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NANOSTRUCTURAL FORMATION BY SEVERE PLASTIC DEFORMATION

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The influence of severe plastic deformations on structural, mechanical and plastic properties of ARMCO-Fe in equal-channel angular pressing procedure was investigated. Mathematical simulations of stress and temperature fields were applied, too.

Key words: *severe plastic deformation, nanostructure, ARMCO-Fe, ECAP, FEM*

Nanostrukturalno oblikovanje jakom plastičnom deformacijom. Istraživao se utjecaj snažnih plastičnih deformacija na strukturalna, mehanička i plastična svojstva ARMCO-željeza u postupku prešanja s istiskivanjem kroz jednake kanale (ECAP) postavljene pod nekim kutom. Primjenjivale su se također i matematičke simulacije područja naprezanja i temperaturnih područja.

Kjučne riječi: *snažna plastična deformacija, nanostruktura, ARMCO-Fe, ECAP, metoda konačnih elemenata*

INTRODUCTION

At the present time the topic of intense research is the refining of various material structure type, which has the low value of the basic deformation resistance during the bulk deformation processes by severe plastic deformation - SPD at the ambient temperature. The purpose of SPD is to obtain the result structure at the nm level (ultrafine structure) from the original mm level [1, 2].

There are two ways of SPD realization [2]: Equal-channel angular pressing (ECAP), and high-pressure torsion (HTP) realized by the high stresses. Historical ECAP was developed in former USSR before more than 20 years [3], but the interest in its application began occur approximately 8 years before [4].

High value of hardness, elongation, fatigue facilities and increasing of superplasticity characterize materials with the ultrafine structure in SPD. Achievement of listed facilities is conditional by nanocrystalline structures, its distribution in volume, internal stresses, texture and other characteristics of structure. Experimental works, which are realized by SPD in ECAP on Ni, Al, Cu, Ti materials and their alloys, are described in the literature [6, 7]. There is only some references on SPD realized on ARMCO-Fe material namely by the HTP process [5].

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The paper deals with influence of SPD realized in ECAP on the mechanical properties and the structure of ARMCO - Fe.

MATERIAL AND EXPERIMENTAL METHODS

ARMCO-Fe alloy was used in the experiments. The mathematical simulations of the first pass were found by software product FORMFEM, which is based on the FEM. Experimental material was extruded in ECAP matrix. Six deformations were realized at ambient temperature in ECAP matrix. The extrusion materials were rotated before next input about 180°. The ECAP process was realized by hydraulic equipment, which makes it possible to realize maximal force on the level 1 MN. Short testing specimens (d_0 = 5 mm, l_0 = 10 mm) for static tensile test were made from extruded samples in ECAP process. Two testing specimens were made from each extruded sample. As a result was

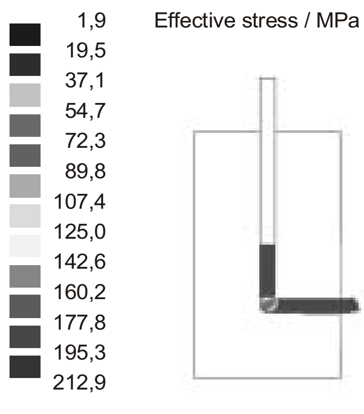

Figure 1. **The course of effective stress**
Slika 1. **Tijek stvarnih naprezanja**

used the average value from data of two testing specimens. The static tensile test was realized at ambient temperature by ZWICK 1387 equipment in accordance with STN 420310 (STN EN 10002 - 5) standard. Microhardness was measured by Vickers method on Hanemann device.

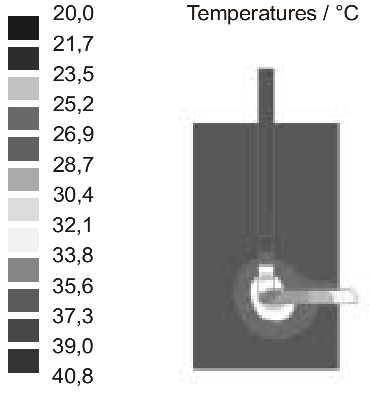

Figure 2. **The course of temperatures**
Slika 2. **Tijek rasprostiranja temperature**

RESULTS AND ANALYSES

The mathematical simulation results of the first ECAP pass are given in Figure1. for stress fields, in Figure 2. for temperature fields and in Figure 3. for deformation fields. The stress concentration during deformation is cumulated into narrow band of the bending elbow. A part of plastic deformation work is changed into the heat and deformed sample and die are warmed-up. The course of extrusion compression stress as a function of ECAP passes is shown in Figure 4. The stress – strain curves from static tensile test of samples without deformation and after (2^{nd}, 4^{th}, 6^{th}) ECAP passes are presented in Figure 5.

