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Grain coarsening behavior in a nanocrystalline copper subjected to sliding friction

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ABSTRACT

A grain coarsening behavior was reported in this work in nanocrystalline copper during sliding friction. The cross-sectional microstructure and micro-hardness of the pure copper subjected to sliding friction were investigated in detail. A nano-grained surface layer of copper was obtained after sliding against a WC-Co ball for the first 100 cycles. However, a pronounced grain coarsening was observed during the subsequent sliding cycles. Such a behavior is dominated by high stress, high strain as well as large amplitude adopted in sliding friction.

1. Introduction

A near-surface material with concomitant changes in microstructure is commonly observed during sliding [1–3]. For example, in our previous study, a thick nanocrystalline surface layer in excess of 100 μm was produced underneath the worn surface of pure copper subjected to sliding against a WC-Co ball under dry condition [3]. Most investigations have been focused on the mechanism and the evolution of grain refinement during the sliding process, in that it is a common phenomenon for the coarse-grained material to be intensively refined by the introduction of dislocation-cell structures during the plastic deformation [4].

To our knowledge, only few literatures have been reported concerning the grain coarsening behavior during sliding [5–7]. In the case of the Pb–Sn alloy sliding against a 52100 steel ball in an early study, an original lamellar structure becomes equiaxed and coarsened after repetitive sliding [5]. After sliding wear, high stress triggers a microstructural evolution in nanocrystalline Ni–W alloy increasing the grain size from 3 nm in the initial state to 20 nm in the subsurface layer with a thickness of a few hundred nanometers [6]. This phenomenon is consistent with other SEM observations for the worn subsurface structure in Ref. [7], where the grain growth during recrystallization of the nanostructured copper in some local zone has been noted.

In this work, a pronounced grain growth phenomenon was observed in the copper subjected to dry sliding, the study of which is helpful for the insight understanding of the metals in the microstructural evolution during sliding.

2. Experimental

Sliding experiments were performed on a unique sliding friction treatment (SFT) apparatus in a ball-on-disc contact configuration under a dry condition at room temperature. An annealed Cu disc of 99.95 wt.% in purity, $200 \times 200 \times 3\ mm^3$ in dimension, and 0.4 μm in surface roughness (Ra) slid against a WC-Co ball of 10 mm in diameter. A detailed description of the sliding friction treatment (SFT) setup and procedures used in this study were reported previously [8]. Compared with the traditional friction and wear tester, the unique equipment employed in this work possesses higher sliding velocity and offset displacement (100 μm in this work) perpendicular to the sliding direction after each sliding run for producing a large treated surface with refined grains. The sliding experiments were carried out at an amplitude of 50 mm, normal loads of 200 N, a sliding velocity of 0.2 m/s, and a duration of 100–300 cycles.

Variations of the micro-hardness along the depth from the treated layer were measured on cross-sectional samples by using a Vicker's hardness tester under a load of 10 g and a duration of 10 s.

The microstructure of the deformed surface layer on Cu sample was characterized by using an electron back-scattered diffraction (EBSD) method in a FEI Quanta 400 scanning electron microscope

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(SEM) equipped with a field emission gun and a JEOL JEM-2100 transmission electron microscope (TEM) operated at a voltage of 200 kV. Cross-sectional thin foils were prepared by electroplating a Cu layer, cutting a cross-sectional piece and grinding carefully followed by electropolishing and ion thinning at low temperatures for the EBSD and TEM observations respectively.

3. Results and discussion

Fig. 1(a)–(c) show the optical longitudinal cross-sectional microstructures of the Cu samples subjected to SFT under different cycles. Pronounced plastic deformation and traces of plastic flow can be observed in the surface layer, within which grain

