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# PROPERTIES OF ARMCO-Fe AFTER ECAP PROCESSES

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## ABSTRACT

The present research work was to determine the influence of severe plastic deformation (SPD) realized by ECAP (equal-channel angular pressing) on the structural, mechanical and plastic properties of ARMCO – Fe material. The ECAP process does not influence sample shape and size and produced ultrafine nanocrystalline structures. The ECAP process was numerically simulated (namely its course of temperature and stress fields) by FormFEM software.

**Keywords:** ultrafine, nanostructure, ARMCO iron, severe plastic deformation, material properties, ECAP, numerical simulation.

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## INTRODUCTION

At the present time the topic of intense research is the refining of various types of material structure, which has a low value of the basic deformation resistance in the volume 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 μm level one (Valiev, 2002; and Lowe, *et al.* 2000). There are two ways of SPD realization (Lowe and Valiev, 2000): Equal-channel angular pressing – ECAP, and High-pressure torsion – HT P realized by the high stress. Historical ECAP was developed in the former USSR more than 20 years ago Sega, *et al.* (1981), but its application occurred approximately 8 years ago (Furukawa, *et al.* 2001). Materials with the ultrafine structure in SPD are characterized by high values of hardness, elongation, fatigue properties and the increase of superplasticity. Achievement of listed properties is conditioned by nanocrystalline structures, its distribution in volume, internal intensity, texture and other characteristics of structure. Experimental works, which are realized by SPD on Ni, Al, Cu materials, and their alloys, are described in the literature. There is only one reference on SPD realized on ARMCO-Fe material namely by the HT P process (Rybin, 1984).

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

## MATERIALS AND EXPERIMENTAL METHODS

The mathematical simulations of temperature and effective stress fields were investigated by Form FEM software as a 2D problem. Alloy ARMCO-Fe was used for the experiments. This material was pressurised by the ECAP unit. Six deformations were performed at ambient temperature in the ECAP unit. The die materials were rotated before input by 180°. The ECAP process was performed by hydraulic equipment, which makes it possible to realize maximum force on the level of 1 MN. Short examinational bars ($d_0$=5 mm, $l_0$=10 mm) were made from die samples after the ECAP process for tensile test. Two examinational bars were made from each die sample. As a result the average of two examinational bars was used. The tension static proof was performed at ambient temperature by ZWICK 1387 equipment in accordance with STN 420310 (STN EN 10002 – 5). Micro-hardness was measured by the Vickers method on a Hanemann device.

## RESULTS AND ANALYSES

The results from the mathematical simulation investigated as a 2D problem are given in Figure 1 and Figure 2. The effective stresses were the highest in the corner of the channel with a diagonal direction. Severe plastic deformation generated deformation heat that consequently warmed up the sample and the die during pressing, as shown from simulations.

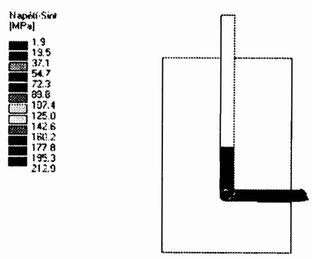


**Figure 1** The course of effective stress field during the pressing simulation.

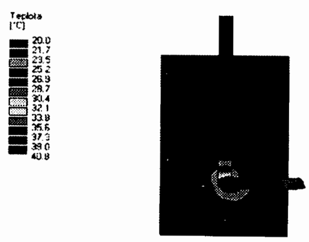


**Figure 2** The course of die and sample temperature field during the pressing simulation.

The course of maximum stress in the sample as a function of ECAP passes is shown in Figure 3. Stress – strain diagrams of samples without deformation and after (2,4,6) ECAP pass are shown in Figure 4.

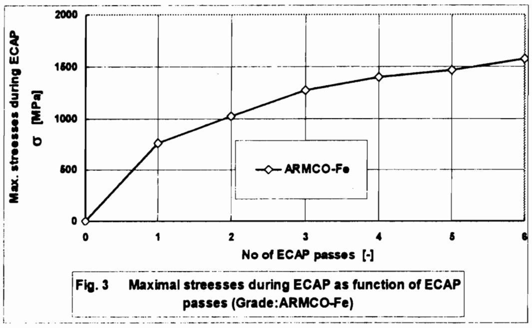


**Figure 3** Maximum stress during ECAP as a function of ECAP passes (Grade:ARMCO-Fe)

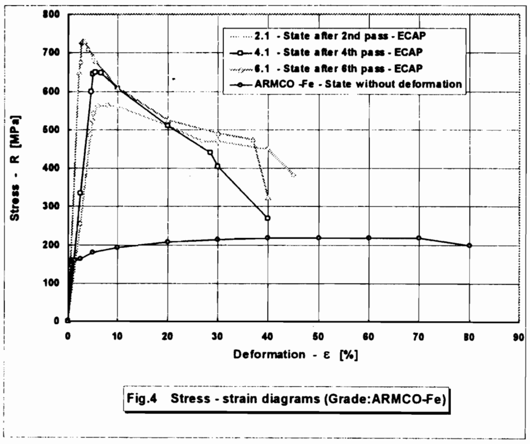


**Figure 4** Stress - strain diagrams (Grade: ARMCO-Fe).

Tensile strength ($R_{p0,2}$), as well as yield strength ($R_m$), elongation (A), and micro-hardness (HV) as a function of ECAP passes are shown in Figure 5, Figure 6, and Figure 7 respectively.