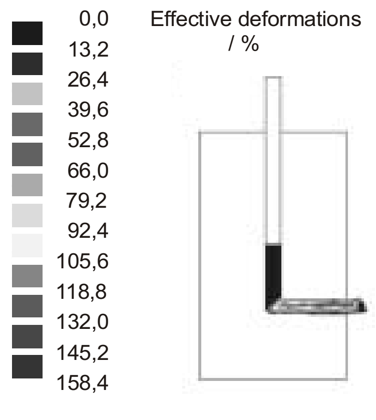

Figure 3. **The course of effective deformations**
Slika 3. **Tijek stvarne deformacije**

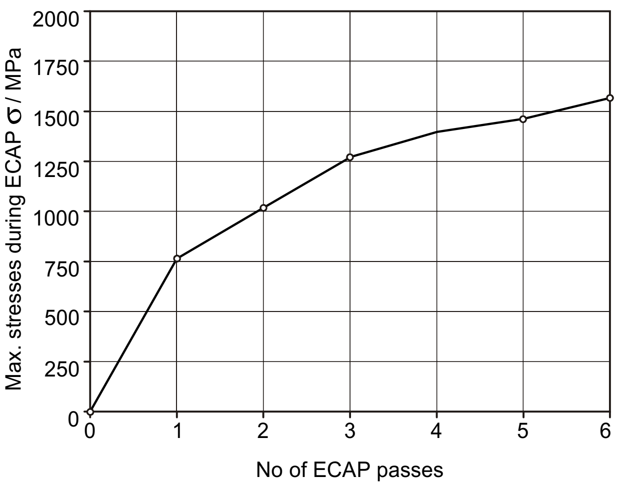

Figure 4. **Maximal streesses during ECAP as function of ECAP passes (Grades: ARMCO-Fe)**
Slika 4. **Maksimalna naprezanja tijekom ECAP kao funkcija ECAP prolaza (kakvoća: ARMCO-Fe)**

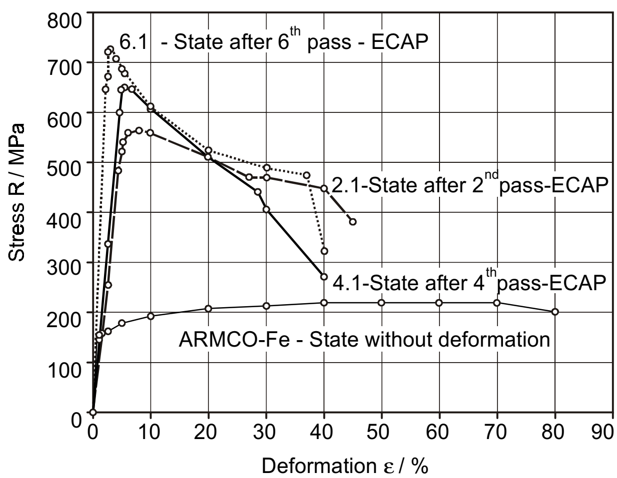

Figure 5. **Stress - deformation diagrams (Grade: ARMCO-Fe)**
Slika 5. **Naprezanje - dijagram deformacija (kakvoća: ARMCO-Fe)**

Graphical course of yield strength ($R_{p0,2}$), tensile strength (R_m), elongation (A) diagrams as a function of ECAP passes are shown on Figure 6., and Figure 7.

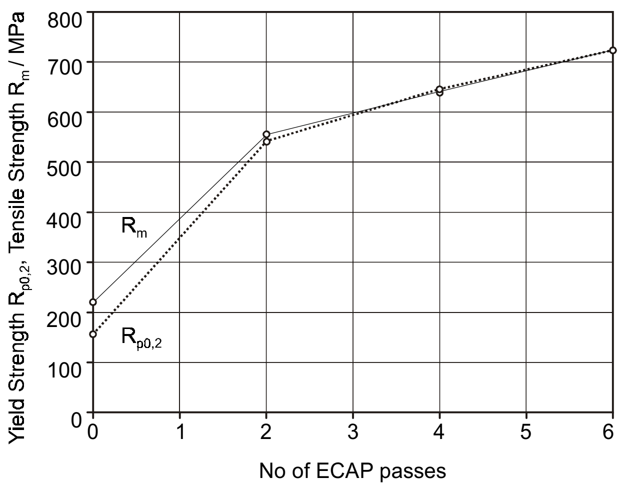

Figure 6. **Mechanical properties as function of ECAP passes (Iron grade:ARMCO-Fe)**
Slika 6. **Mehanička svojstva kao funkcija više ECAP prolaza (kakvoća: ARMCO-Fe)**

