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Dry sliding wear of Cu–15Ni–8Sn alloy

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ABSTRACT

Using a pin-on-disc apparatus, the wear behavior of Cu–15Ni–8Sn alloy aged for different periods of time at 400 °C was investigated under dry condition. The results showed the wear rate was inversely proportional to the hardness of the alloy, but the maximum wear resistance was not consistent with maximum hardness. The alloy contained about 10% (volume) cells precipitated along grain boundaries had the lowest wear rate. The friction coefficient was constant for different hardness. SEM micrographs of the debris and pin revealed that the removal process of surface material involved subsurface deformation, crack nucleation, crack propagation and delamination of the material.

1. Introduction

The Cu–Ni–Sn alloys have gathered a considerable amount of interest since they were developed by Bell Telephone Laboratory in 1970s because the strength levels of these alloys with proper thermomechanical processing are equal to those of high strength Cu–Be alloys [1–4]. Furthermore, Cu–Ni–Sn alloys do not present the health hazards associated with Cu–Be alloys. Cu–Ni–Sn alloys are, therefore, possible substitutes for Cu–Be alloys in manufacture of connectors, components, etc., in the electronic industries. Besides as the excellent spring materials the Cu–Ni–Sn alloys, especially the Cu–15Ni–8Sn alloy, can also be used as the tribomaterial to make high-performance bearings for aerospace, roller cone rock bit and heavy duty mobile industrial equipment [5,6].

However, wear behavior of Cu–15Ni–8Sn alloy after different ageing treatment condition has not been reported in detail. The aim of the investigation was to give a contribution to the understanding of the dry sliding wear behavior of the Cu–15Ni–8Sn alloy and, in particular, to highlight role of material microstructure and hardness.

2. Materials and experimental procedures

Electrolytic pure Cu, pure Ni and industrial pure Sn were used to prepare the Cu–15Ni–8Sn alloy. The alloy ingot was prepared by induction melting in a high purity graphite crucible under vacuum condition and poured about 1300 °C into an investment cast mold, with a size of 160 mm × 100 mm × 17 mm. The analyzed chemical compositions of the alloy are 15.15% Ni, 7.77% Sn and 77.06% Cu in mass percent. After brushed oxidation resistant coating, the ingot was subsequently homogenized at 820 °C for 10 h and cooled in furnace. Solution heat treatment was conducted at 820 °C for 1 h and water-quenched. Then the ingot was cut into blocks 160 mm × 7 mm × 7 mm by spark cutting. These blocks were aged at 400 °C for different periods of time followed by quenching in water. After heat treatment, every block was machined into some pin samples, with a size of ∅4.8 mm × 14 mm. One section of each pin was polished with SiC abrasive paper (wet) of different grit size and 3 μm diamond polishing compounds. Then they were washed ultrasonically with soap and water, rinsed with acetone and dried with an air blower. The specimens were then weighed to an accuracy of 0.1 mg and test.

Wear tests were carried out on a pin-on-disc wear tester under dry condition in Ar atmosphere. The schematic diagram of the wear test apparatus is shown in Fig. 1. The Cu–15Ni–8Sn alloy pin was sliding against a stationary GCr15 bearing steel disc heat-treated to HRC60. The pin speed during wear tests in all cases was 0.25 m/s (200 rpm) and the test duration was 30 min. The load for tests was 20 N. During the experiments, the friction coefficients were continuously measured. When each tests was completed, the Cu–15Ni–8Sn pin was slighted blown to remove loose debris and weighed to determine changes. Then the weight loss was converted into wear rate. After each wear test, the wear track surface, subsurface and wear particles were examined by a Hitachi-502 scanning electron microscopy (SEM), and energy-dispersive analysis of X-rays (EDAX).

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The measurement of the amount of the cells precipitated along grain boundaries was carried out by using a optical metallographic microscope equipped for Leco image analyzer. The hardness was measured by a Vickers hardness tester with the load of 98 N and a micro-Vickers hardness tester with the load of 0.49 N.

Not less than three tests were conducted for each heat treatment condition.

3. Results and discussion

Fig. 2 shows representative optical metallographic microstructures of the Cu–15Ni–8Sn alloys. When Cu–15Ni–8Sn alloy was aged at 400 °C after solution heat treatment, the supersaturated solid solution α was decomposed as follows [2,7]. The modulated structure with Sn-rich and Sn-poor regions formed as a result of spinodal decomposition first. The modulated structure was on the nanoscale, and was continuous throughout the grains up to the grain boundaries. Then the metastable coherent γ'-$(Cu_xNi_{1-x})_3Sn$ phase with DO_{22} structure was formed in the Sn-rich zone and changed to the γ-$(Cu_xNi_{1-x})_3Sn$ phase with DO_3 structure which was incoherent to the matrix (not visible by optical metallography). Soon after beginning of the stage, the cells with DO_3 phases (black) were formed at grain boundaries and engulfed completely the matrix grains in the end. Fig. 3 shows the change in the amount of cell of Cu–15Ni–8Sn alloy on aging at 400 °C. The cells started to precipitate slowly near 60 min, and the amount of cells was 100% after 28 h. The modulated structure and cells formed during aging treatment had a significant influence on the mechanical and tribological properties of the Cu–15Ni–8Sn alloy.

