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SEVERE PLASTIC DEFORMATION INFLUENCE ON ENGINEERING PLASTICITY OF COPPER

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Abstract. In present paper experimental research results of extra-pure Copper mechanical properties after severe plastic deformation are presented. Equal channel angular pressing was used for processing. Engineering plasticity of ultrafine grain Copper during cold rolling was estimated.

Keywords: equal channel angular pressing; extra-pure Copper; mechanical properties; cold rolling.

1. Introduction

One of the crucial tasks of material science is developing of new materials as well as improving the ones already known that have high physical-and-mechanical properties. Solving of such problems is in the field of highly effective technology creation and is possible with use of modern and advanced technologies.

During recent years there were many researches aiming to improve strengthening characteristics of metals and alloys due to structure refinement up to submicrocrystalline level [1-2]. As it is known, combination of high strength at the current proper plasticity is necessary condition for developing of advanced materials of high quality. Use of new methods of physical-and-mechanical strengthening and plastic deformation allows improving the level of mechanical and working properties of materials that have different functional area. Similar works with alloys on basis of Aluminum [3], Titanium [4], Copper [5] etc.

Structure size reduction is performed by methods basing on severe plastic deformation. In particular, one of them is equal channel angular pressing (ECAP) with its advantage of possibility to obtain bulk billets. This allows researching not only of the structure forming during treatment but also mechanical properties of materials.

2. Experimental research

In present paper samples of Copper alloys: HCP (99,95% Cu) and OFE (99,99% Cu) were used as test materials.

HCP Copper is alloyed with small amount (0,002-0,007%) of phosphorous. This small quantity of phosphorous will not reduce significantly the electrical and thermal conductivity of the alloy but help to obtain homogenous grain size in the product. This copper may be heat treated, welded and brazed without need for special precautions to avoid hydrogen embrittlement. Oxygen Free Electronic Copper (10 mg/dm^3) as well as HCP Copper do not need special conditions during heat treatment, welding and brazing.

This copper of high purity is used in microelectronics, radio- and instrument making (thin-film technologies and cables in audio-systems, jewelry and building industry (pipes and wires for working in strong electromagnetic fields, electrochemistry anodes etc).

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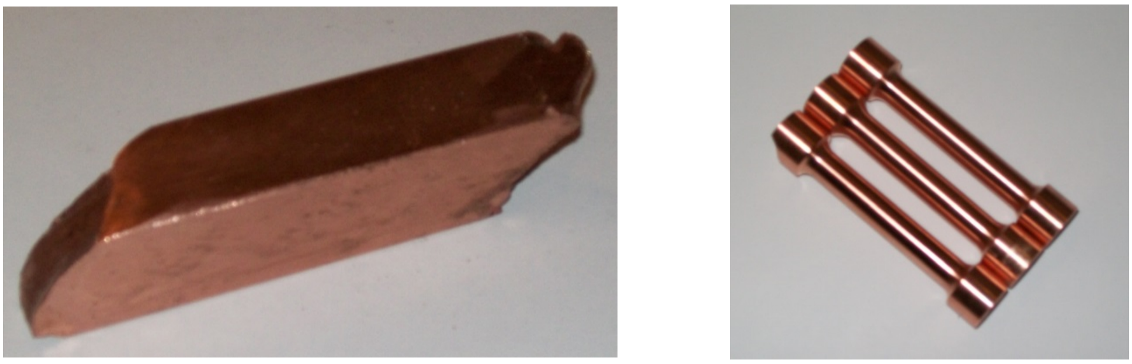
Samples of square cross-section 20x20x120 mm were processed by ECAP with help of special instrument presented on Fig. 1. The die has two channels of 20mm width with intersection angle of 105° [6]. Samples were deformed by the scheme relating to route B_c. Total deformation after treatment was ε ~ 6,3 (number of passes n=9).

Fig. 1. Experimental equipment for ECAP.

In total more than 40 copper billets with sizes 20x20x110mm were deformed. After each pass four samples were selected: three for mechanical properties investigation of the billet material and one for structure research. Fig. 2a shows photo of the sample of copper alloy after sequential ECAP pass.



a) b)

Fig. 2. Appearance of copper billet after sequential ECAP pass (a) and samples for tensile testing (b).

