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Influence of strain on the copper structure under controlled deformation path conditions

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Materials

ABSTRACT

Purpose: One of the methods of plastic deformation under complex deformation path conditions is compression with oscillatory torsion. The observable effects in the form of changing force parameters and structure changes confirm the possibility of deformation to a value many times higher than in the case of methods traditionally applied for forming. This article presents the results of the influence of compression with oscillatory torsion on structural phenomena occurring in copper deformed in such a way.
Design/methodology/approach: The examinations were conducted at a compression/oscillatory torsion test stand. The structural examinations were conducted with the use of light and electron microscopy.
Findings: In experimental investigations, a reduction of unit pressures was observed when compared to conventional compression. The structural examinations indicated substantial differences in the mechanisms of plastic deformation conducted in both conventional and combined way.
Research limitations/implications: There are premises which show that a metallic material of a nanometric structure can be obtained in this way (top-down method), by the accumulation of great plastic deformation. Metallic materials characterized by grain size below 100nm are distinguished by unconventional properties. Further examinations should focus on conducting experiments in a way that would enable grain size reduction to a nanometric size. This will enable the cumulation of greater deformation in the material.
Originality/value: The method of compression with oscillatory torsion is an original method developed at the Silesian University of Technology, owing to which it is possible to obtain high deformation values (SPD) without risking the loss of cohesion of the material. Thorough understanding of the changes taking place in the structure of metals subjected to compression with oscillatory torsion will allow the optimal choice of process parameters in order to achieve a gradual grain size reduction.
Keywords: Nanomaterials; Plastic forming; Microstructure; Compression with oscillatory torsion

1. Introduction

Materials with ultrafine (both nano- and submicrometric ones) have competitive physical and mechanical properties compared to conventional alloys. Some of them show superplastic features. There is a number of methods to obtain ultrafine grain material, the most important being : high pressure torsion (HPT) [1-3], equal-channel angular extrusion (ECAE) [4÷6], cumulated plastic deformation [7] or cyclic extrusion compression (CEC) [8].

Nanometric structures obtained by different methods differ from one another in many aspects: the degree of structure refinement, structure homogeneity, and the physical and mechanical properties [9 -13].

One of the methods of plastic strain under controlled deformation path conditions is compression with oscillatory torsion. The observable effects in the form of changing force parameters and a changing structure corroborate the little yet known possibility of effective strain to a value many times higher than in the case of methods traditionally applied for forming The literature shows explicitly that there is no information as regards the influence of the presented material deformation method on the structural phenomena accompanying the grain refinement processes after such deformation.

The construction of a device used for this purpose is an original solution developed at the Department of Process Modelling and Medical Engineering of the Silesian University of Technology [14,15]. The paper presents the influence of oscillatory compression parameters on the properties of submicrometric and nanometric structures of electrolytic copper. The properties of a structure being formed as a result of deformation under controlled path conditions are determined.

2. Material and methodology

The research was conducted on rolled samples made of electrolytic copper M1E of an initial diameter $d_o = 10$ mm and initial height $h_o = 15$ mm ($h_o/d_o = 1.5$). Before strain, the copper was annealed for 2 hours at a temperature of 550°C, with cooling in the air. After annealing, the mean grain diameter of the copper was 35 μm.

The samples were deformed at absolute draft $\Delta h = 7.5$ mm, which corresponds to 50% of the initial height h_0 , applying additional torsion at a frequency of the lower punch oscillation in the range from 0 (conventional compression) to 1.6 Hz and a torsion angle equal 6°.

An area representative for the microstructural investigations after oscillatory compression was selected from the centre of the sample's height at a distance of ca. 0.8 of the sample's external surface radius.

Metallographic investigations were conducted on a Reichert Me-F2 light microscope. Structural investigations on a transmission electron microscope were carried out using thin film techniques. Structural investigations were conducted using a JOEL's JEM 100B transmission microscope with accelerating voltage of 100 kV.

3. Results

Based on the measurement conducted during samples' strain, the dependence was determined between the average unit pressure values, p, and the strain ε (Fig. 1). As the torsion frequency increases, a gradual fall of the mean unit pressure values is observed as compared to conventional compression.

Microstructural investigations were conducted on a light microscope, using interference contrast for a detailed analysis of the morphologies of the slip and shear bands being formed. A change of the deformation method (conventional compression and compression with oscillatory torsion) at predefined process parameters does not change the basic features of the microstructure (Fig. 2). In the case of conventional deformation or oscillatory compression, the occurrence of one system of slip was most often observed; in some cases, single deformation bands were grouped into clearly visible macrobands.

The observed structure of mutual intersection or uniformly distributed slip bands may testify to a homogeneous deformation method and lack of privileged concentrations of slips in selected planes.