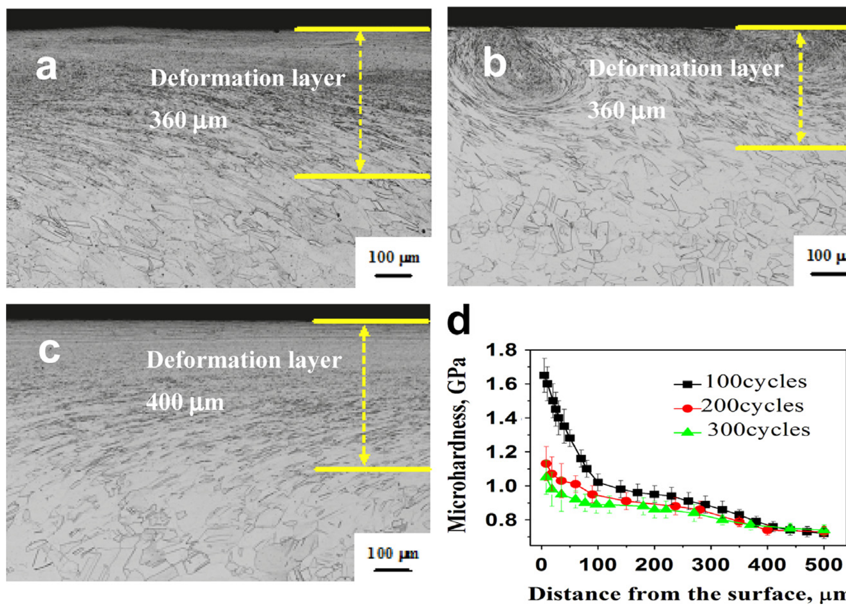

Fig. 1. Cross-sectional optical micrographs of as-treated Cu samples subjected to sliding at (a) 100, (b) 200, and (c) 300 cycles, and (d) variation of micro-hardness with the depth from top-treated surface in the three samples.

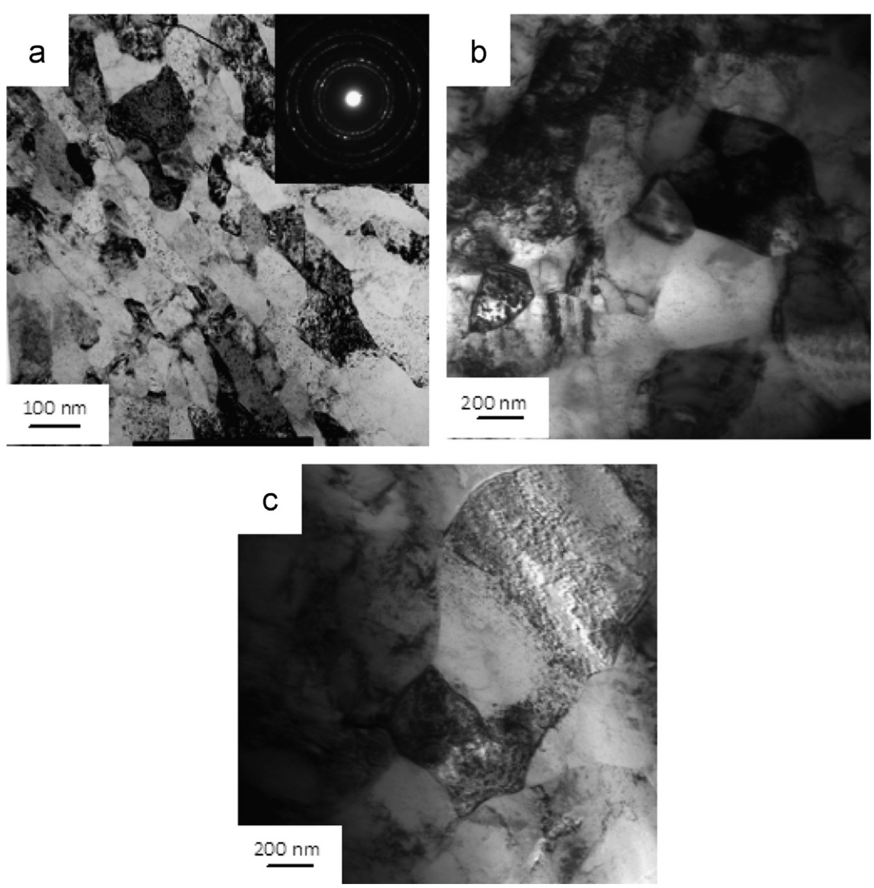

Fig. 2. Bright-field TEM images of the top surface in the as-treated Cu samples subjected to sliding at (a) 100, (b) 200, and (c) 300 cycles.