

The structure and properties of chosen metals after ECAP

**M. Greger^{a,*}, R. Kocich^a, L. Čížek^a, L.A. Dobrzański^b, M. Widomská^b,
B. Kuřetová^a, A. Silbernagel (jun.)^c**

^a Faculty of Metallurgy and Materials Engineering, VSB-Technical University Ostrava,
17.listopadu 15, 708 33, Czech Republic

^b Division of Materials Processing Technology and Computer Techniques
in Materials Science, Institute of Engineering Materials and Biomaterials,
Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland

^c Faculty of Engineering, VSB-Technical University Ostrava,
17.listopadu 15, 708 33 Ostrava Poruba, Czech Republic

* Corresponding author: E-mail address: miroslav.greger@vsb.cz

Received 15.03.2006; accepted in revised form 30.04.2006

Materials

ABSTRACT

Purpose: This paper was aimed at verification of functionality of the ECAP technology at extrusion of the copper, aluminium alloys and steel.

Design/methodology/approach: Experiments were made on equipment, which is demonstrated in the Fig 1. Deformation forces were measured during extrusion, resistance to deformation was calculated and deformation speed was determined approximately. Analysis of structure was made with use of light microscopy and TEM.

Findings: The samples of Cu and Al alloys were extruded at room temperature. For the samples of steel was used the two-stage pressing, when the samples were extruded at temperature of approx. $T_1 = 325^\circ\text{C}$ and $T_2 = 220^\circ\text{C}$. In order to increase concentration of deformation in volume of the sample the samples were after individual passes turned around their longitudinal axis by 90° and they were extruded again.

Research limitations/implications: research were limited to the die with constant extrusions angles within the value of 90° . In the future, it is planned to analyse the influence of changes of the angle and relative reduction ratio on the ECAP process.

Originality/value: Cross-section of original samples of Cu and Al alloys was 8×8 mm and their length was 32 mm and cross-section of original samples of Fe alloy was 10×10 mm and their length was 40 mm.

Keywords: Nanomaterials; ECAP; Microstructure; Mechanical properties

1. Introduction

New forming technologies, to which the ECAP technology (Fig. 1) belongs as well, are focused on refining of grains by intensive plastic deformations [1-6]. The objective consists in fabrication of structural metallic materials with ultra-fine grain with higher mechanical properties.

Fine-grain materials are the materials, the structure of which consists of components, which have at least one dimension within

the range between 100 – 500 nm (these materials are also called ultrafine-grain materials). From the viewpoint of strength properties these components can be represented by sub-grains, grains, lamellas, layers, fibres, etc. For example lamellar pearlite can be considered as nano-composite material, which is formed by ferrite and cementite lamellas with width mostly below 100 nm. The value 100 nm does not have a physical meaning [7]. The term ultrafine-grain material is used also for materials composed of particles below 1 micrometer.

Table 1.
Chemical composition of alloys

Alloys	Chemical compositions (%)												
	C	Si	Mn	P	S	Cu	Cr	Ni	Al	Mo	V	Ti	B
P355Q	0.028	0.040	0.27	0.009	0.015	0.06	0.06	0.03	0.004	0.013	0.004	0.177	0.005
C 10200	0.005	-	-	0.003	0.005	99.95	-	0.002	-	-	-	-	-
AlCu2,5Mg	-	0.25	0.12	-	-	2.6	-	-	97	-	-	-	-

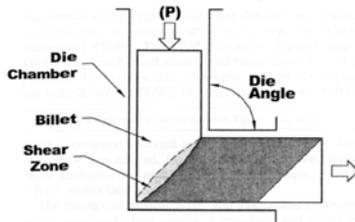


Fig. 1. Schematic of the of ECAP process [1]

2. Experimental techniques

The experiment was divided in the three parts. In the first part of experiment was pressed the copper grade C 10200 (ASTM B152), in the second part was extruded aluminium alloy AlCu2.5Mg and in the final part was pressed the steel P355Q. The chemical composition of all alloys is demonstrated in the Table 1. Cross-section of original samples of Cu and Al alloys was 8 x 8 mm and their length was 32 mm and cross-section of original samples of Fe alloy was 10 x 10 mm and their length was 40 mm. The samples of Cu and Al alloys were extruded at room temperature. For the samples of steel was used the two-stage pressing, when the samples were extruded at temperature of approx. $T_1 = 325\text{ }^\circ\text{C}$ and $T_2 = 220\text{ }^\circ\text{C}$. In order to increase concentration of deformation in volume of the sample the samples were after individual passes turned around their longitudinal axis by 90° and they were extruded again.

The experiments were aimed at determination of extrusion force, pressure necessary in individual stages of extrusion, change of strength properties in dependence on number of extrusions and change of structure. In the first part of the experiment we have used for extrusion the copper grade C 10200. Original samples were processed by cold forming and they were afterwards annealed at temperature of $600\text{ }^\circ\text{C}/3\text{h}$. Initial shape of the samples and shapes of samples after individual stages of extrusion are shown in Fig 2.



