Letter to the Editor

Fracture micromechanisms of Cu nanomaterials prepared by ECAP

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Abstract

Fracture micromechanisms of nanocrystalline Cu prepared by ECAP method are analysed in this paper. It follows from the analyses that the fracture micromechanism is influenced by the number of ECAP passes. Transcrystalline ductile fracture took place in the range from 1 to 14 passes, whereas mixed fracture (transcrystalline ductile fracture with intercrystalline facets) occurred after 15 and 16 ECAP passes. Probable reasons of different fracture mechanisms are explained.

K e y w o r d s: nanocrystalline copper, fracture micromechanisms, transcrystalline ductile fracture, intercrystalline fracture

1. Introduction

Mechanical properties of copper prepared by severe plastic deformation, namely by the equal channel angular pressing (ECAP), were analysed in [1, 2]. Reports [3–11] deal with evolution of Cu microstructure, modelling of ECAP processes and analysis of mechanical properties. The detailed analysis of fracture micromechanisms of nanomaterials in [1, 2] was limited by the number 10 of deformation passes. In the present examination, a broader range of the number of passes (up to 16) was accomplished and the fracture mechanism after tensile loading determined again.

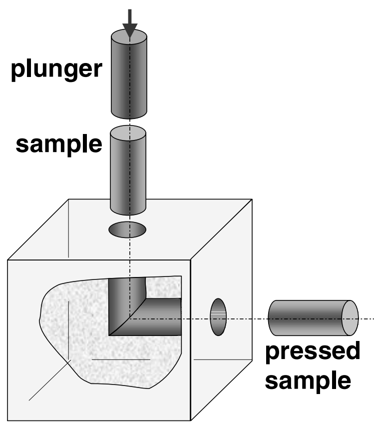

Fig. 1. Scheme of ECAP.

2. Experimental material and methods

Commercial pure copper (99.9 % Cu) with the initial grain size of 7 μm was used as an experimental material. The cylindrical specimens (diameter 10 mm, length 70 mm) were obtained by repeated pressing using the ECAP equipment (Fig. 1) at room temperature by route C; the number of passes ranged from 1 to 16; the hydraulic press used for ECAP is able to produce a load of 1 MN. The specimens (diameter of 3 mm, length of 15 mm) were then produced by machining and tensile tested on the TIRATEST machine up to fracture. The analysis of fracture surfaces was then carried out by means of scanning microscope JEOL JSM 7000 F. At least one hundred fracture fa-

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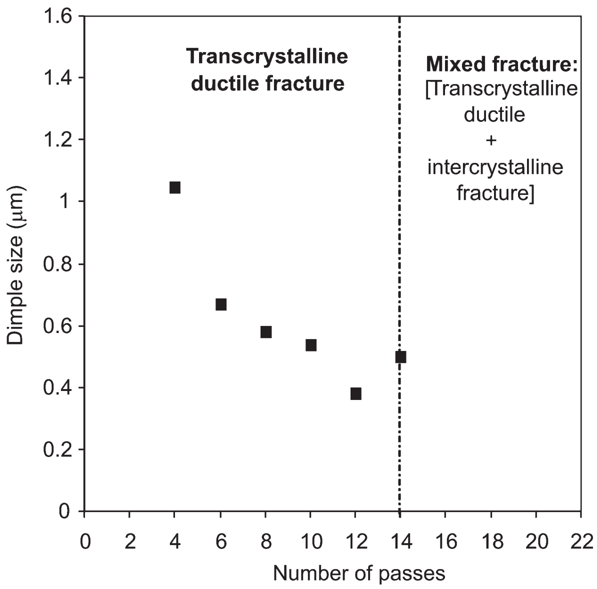

Fig. 2. Dimple size in dependence on number of ECAP passes.

cets were analysed in each specimen state and the mean dimple size was estimated.

3. Results and discussion

The analysis of fracture surfaces was made in order to determine the fracture micromechanism and the following results were obtained:

a) transcrystalline ductile fracture occurred after the number of ECAP passes ranging from 1 up to 14,

b) mixed fracture (intercrystalline fracture with transcrystalline fracture areas) was observed after 14 ECAP passes.

In the case a), two different dimple categories can be distinguished identified on the transcrystalline ductile fracture surfaces: large dimples (ca 5 μm) initiated by decohesion on the inclusion/matrix interface and fine dimples created probably by the dislocation mechanism. Assuming three development stages of ductile fracture (initiation, growth and coalescence of cavities), a special attention was devoted to the initial fracture stage, in which the density of dimples increased with growing deformation. The reason of this behaviour is the coalescence of dislocations, increasing number of the profile triple grain junctions and the development of high angle boundaries at which cavity formation proceeds. Consecutive stages of the ductile fracture formation, namely growth and coalescence of voids are accomplished by the usual mechanisms. An average size of dimples was estimated by means of statistic analysis on samples set of fine dimples. It was proved, that the average dimple size of ductile fracture decreases with increasing number of ECAP passes, Fig. 2.

