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EBSD study on the evolution of microstructure in pure copper after processing by high-pressure torsion

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The evolution of microstructure in high purity copper subjected to high-pressure torsion (HPT) has been examined by Electron backscattered diffraction (EBSD). Copper disks were processed in HPT for 1/4, 1/2, 1, 5, and 10 turns under a pressure of 6.0 GPa. Results indicate the formation of Σ3 twin boundaries by recrystallization before complete microstructural refinement. A gradual increase in the homogeneity of the microstructure occurred with increasing numbers of turns, reaching stabilized ultra-fine grain structure at 5 turns with minimum grain size of 150 nm. In addition, microhardness measurements indicate softening by recrystallization at early stages of HPT straining; further straining at large number of turns results in hardness homogeneity with maximum hardness of 157 Hv.

Introduction

The production of bulk ultra-fine grained materials has been possible by applying a severe plastic deformation process such as high-pressure torsion (HPT) [1]. In such method, a disk is subjected to a compressive pressure of several GPa and concurrent torsional straining that occurs by rotation of the lower anvil while the upper anvil is kept fixed (Fig.1). The process causes large shear strain without any significant changes in the disk dimensions, resulting in grain refinement in the microstructure with an average grain size in the submicron level (0.1-1 µm). This provides an excellent combination of strength and ductility in metals and alloys [1]. The aim of this work is three fold. First, to investigate the evolution of microstructure by EBSD for high purity copper subjected to HPT. Second, to provide some insight into the recrystallization process observed at the early stages of HPT straining. Finally, to correlate microstructural refinement by HPT to the evolution of microhardness with increasing number of turns.

Experimental Procedure

High purity copper rods were annealed for 1 hr at 400 °C and later cut into disks with diameter of 10 mm and thickness of 0.8 mm. The disks were HPT processed for number of turns N = 1/4, 1/2, 1, 5, 10. Compressive pressure of 6 GPa was applied and each disk was strained in torsion at rotational speed of 1 rpm. The microstructure was examined by Electron Back Scattered Diffraction (EBSD) technique equipped in Scanning Electron Microscope (SEM). Vickers microhardness was made under a load of 200 gf and dwell time of 15 sec.

Results

Figure 2 presents EBSD maps of grain boundary reconstruction, illustrating evolution of microstructure at three radial positions (center, mid-radius and near-edge) with increasing N. In the early straining stage (N = 1/4 turn), grain refinement and concurrent recrystallization occurred at the near-edge position, producing large fraction of Σ3 twin boundaries. Recrystallization shifted toward the center of the disk upon further straining. Full grain refinement was first observed in the near-edge position for N = 1 turn. More homogeneous and stable grain structure was achieved at 5 and 10 turns. At this level of high strain, the grain size reaches a minimum of about 150 nm. Moreover, the microhardness results in Fig.3 suggest the occurrence of recrystallization at initial stages of HPT as observed by the drop in the hardness values near the edge. Such drop shifts toward the disk center with increasing number of turns. At N = 5 turns and higher, more homogeneity in microhardness is achieved.

Conclusion

- Recrystallization occurs initially at early stages of HPT straining, followed by homogeneous grain refinement at higher strains.
- Drop of microhardness at near-edge indicates softening by recrystallization; further straining results in hardness homogeneity.

1. The authors would like to acknowledge Kuwait University funding project (GE 01/07) and PAAET project (TS-12-03).
2. Zhilyaev and Langdon, *Prog. Mat. Sci*., 2008, 53, 893.
3. Xu, Horita, and Langdon, Acta Mater., 2008, 56, 5168.

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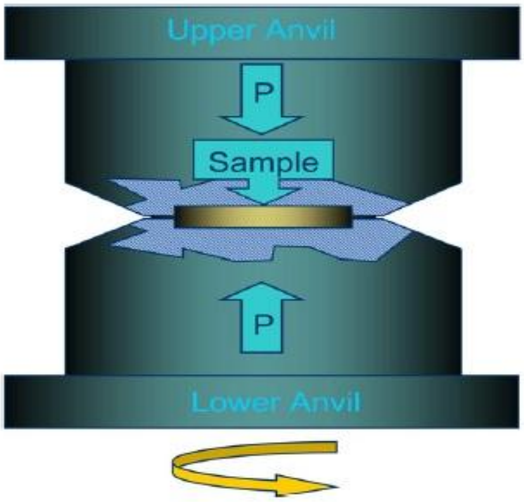

Figure 1. Schematic illustration of HPT processing [2].

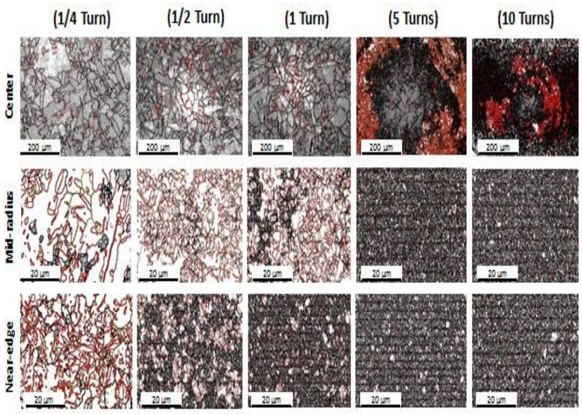

Figure 2. Grain boundary reconstruction from EBSD maps for samples processed at *N* = 1/4, 1/2, 1, 5, and 10 turns. Grey lines denote LABs, black lines denote random HABs, and red lines represent Σ3 boundaries.

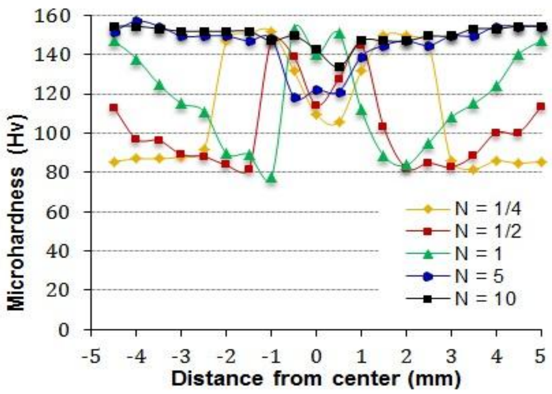

Figure3. Microhardness plots of HPT copper samples processed at *N* = 1/4, 1/2, 1, 5, and 10 turns