Rev.Adv.Mater.Sci. 18(2008) 600-603

FATIHGUE DAMAGE IN NANO-SIZE GRAINED OXYGEN FREE COPPER

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Received: March 29, 2008

Abstract. In order to understand the fatigue behavior of ultra fine grained copper, rotating bending fatigue tests were carried out. After the 4 and 8 pass of ECAP (*equal channel angular pressing*) with Bc route (after each pressing, the billet bar is rotated around its longitudinal axis through 90°), grains with about 300 nm diameter were formed. Significant morphological difference in fatigued surfaces between high and low cyclic stress amplitudes was observed. To clarify the formation process of surface damage, morphological change in surface damage caused by cyclic stresses was monitored successively by using optical microscope and scanning electron microscope (SEM). It was found that the surface feature for the ECAPed copper varied substantially with damage accumulation during cyclic stresses.

1. INTRODUCTION

To improve the strength of copper, addition of alloying elements has often been carried out. However, this alloying method causes considerable drop of electric conductivity and ductility. In order to overcome this inherent shortcoming associated with the conventional processing, the development of copper with refined grain size has been explored by severe plastic deformation, such as ECAP process [1]. The refinement of copper grain results from the combination of recrystallization and severe plastic deformation. For copper and copper alloys, average grain size ranging from 200 to 300 nm has been obtained by ECAP [2,3]. For the use of ultra-fine grained materials as the members of machines and structures, fatigue characteristics must be clarified. At present, only a limitied number of reports have been published on the fatigue characteristics of ultra-fine grained materials [4,5].

In the present study, fatigue tests of a ECAP processed copper with grain size of approximately 300 nm were performed. Successive observations of the surface morphology were carried out to clarify the fatigue mechanism particulary the fatigue damage formation for the ECAP processed copper. From the microstructural observation for each specimen, surface damage in ultra-fine grained copper is discussed.

2. EXPERIMENTAL PROCEDURES

The material used in this study was 99.99% pure oxygen-free copper. Before the ECAP process, the material was annealed at 500 °C for 1 hr. Repetitive ECAP was accomplished by Bc route (after each pressing, the billet bar is rotated around its longitudinal axis through 90°). ECAP process was carried out at room temperature up to 4 and 8 passes. After ECAP, microstructural change was

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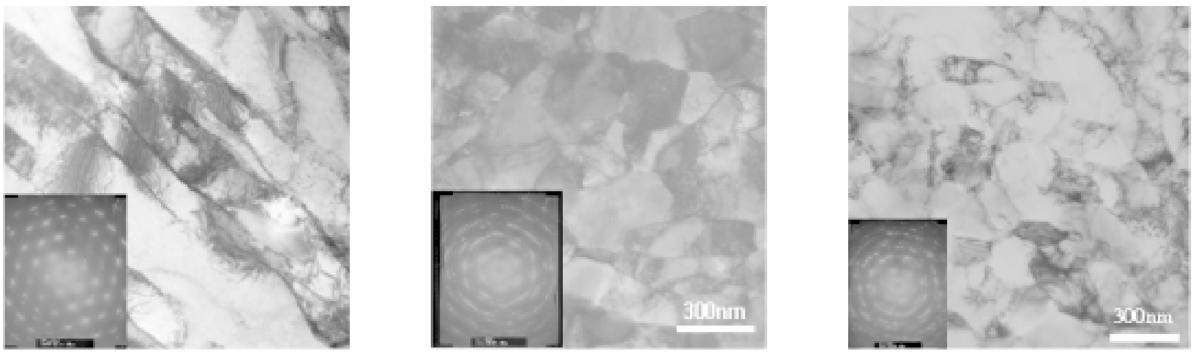
Table 1. Mechanical properties of the ECAPed copper specimens.

Number of Pass	Yield strength (MPa)	Tensile strength (MPa)	Tensile elongation (%)	Vickers Hardness
0	63	232	51	63
1	319	339	25	128
4	358	413	21	138
8	379	429	24	145



a) After 1 pass of ECAP (b) After 4 passes of ECAP (c) After 8 passes of ECAP

Fig. 1. TEM micrographs of ECAPed copper.

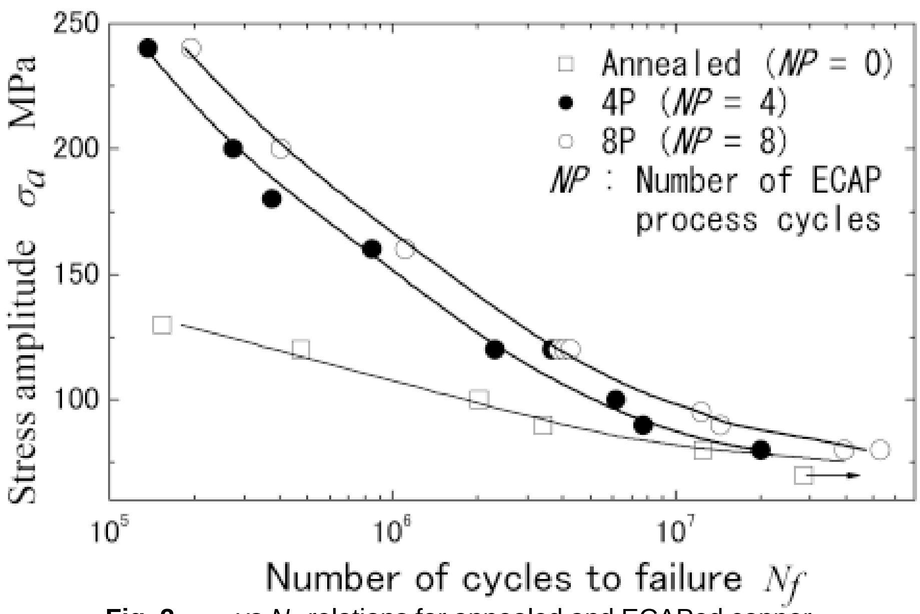


Fig. 2. $\sigma\sigma_a$ vs N_f relations for annealed and ECAPed copper.

observed and the associated mechanical properties were measured. The observations of fatigue damage on specimen surface were carried out by using optical microscope and SEM.

