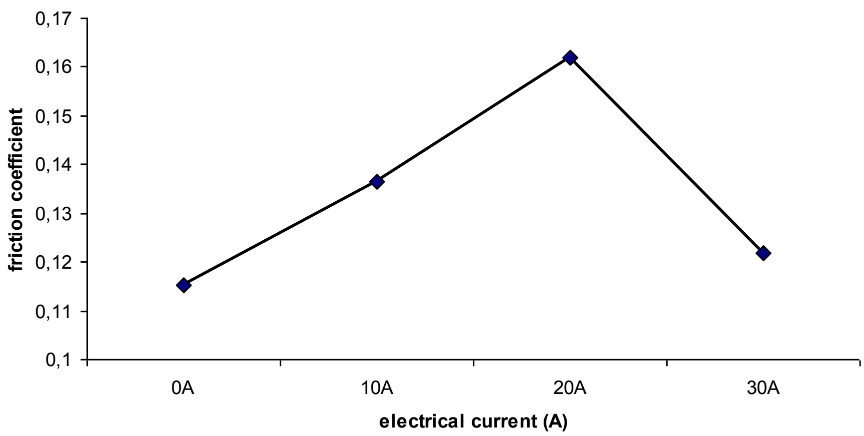
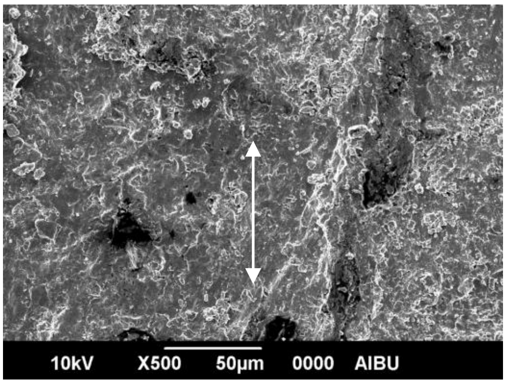
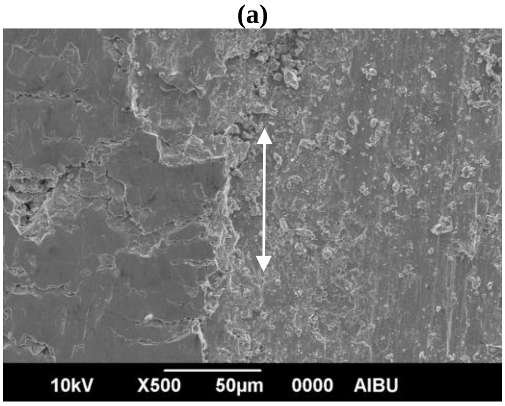


Figure 6 Variation of Friction Coefficient with Electrical Current (After Aging 500 ^{O}C for 3 h).

Fig. 7a-d shows the SEM micrographs of worn surfaces of the Cu-Be alloy under various electrical current conditions. Large amounts of wear particles and plastic deformation were observed on the worn surfaces. This can be attributed to the presence of high shear stresses and low normal stresses and indicates adhesive wear in which metal transfer is the main wear mechanism under electrical current. Adhesive wear with characteristic grooves can be observed on the worn surface shown in Fig. 7b-c. The large wear fragments are pulled out and come off of the worn metal surfaces. Because of the electrical current, the pin was severely eroded and a large spalling exists on the worn surface of the alloy, as shown in Fig. 7b. In Fig 7d, there are much less wear particles and groves seen in this surface. On the other hand, the temperature on surface of the pin and disk rises due to the dissipated heat in the interface during electrical sliding. It is suggested that softening was major erosion damage in this situation. It is seen that the temperature rises are fairly low, a maximum 25 °C in nonelectrical sliding. However, the temperature in electrical sliding increased reaching a maximum of 50 °C under 30 A. This temperature can be attributed to the presence of high cooling rate and low sliding speed, which result in the decrease of the temperature of the copper alloy pin. In a similar electrical sliding wear study, Tu et al indicated that the temperature of Cu-Nb composite pin and a hardened tool steel disk in ambient atmosphere is fairly low, a maximum 12 °C for stationary electrical contact, and 21 °C for non-electrical sliding. However, the temperature in electrical sliding increased erratically reaching a maximum of 276 °C under sliding speed of 2.5 m s-1. This is because of the higher temperature rise that occurred at the higher sliding speed [6]. Similar results were also reported by Bouchouchaa et al for electrical contact copper–stainless steel [13]. Adhesive wear and abrasive wear were the dominant mechanisms during the electrical sliding processes in this study. But arc erosion couldn't be observed clearly on the worn surfaces of the Cu-Be alloys. According to previous investigation [9, 14], arc erosion was one of the main wear mechanisms under electrical contact, and the material with the combination of high strength and high conductivity generally exhibited high arc erosion resistance.



(a)



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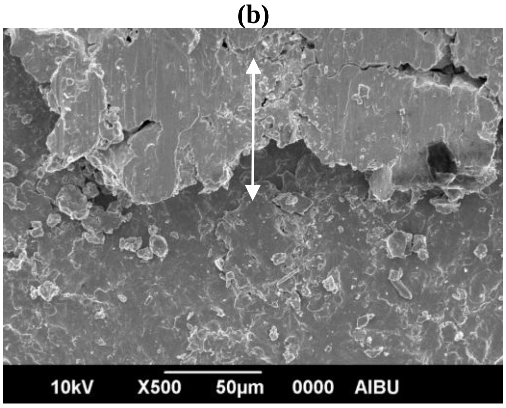

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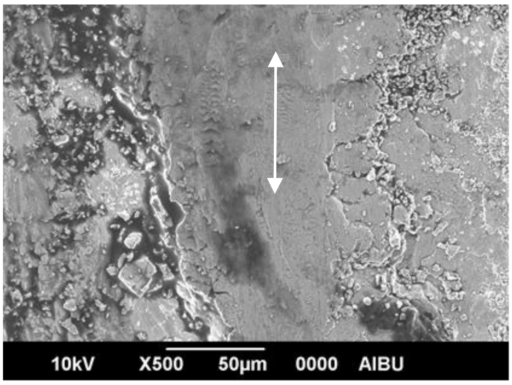

(d)

Figure 7 SEM Micrographs of Worn Surfaces of the Aged (500°C for 3 h) Cu-Be Alloy After Electrical Sliding at Various Current Values (a) 0 A; (b) 10 A; (c) 20 A and (d) 30 A (Arrows Show the Sliding Direction).

IV. CONCLUSION

The following conclusions can be made from this work on the effect of aging treatment on the microstructure and thus, on the sliding wear behavior of Cu-Be alloy rubbing against a steel disk under electrical current conditions.

1. The hardness values for the Cu-Be alloy reached the peak hardness after an aging treatment at 500 °C for 3 h and over-aging occurred at higher temperatures.
2. Both the coefficient of friction and wear loss increased as small electrical current was applied and decreased as the electrical current density increased. Under an electrical current of 20 A, the wear loss and friction coefficient reach a maximum.
3. The Cu-Be alloy aged at 500 °C for 3 h exhibited the best wear resistance in the present work.
4. From the examination of the worn surface of wear specimens, it was found that adhesive wear and abrasive wear were the dominant wear mechanisms under electrical sliding.

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