The course of maximal compression stress value of samples as a function of ECAP passes had the maximal increasing during the third ECAP pass. Compression stress after the third pass had smaller growth intensity. This state corresponds with the summary sample deformation, which depends on the ECAP pass. Namely the first pass has $\varepsilon_1 =$

68,5 %, the second one: ε_2 = 90,0 %, the third one: ε_3 = 96,9 %, and the fourth one: ε_4 = 99,0 %. The increasing of ECAP passes had tended to decrease deformation, which affected also smaller compression stress growth intensity.

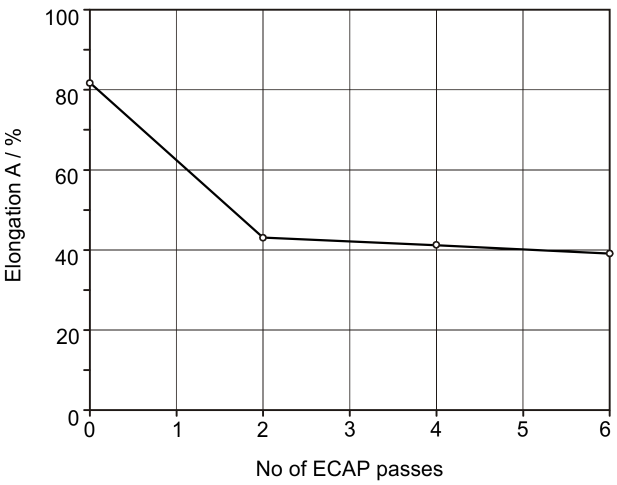

Figure 7. **Elongation as function of ECAP passes (Iron grade:ARMCO-Fe)**
Slika 7. **Izduživanje kao funkcija ECAP prolaza (kakvoća: ARMCO-Fe)**

The tensile test diagrams have shown noticeable increasing of $R_{p0,2}$ and R_m values in samples after ECAP passes when compared with annealing state, and also decreasing of deformations corresponds to these values by increasing of pass number. Difference between the $R_{p0,2}$ and R_m values was remarkable up to the second pass whereas these values are identical after other passes. Yield strength was increased by 4,65 times and tensile strength by 3,31 times after the sixth ECAP pass with compare to the initial annealing state, i.e.:

$$R_{p0,2 \text{ after 6. ECAP}} = 4,65 \cdot R_{p0,2 \text{ initial. state}}$$

$$R_{m \text{ after 6. ECAP}} = 3,31 \cdot R_{m \text{ initial state}}$$

Achievement of low elongation on Cu samples after ECAP, whose level is ca 10 %, was shown in [1]. The elongation achieved ca 40 % for investigated ARMCO – Fe after the sixth ECAP pass too. The development of elongation and micro-hardness is depend on summary deformation after ECAP passes and processes of mechanical strengthening likewise as development of pressure stresses.

Microstructural investigation of samples showed creation of band structure which had a lot of low-angle grain boundaries. Authors of [6] noticed on the important fact that the structure evolution in process of intensive plastic deformation is independent on further structure refinement but depend on the transformation of the dislocation substructure to the ultrafine structure with high-angle grain boundaries. According to [7] plastic deformation of nanostructural materials is realized at the same time acting of dislocation slips into the grains and with expansion of slips along the grain boundaries during low-temperatures that correspond with the ambient temperature

CONCLUSION

The following conclusions, which are based on achievement of the own experimental results and also on literature, were obtained:

- deformation effective stresses are cumulated into the narrow deformation band,
- during ECAP pressing are warmed - up sample and die,
- for ARMCO - Fe material we obtained the following properties with compared with initial annealing state using SPD by ECAP:
- increasing of $R_{p0,2}$ by 4,65 times to the value $R_{p0,2}$ = 724 MPa,
- increasing of R_m by 3,31 times to the value R_m = 725 MPa,
- decreasing of elongation by 2 times to the value A = 41 %,
- the ECAP process realized by intensive deformations is running without any radical change of shape and sizes of sample.

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