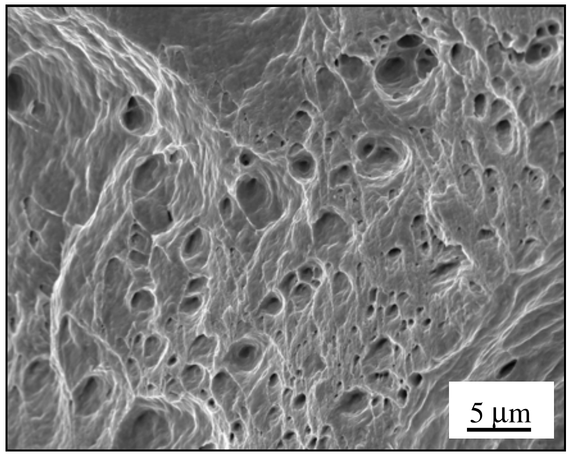

Fig. 3. Transcrystalline ductile dimple fracture (6 passes of ECAP).

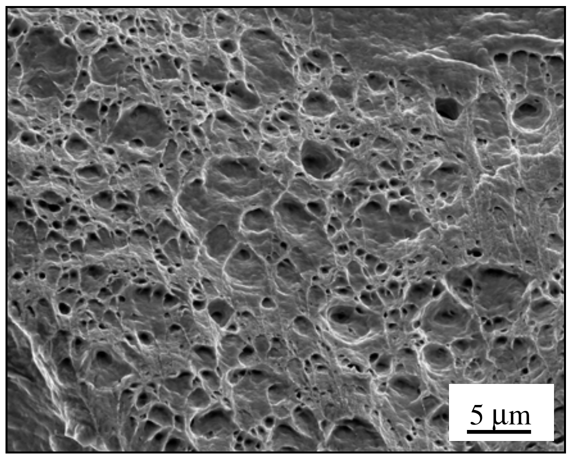

Fig. 4. Transcrystalline ductile dimple fracture (10 passes of ECAP).

In the case b), mixed morphology of fracture developed at the highest degree of critical pressing deformation (i.e. after 14 passes). Beside areas of intercrystalline fracture also localities of transcrystalline ductile fracture with fine dimples of size (∼ 0.4 μm in diameter) were observed. They cover only about 20–25 % of the total fracture surface. We assume that intercrystalline facets have been created at places of incompletely developed high angle boundaries after the exhaustion of plastic deformation of the material. A simultaneous degradation of mechanical properties was also observed. It caused the decrease of the mechanical properties [2]. Both types of the observed fracture mechanisms are illustrated in Figs. 3–5.

4. Conclusions

The following conclusions can be made:

By the fracture surface analysis two fracture

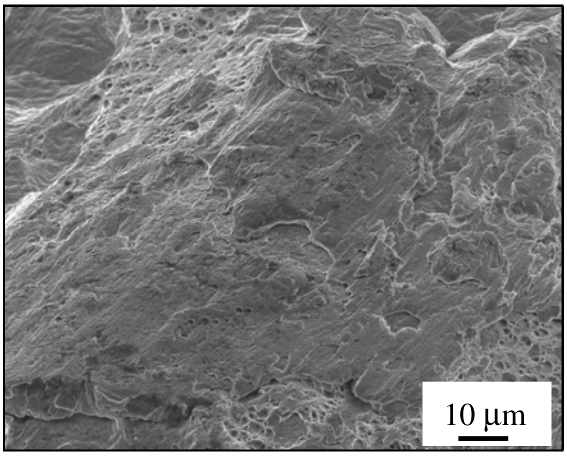

Fig. 5. Mixed fracture (16 passes of ECAP).

micromechanisms were identified depending on the amount of plastic deformation accumulated by the repeated ECAP passes:

a) Fracture surfaces up to 14 ECAP passes (90° channel angle) have transcrystalline character with the dimple morphology. With the growing number of ECAP passes, the dimple size decreases and the quantity of dimples increases. Dislocation coalescence and changes in the triple grain junctions manifested by the increasing number of profile vertices with the amount of deformation are the probable fracture mechanisms affecting the fracture initiation, i.e. the first stage of the ductile fracture formation. Void growth and void coalescence are controlled by usual mechanisms.

b) Mixed fracture surfaces with intercrystalline facets and fine dimple ductile fracture surface are typical after more than 14 ECAP passes. It is assumed that microcracks on high angle boundaries and plasticity exhaustion are the reasons of the different deformation mechanism.

Acknowledgements

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