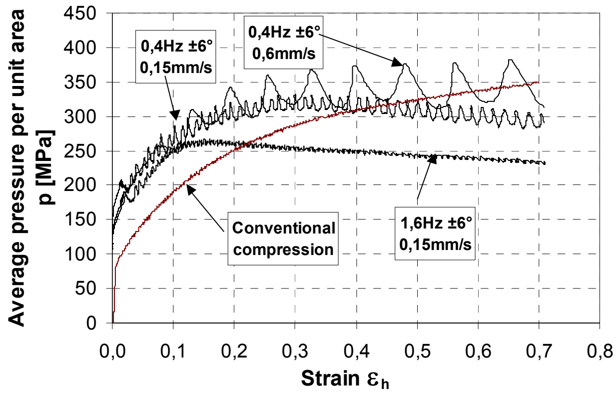

Fig.1. Influence of the parameters of compression with oscillatory torsion on mean unit pressure values

A change of the deformation method into oscillatory compression in the investigated range of parameters' change does not intensify the process of slip bands or shear bands formation. At this stage of structural investigations, no deformation localization phenomena were observed.

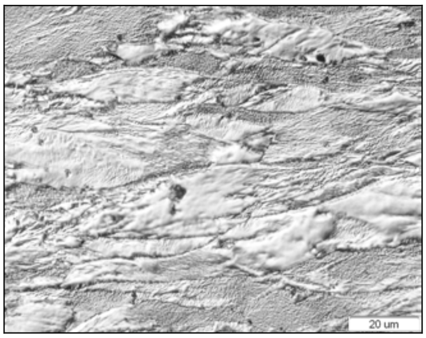

Fig. 2. Copper microstructure after oscillatory compression at the following parameters: f = 0.4 Hz, α = 6° and v = 0.15 mm/s

The substructure investigations shoved the formation of two types of dislocation structure: flat elongated systems of dislocation boundaries (most often, dislocation cells are visible between elongated systems of boundaries) and often, equiaxial cell dislocation structures. Conventional deformation, apart from the accompanying cellular structure and dislocation bands, is accompanies by a system of dislocation bands' intersections,, which indicates the initiation of deformation in two systems of slip.

The microstructure of Cu samples after compresion with oscillatory torsion intensifies the formation of microbands which differ from one another with mutual disorientation. Most frequently, microbands were formed in the areas of cellular dislocation structures (Fig. 3). The image of the banded dislocation structure was different than that of typical long bands characteristic of conventional compression. Systems built in major part from well-shaped, elongated subgrain prevailed. The microbands were detected in the vicinity of dislocation cells.

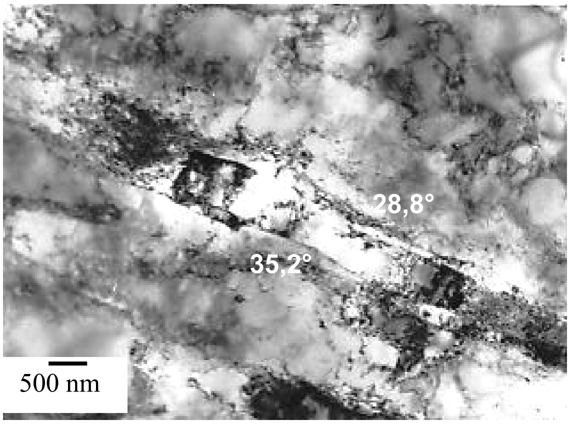

Fig. 3. Copper substructure after oscillatory compression at the following parameters: f = 0.4 Hz, α = 6° and v = 0.15 mm/s

In other microregions of Cu subject to strain at f = 1.6 Hz, α = 6° and v = 0.6 mm/s, numerous shear bands were observed (Fig. 4). The width of the bands was in the range from ca. 200 nm to 8.5μm. Inside the shear bands formed, fine grain structures, often elongated (Fig. 4 b, c) were formed.

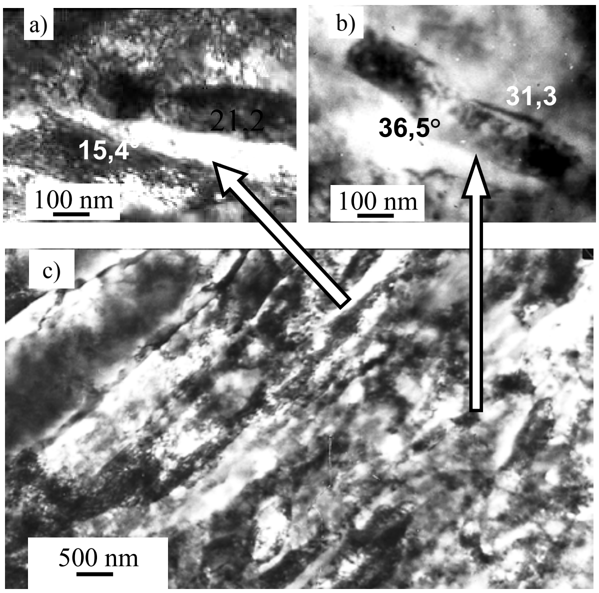

Fig. 4. Copper substructure after oscillatory compression at the following parameters: f = 1.6 Hz, α = 6° and v = 0.6 mm/s. The structure inside wide shear bands is composed of crystallites differing with respect to high crystallographic disorientation.

Based on diffraction investigations, it was proved that the structures being formed were separated from one another with wide angular boundaries (Fig. 4 b, c).