Mechanical characteristics were estimated on Zwick/Roell Z100 tensile testing machine. Fig. 2b shows samples for tensile testing. Due to deformation process features specimens used in the present work were short and cylindrical.

As an example, mechanical characteristics test results of one of the materials (OFE copper) are presented in table 1 and on Fig. 3. The behavior of the second material is similar therefore HCP copper data is not performed.

Table 1. Mechanical characteristics of OFE copper after ECAP.

Pass number, n	Yield stress $\sigma_{0.2}$, MPa	Tensile strength σ_b, MPa	Vickers microhardness	Percent elongation δ, %	Contraction Ψ, %
0	98.4	299.4	54.4	47.4	96.3
1	321.7	349.9	93.1	17.4	50.9
2	379.3	390.4	101.6	14.1	45.7
3	398.2	413.8	106.8	12.9	44.4
4	399.5	415.4	108.3	12.9	44.4
5	405	418,3	107.2	12.8	45.1
6	408	419.1	111	12.8	44.6
7	410	420.2	111.5	12.7	43.4
8	409	419.9	107.6	12.6	42.8
9	410	420.4	108.6	12.6	41.7

The analysis of the table data shows that significant changes of both strength and plasticity characteristics of the material are observed after first four passes. To make the picture perception easier the flow curves of OFE copper are presented only after these passes.