Fig. 4 shows the variation in the hardness of the Cu–15Ni–8Sn supersaturated solid solutions aged for different times as a function of the aging time. The hardness was HV109.3 for solid solution and HV306.8 for peak aged alloy (aged for 120 min). Spinodal decomposition in the Cu–15Ni–8Sn alloy tripled the

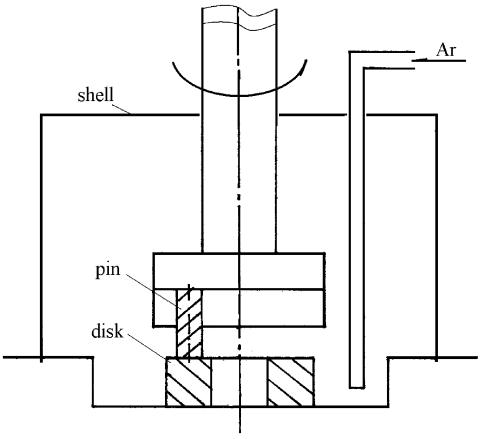

Fig. 1. Schematic of the pin-on-disc testing method.

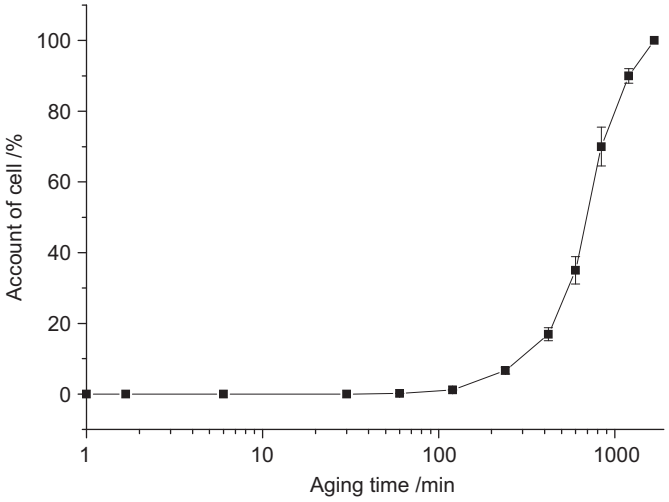

Fig. 3. Change in the amount of cell of Cu–15Ni–8Sn alloy on aging at 400 °C.

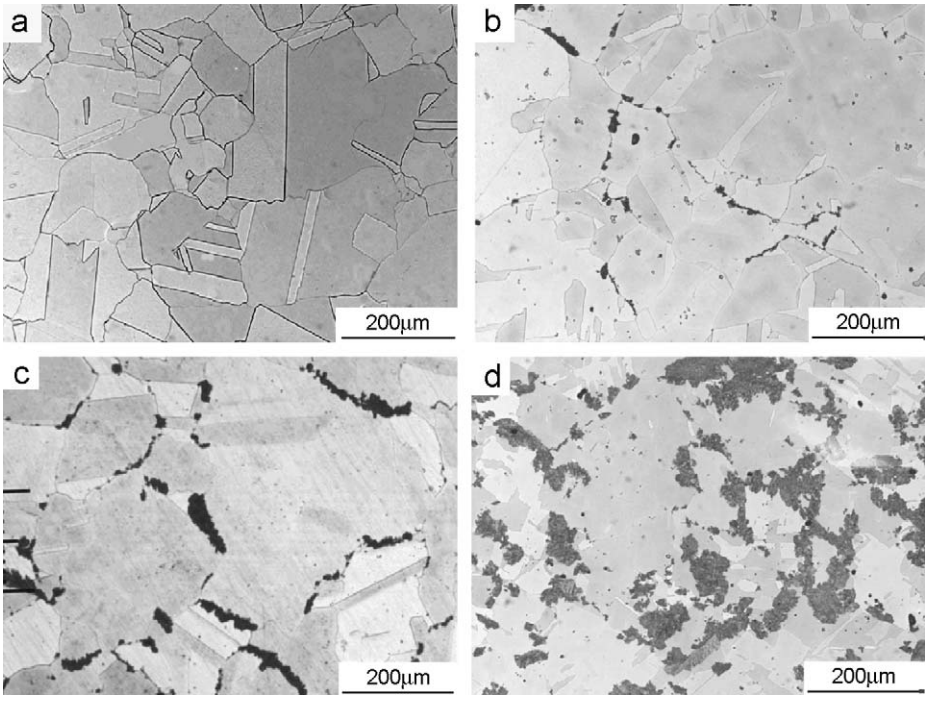

Fig. 2. Microstructures of Cu–15Ni–8Sn alloy obtained after different ageing times of (a) 0 min, (b) 120 min, (c) 240 min and (d) 420 min. The aging temperature was 400 °C.