Fig. 2. Copper samples after individual passes with use of the ECAP technology

The samples were extruded at temperature of approx. $20\text{ }^\circ\text{C}$. The samples are ordered from the left to the right according to number of passes. We have measured at extrusion the deformation forces and we have also calculated the pressure needed for extrusion. We have approximately determined the strain rate, which was approx. $2,3 \cdot 10^{-2}\text{ s}^{-1}$. Structure analysis was made by optical microscopy. Structure of original samples and that of samples after individual stages of extrusion is shown in Fig3.

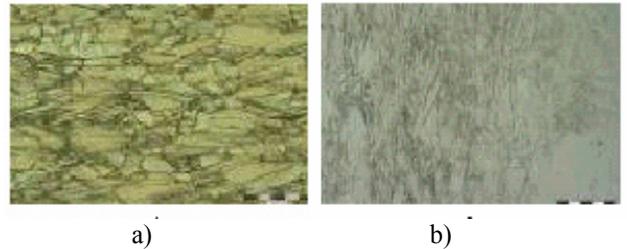


Fig. 3. Development of structure (in longitudinal direction) at extrusion of copper: a – initial structure, b – structure after the 1st extrusion, c – structure after the 2nd extrusion, d) structure after the 4th extrusion

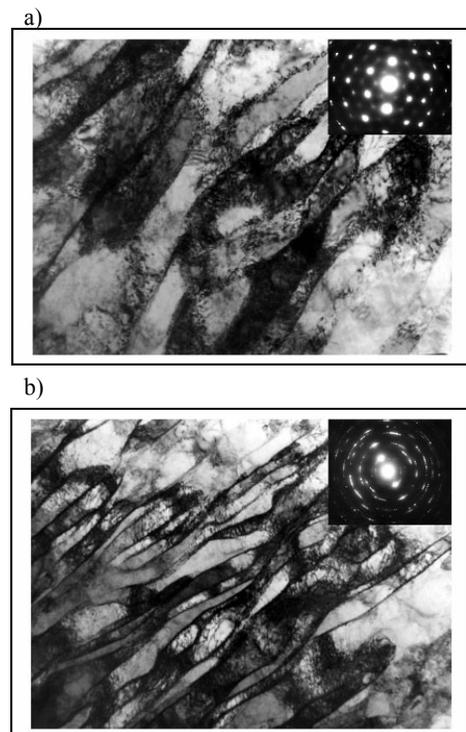


Fig. 4. The substructure of copper after 1th (a), 4th passes (b)

Average grain size in transverse direction was determined by quantitative metallographic methods and it varied around 50 μm at the beginning of extrusion, and around 15 μm at the end of extrusion, i.e. after the 4th pass.

In the second part of the experiment was pressed Al alloy AlCu2.5Mg. The samples were extruded at room temperature. Before pressing the samples were annealed at temperature of 380 $^{\circ}\text{C}$ [8, 9]. Structure of original samples and that of samples after individual stages of extrusion is shown in Fig.5. Average grain size in transverse direction varied around 150 μm .

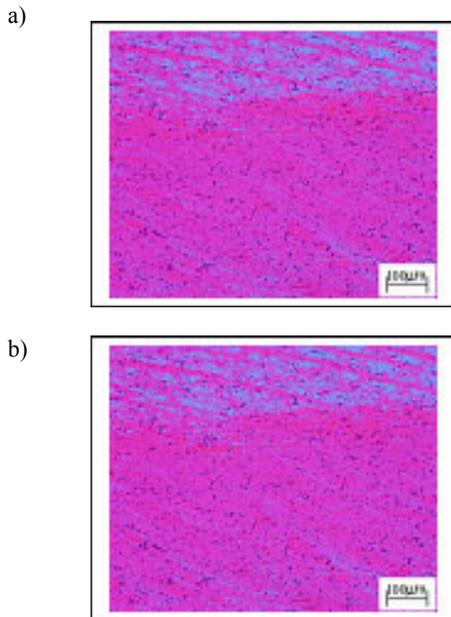


Fig. 5. Development of structure (in longitudinal direction) at extrusion of AlCu2.5Mg: a – initial structure, b – structure after 4th extrusion

The modification of sample form and sustaining solid metal in particular periods of pressing depends on the pasting level and the radius fillet of edges in the pressing channel [10, 11]. During pressing in the channel with a small radius fillet working edges the splits are coming up in the whole length of the pressing channel.

After particular through pass happened to the cumulation of the deformation's consolidation, which was the basic in the creating substructure [12]. It is demonstrated in Fig 6.

In the last part of experiment was pressed steel P355Q. Before pressing the samples were annealed for ECAP. The temperature of anneal was 500 $^{\circ}\text{C}$ and the idle period of the anneal temperature was 30 min. After annealing the metallografical examination of structure was made (Fig. 7).