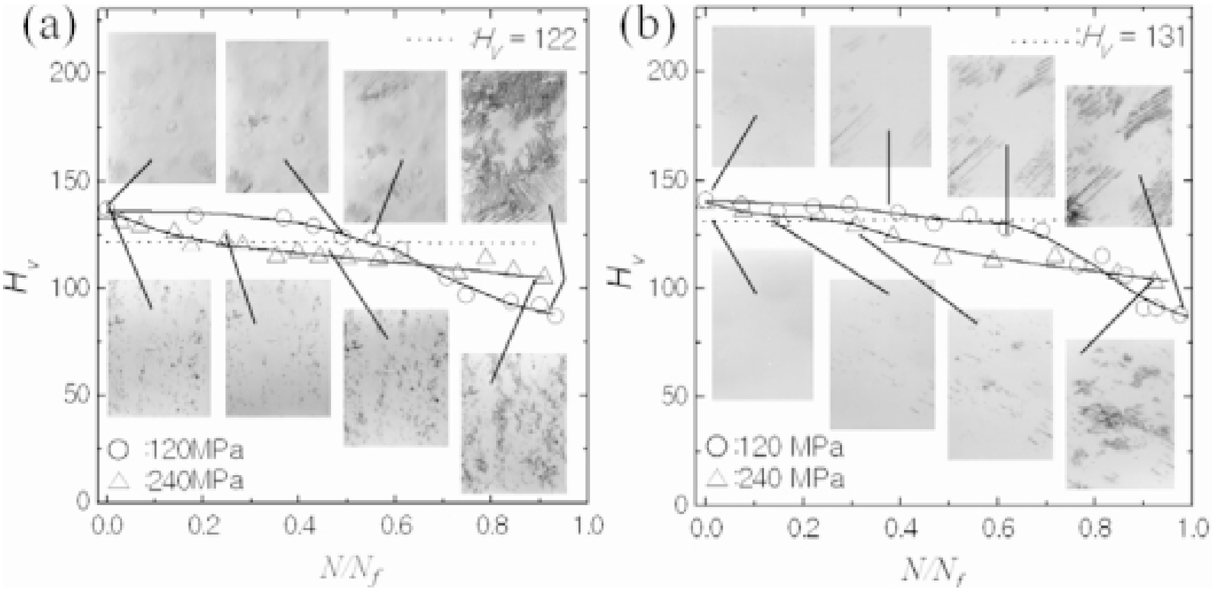


Fig. 3. Change in surface hardness due to cycling along with OM micrographs of surface damage; (a) 4 and (b) 8 passes.

3. RESULTS AND DISCUSSION

Table 1 shows the mechanical properties of the annealed and ECAP processed copper specimens. The specimen with 0 pass represents the annealed copper without ECAP.

Fig. 1 shows typical TEM micrographs and the matching SADP (selected area diffraction patterns) of center area, 1 mm in diameter) for the specimens; (a) 1, (b) 4 and (c) 8 passes. After the ECAP processing, average grain size was about 300 nm. Fig. 2 shows the fatigue endurance curve for annealed and ECAP processed (4 and 8 passes) specimens. In general, the value of fatigue limit stress at 10^7 cycles, σ_w, for the metals with ordinary grain size is roughly proportional to the static tensile strength [5]. However, there was little difference in σ_w between annealed and ECAP processed copper, despite the fact that the tensile strength of ECAP processed copper is about 1.8 times larger than annealed one. For the stress beyond fatigue limit stress, fatigue life (number of cycle to failure: N_f) of ECAP processed specimens was larger than annealed one, and the difference in fatigue life increased with an increase of stress amplitude. Generally fatigue limit is dependent on the yield strength of metal, however nano-grained copper in this study showed abnormal fatigue strength values.

Fig. 3 shows the surface hardness variation with number of cyles at applied stresses of 120 and 240MPa, respectively, for the specimen with (a) 4 and (b) 8 passes, respectively [5]. At first stage of cyclic strsses, surface hardness maintained initial value however the hardness was decreased with increasing damaged area. With increasing number of process cycle near fracture, fatigue damage was observed within entire surface region. The surface morphology of ECAP processed copper after the repetitions of stress is quite different from that of annealed copper in which fatigue damage is locally originated from slip band.

4. CONCLUSIONS

Experimental results suggest that the fatigue behavior of ultra-fine grained copper prepared by ECAP is substantially different from ordinary grained coppers. Although the static tensile strength is 1.8 times higher than ordinary grained copper, the increase in fatigue limit stress is not observed. Even though the ultra fine grains contribute to the increase of fatigue life at high applied stresses, the increase in damaged surface area with cyclic stress causes the decrease in surface hardness and faigue life at comparatively lower cyclic stresses. The present study srrongly suggests that ultra fine grain formed during ECAP process can easily be displaced and defected by cyclic stress, and accumulation of damage was considerably accelerated in grain boundary regions.

ACKNOWLEDGEMENTS

This research was supported by a grant (code #: 06K1501-00230) from ‘Center for Nanostructured Materials Technology’ under “21st Century Frontier R&D Programs’ of the Ministry of Science and Technology, Korea.

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