In samples subjected to deformation at the parameters: f = 0.4 Hz, α = 6°and v = 0.6 mm/s, recovery and recrystallization processes were observed (Fig. 5).

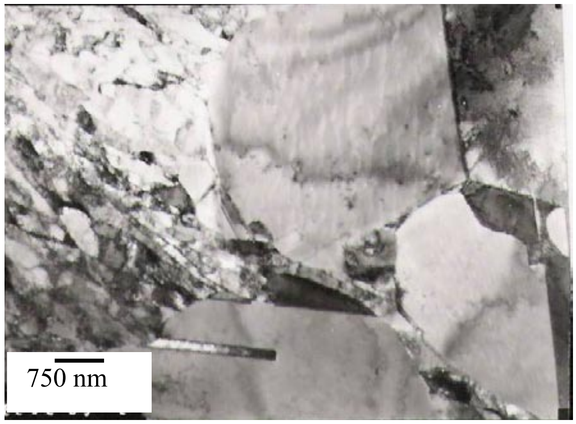

Fig. 5. Copper substructure after oscillatory compression at the following parameters: : f = 0.4 Hz, α = 6°and v = 0.6 mm/s.

The measurement results of the mean diameter of dislocation cells and bands' width are presented in Figure 6. The largest mean diameter of dislocation cells and dislocation bands' width were shown by Cu samples deformed when subject to compression with oscillatory torsion at the parameters: f = 1.6 Hz, α = 6°and v = 0.15 mm/s. The lowest values of the mean diameter of dislocation cells and dislocation bands' width were noted for samples subject to conventional compression and for samples subject to oscillatory compression at the parameters: f = 0.4 Hz, α = 6°and v = 0.15 mm/s.

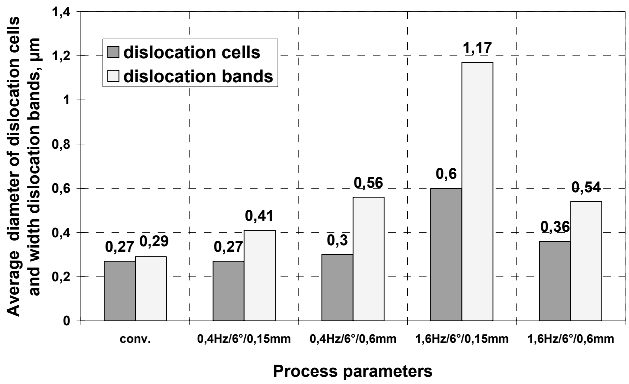

Fig. 6. Diagram of the mean diameter of dislocation cells and bands' width for Cu samples deformed under oscillatory compression at different process parameters.

Comparable measurement results of the analyzed geometric features were obtained for Cu samples deformed at f = 1.6 Hz, α = 6°, v = 0.6 mm/s and f = 0.4 Hz, α = 6°, v = 0.6 mm/s.

4. Conclusions

A parameter characterizing the deformation path is the ratio of strain component induced by torsion to strain component induced by compression. The course of mean unit stresses obtained in the experimental investigations has shown that the course of the deformation path has a decisive influence on their values. A corroboration of such influence is the value of mean unit pressures obtained for deformation processes characterized by parameters: f= 1.6 Hz and v_t = 0.6 mm/s, and f = 0.4 Hz and v = 0.15 mm/s.

There are some differences in the observed process of Cu structure changes during compression with oscillatory torsion and during conventional compression. The differences refer to the mechanism of plastic flow, which changes from a multi-system one, typical of conventional deformation, to a mechanism of plastic flow located in shear bands in the case of oscillatory compression .

The number of microbands and their sizes (width) are determined by the parameters of the oscillatory compression process. The typical image of cellular dislocation structures and next, banded structures with a considerable concentration of dislocation bands observed for the samples subject to conventional deformation, changes during the oscillatory compression process applied. The dislocation cells occupy a relatively large area in the investigated microregions, with their diameters clearly growing as the strain frequency increases from 0.4 Hz to 1.6 Hz. The frequency of narrow dislocation bands' occurrence falls with the strain frequency increase. The dislocation bands, distinct for samples subjected to conventional deformation, gradually pass into systems of elongated subgrain as the strain frequency increases. No process of lamellar structure formation is observed, which would be the effect of dislocation bands concentration, as in the case of conventional deformation.
Another structural process which distinguishes oscillatory compression from conventional compression is the formation of shear bands. A significant development of shear bands is observed at the parameters: f = 1.6 Hz, $\alpha = 6°$ and v=0.6 mm/s. The application of lower strain rates and lower frequency initiates the processes of inhomogeneous deformation.

The initiation of recrystallization processes in the analyzed samples should be attributed to local gradients of reinforcement and temperature. The bands transfer considerable strain and show a reinforcement gradient and therefore, they may constitute the place of new grain nucleation. In order to stop the structure reconstruction during oscillatory compression, intensive heat abstraction should be applied.

The data obtained indicate the possibility of producing nanomaterials from copper using the method of compression with oscillatory torsion.

Acknowledgements

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