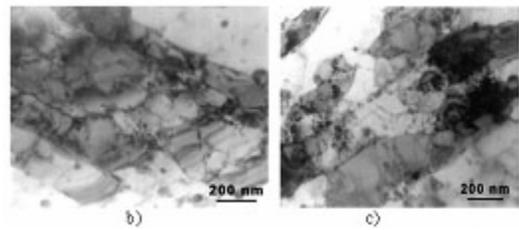
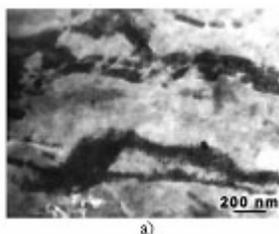


Fig 6. The substructure of AlCu2.5Mg alloy after 1th (a), 3th (b) and 4th passes (c)



Fig.7. Steel samples after individual passes with use of the ECAP technology

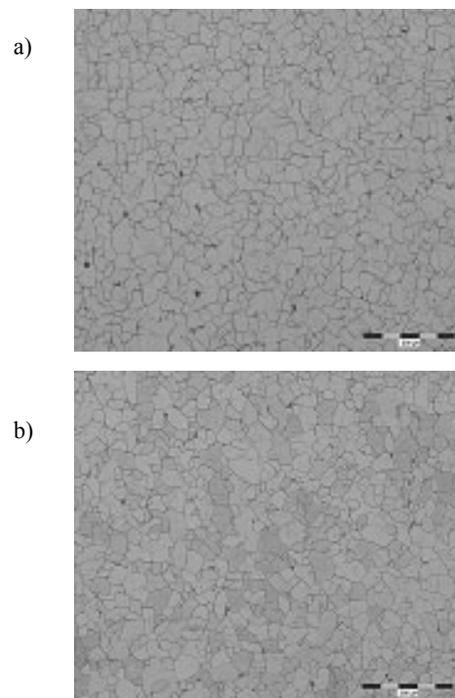


Fig. 8. Structure of steel P355Q after annealing: a) in longitudinal direction and b) in transverse direction

There were used the two-stage pressing, the samples were extruded at temperature of approx. $T_1 = 325^{\circ}\text{C}$ and $T_2 = 220^{\circ}\text{C}$. Structure analysis was made by optical microscopy. Structure of original samples and that of samples after individual stages of extrusion is shown in Fig 9.

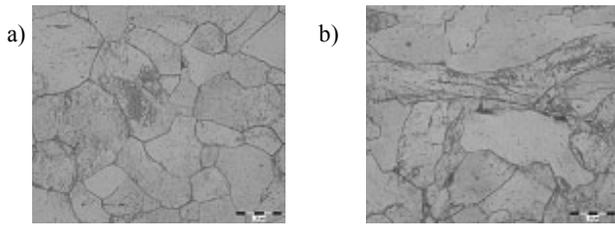


Fig. 9. Development of structure at extrusion of steel P355Q: a – structure after the 1th extrusion and b) structure after the 3th extrusion

The structure along the cross section of sample is not equal with expressive areas of shearing deformation [13]. There are rising up with growing deformation (Fig. 9).

3. Obtained results and their analysis

For copper: After individual passes there has occurred an accumulation of deformation strengthening, e.g. at extrusion with radius of rounding of inside cants ($R = 0.5$) the extrusion pressure at the beginning varied around $\tau_1 = 658$ MPa. At the second extrusion it increased to $\tau_2 = 965$ MPa, and at the third extrusion it increased to $\tau_3 = 1188$ MPa.

For aluminium: At extrusion with radius of rounding of inside cants ($R_v = 2$ mm; $R_{vn} = 5$ mm) the extrusion pressure in die was after the first pass about $\tau_{max} = 620$ MPa and then increased. After the 4th extrusion was about $\tau_{max} = 810$ MPa.

For steel: During pressing the press power was moving due to depending on degree of fulling the die channel. For the 1th sample was $F_{max} = 92$ KN, for the 2nd sample was $F_{max} = 95$ KN and for the 3th sample was $F_{max} = 123$ KN. These powers correspond to these stresses: 1438 MPa, 1484 MPa and 1922 MPa. The press power was going up with growing deformation (the hardening sample). The stability properties are going up with size of deformation ($e = 3.54$) and during four passes raise double. The tensibility is going down [14, 15]. It is caused due to recovery processes, which were not passed. The tensibility is going up due to softer seen.

4. Conclusions

Experiments made on poly-crystalline copper of the grade C10200, on Al alloy AlCu2.5Mg and on steel P355Q have confirmed that the ECAP method is efficient tool for refining of grain. Microstructure depends of experimental conditions, particularly on number of passes and on rotation of the sample between individual passes. The angle between horizontal and vertical part of extrusive channel was for this experiment around 90° for Cu and Al, for steel around 105°. Radii of rounding of working parts of extrusive channel must correspond to conditions for laminar flow of metal.

Acknowledgement

The authors would like to thank to possibility of to use experimental apparatus. The work was financed by the Project MSMT no. 6198910013.

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