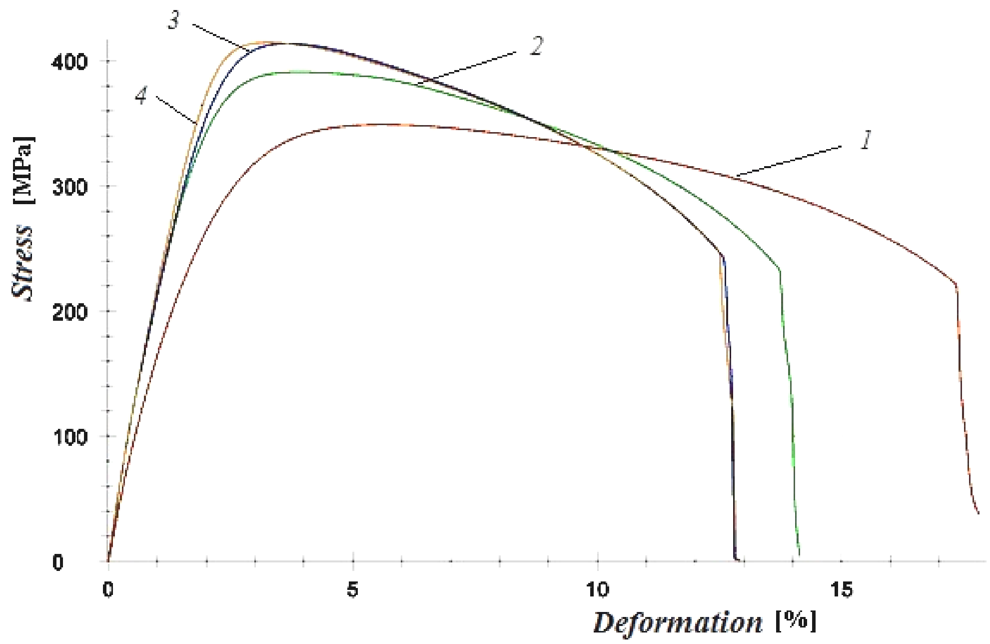


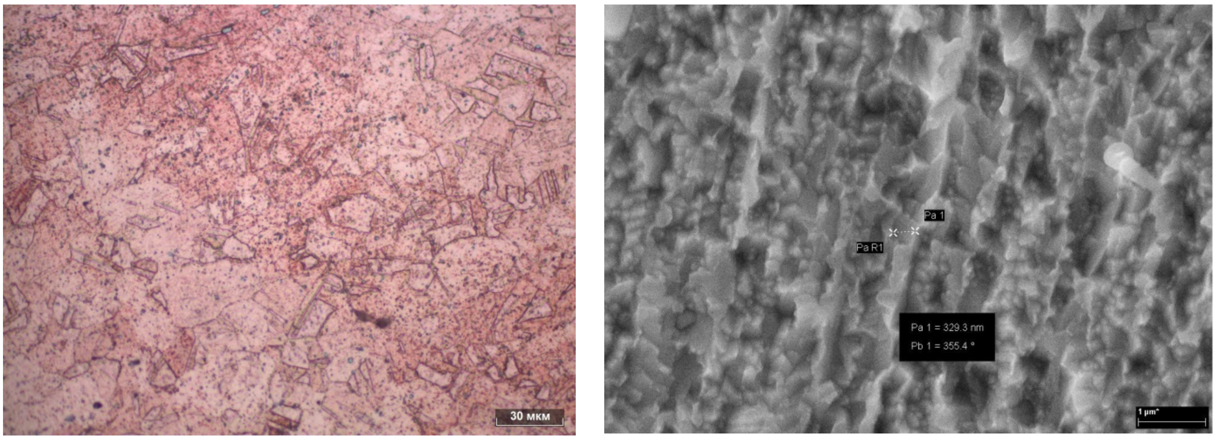
Fig. 3. Flow curves of OFE copper during tensile test for 1-4 passes correspondingly.

Figure 4 shows microstructure of OFE copper samples in the initial state (a) and after the 9th pass (b) obtained by the optical microscope Zeiss and the raster electron microscope Supra 55VP accordingly.

The initial structure of copper samples is characterized by the grain size of 47 µm. After severe plastic deformation the ultrafine grain copper with the average size of structure elements of 330 nm (cross direction) was received.

The material was exposed to cold deformation in order to study its engineering plasticity. Rolling process by the smooth rolls was carried out the following way. For width h=2 mm the draught was 0,5mm for the pass. Further the sample was deformed with

Δh=0,2 mm for each pass until the final width of h=2mm. No half-way heat treating operations during rolling process were required.



a) b)

Fig. 4. Photos of OFE copper samples. Initial microstructure (a) and after nine ECAP passes (b).

Figure 5 shows a photo of ultrafine grain copper sample before and after cold rolling. It can be seen that cold deformation of ultrafine grain copper sample goes on without any difficulties. And, in spite of not high plasticity values shown during standard tensile tests, in case of stress condition scheme change there is also a significant change in material behavior.

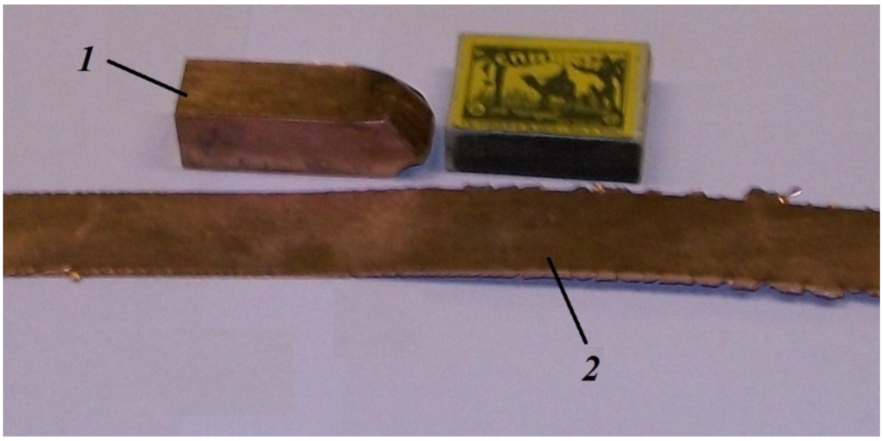


Fig. 5. Copper sample after ECAP, n=9 before (1) and after (2) cold rolling.

Along the edges of deformed stripe there are transverse cracks, though they are located in overflows and their sizes are not big. The occurring of similar defects is explained by specific features of the deformation zone.

3. Conclusions

Thus the researched material after ECAP along with strength increase and expected plasticity decrease at uniaxial tension shows high level of engineering plasticity. This quality will allow using it in the next forming operations and reduce accompanying labour costs.

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