The maximum value of stress at samples as a function of ECAP pass has the maximum increasing in the third ECAP pass.

After this ECAP pass the intensity of stress decreases. This state corresponds with the total strain at samples, which depends on the ECAP pass. Namely the first pass, has $\varepsilon_1$=68,5%, second one: $\varepsilon_2$=90%, third one: $\varepsilon_3$=96,9%, and fourth one: $\varepsilon_4$=99%.

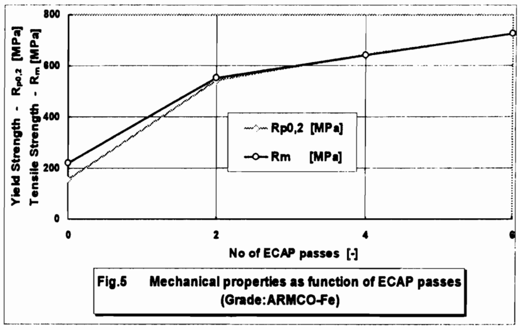


**Figure 5** Mechanical properties as a function of ECAP passes (Grade:ARMCO-Fe).

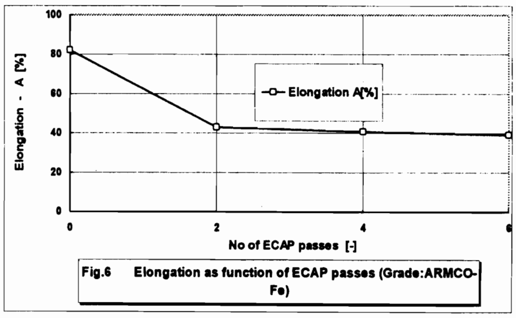


**Figure 6** Elongation as a function of ECAP passes (Grade:ARMCO-Fe).

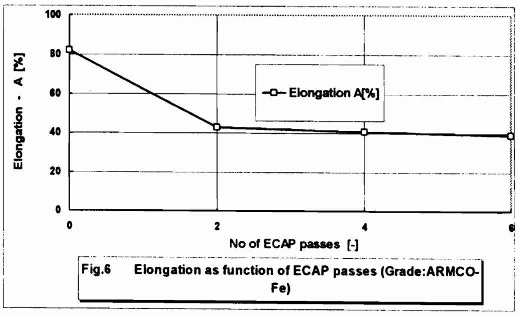


**Figure 7** Microhardness during ECAP as a function of ECAP passes (Grade:ARMCO-Fe).

The decrease in addition of strain occurs by the increase of number of ECAP passes, which yields from the scheme of deformation.

The stress-strain diagrams show a noticeable increase of $R_{p0,2}$ and $R_m$ on samples after ECAP passes compared to the annealing state, and also on fact of decrease of strain corresponds to these values by increasing the number of passes. The difference between the $R_{p0,2}$ and $R_m$ is remarkable during the second pass whereas these values are identical after other passes. Tensile strength was increased by 4,65 times and yield strength by 3,31 times after the sixth ECAP pass compared 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 in Cu samples after ECAP, which level is ca 10%, was shown in (Valiev, 2002; and Lowe, *et al.* 2000). The elongation achieved ca 40% for investigated ARMCO – Fe after sixth ECAP pass; the development of micro-hardness depends on total strain after ECAP passes and processes of mechanical strengthening as well as development of stresses.

Microstructural investigation of samples showed the creation of a "striped-structure" having a lot of low-angle grain boundaries. Authors Valiev, *et al.* (1997) noticed the important fact that the evolution of structure in the process of intensive plastic deformation was independent on further refinement of structure but with the transformation of the dislocation structure to the ultrafine structure with high-angle grain boundaries. According to Gertsman, *et al.* (1996) plastic deformation of nanostructural materials performed at the same time of dislocation slips into the grains and with expansion of slips along the grain boundaries during low-temperatures, which correspond with the ambient temperature.

## CONCLUSION

The following conclusions, based on experimental results and also on literature, were obtained:

- For ARMCO – Fe material, we obtained the following properties compared to the initial annealing state by the application of SPD by ECAP were obtained:
  - Increase of $R_{p0,2}$ by 4,65 times to the value $R_{p0,2}$ = 724 MPa.
  - Increase of $R_m$ by 3,31 times to the value $R_m$ = 725 MPa.
  - Decrease of elongation by 2 times to the value A = 41%.
  - Increase of micro-hardness by 2,2 times to the value HV = 0,21 GPa.
- Each ECAP pass of at least two represents a very intensive plastic deformation of material above 91% of relative deformation which is out-and-out a high value compared to the deformation achievement in conventional forming ways.
- During the ECAP process, intensive deformations were performed without the radical change of shape and size of the sample.

## ACKNOWLEDGEMENTS:

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