12th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2008, Istanbul, 26-30 August 2008

MODELLING OF SEVERE PLASTIC DEFORMATION AT ECAP TECHNOLOGY PROCESS

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ABSTRACT
The technology, ECAP – Equal Channel Angular Pressing, belongs to technologies of accelerated development and it represents a top item R&D agenda in the world. This technology represents a basic method for achieving super fine granularity structures. Especially non-ferrous metals and their alloys are of primary concern. Non-ferrous metals, and their alloys are subject of an easy recycling process, and they increasingly tend to substitute steel on a larger scale. At the same time, a major decrease of production cost for these materials, and their products can be noted. Their importance for applications by automobile industry is ever growing that is also the case for military and space industries.

Keywords: Nano-crystalline materials, severe plastic deformation, ECAP technology, modelling

1. INTRODUCTION
High deformation at comparatively low homological temperatures is efficient method for production of ultra fine-grained massive materials. New advanced technologies, which use high deformation for obtaining fine-grained structure, comprise the following ones [1-3]: High Pressure Torsion, Equal Channel Angle Extrusion, Cyclic Channel Die Compression, Cyclic Extrusion Compression, Continuous Extrusion Forming, Accumulative Roll Bonding and Constrained Groove Pressing.
The concept of the ECAP technology is known already from nineties of the last century, while concrete applications in technical practice aimed at obtaining of nano- crystalline structure are rather exceptional. Basic concept of use of the ECAP technology consists in obtaining of new findings in the area of resistance to deformation, influence of state of stress, physical and technological conditions on formability of materials from the viewpoint of obtaining nano- crystalline materials, which ensure very good plasticity and high mechanical properties.
Final result will bring deeper knowledge of deformation behaviour of metallic materials, influence of plastic deformation, namely change of the deformation route on structure and mechanical properties, as well as project of broader implementation of the ECAP technology in industrial practice.
The ECAP technology makes it possible to obtain ultra-fine grain in larger volumes, when initial cross-section is not changed during extrusion. Possible use is mainly in automotive, military and space industries. Products manufactured by this technology fulfil the basic prerequisites for their subsequent use at super-plastic forming [1-3].

2. MULTIPLE PLASTIC DEFORMATIONS OBTAINED BY THE ECAP TECHNOLOGY
High plastic deformation is achieved by extrusion of the sample through a channel (see Fig.1). The machined sample is inserted into the L-shaped channel. If the angle between two parts of the L-shaped channel is equal to 90°, the tested sample is subjected to a shear stress at the moment of passage from one part into the other one [1].

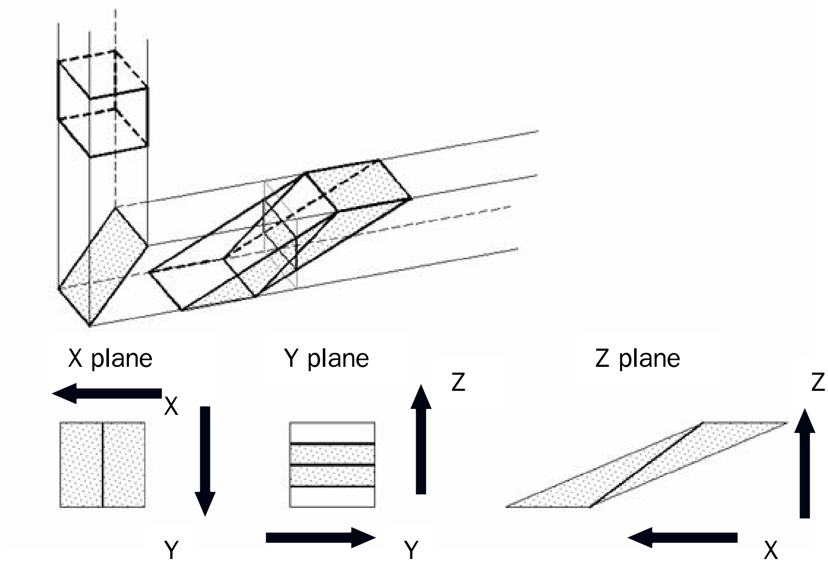


Figure 1. Principle of the ECAP technology

It is obvious that the samples are extruded through the channel without any change of their dimensions at cross section. By this the mentioned property differs from majority of usual methods of metal forming, such as rolling and extrusion, where the forming process is accompanied by reduction of cross section dimensions of the formed piece. In practice it is appropriate to define individual planes inside the sample extruded by the ECAP technology – these planes are shown in the Fig.1. It is namely the plane X that is perpendicular to the longitudinal axis, and the planes Y and Z are parallel to the lateral an upper front of the sample from the point in the order as they were extruded from the tool. Due to the fact that area of the sample cross section does not change at individual places during its passage through the channel, it is obvious that repeated extrusion is made in order to obtain a very high amount of deformation. In practice it is possible to turn the sample between individual extrusions, which activates different shear system. Several research works were focused on evaluation of the effect of turning of the sample between individual passages. At present four different types of passages through the channel are known.

3. MATHEMATICAL MODELLING OF THE PROCESS OF MULTIPLE FORMING WITH USE OF THE ECAP TECHNOLOGY

The main objective was analysis of mathematical modelling of the ECAP technology for the sample made of AlCu4Mg2, extruded through the channel with constant channel width b = 8 mm, various radii of internal and external transition of the walls and angles of the channel are between 90° to 120° (see Fig.2).

Prior to simulation of the forming process by the program FormFem it was necessary to input into the global database of materials the alloy AlCu4Mg2 with its basic characteristics, such as chemical composition, density, coefficient of thermal expansion, conductivity, specific heat, yield strength, dependence of deformation and stress on temperature, as well as other quantities, which served for more precise specification of properties of that material in order to express best the behaviour of material during real forming. Input of characteristics into the global database of the program will have to be done also for material of the tool – steel 19 436.

3.1. Influence of various radii of the ecap channel rounding on forming process, with angles magnitude ϕ , ψ

The proposed rounding of the radius of matrix rounding with magnitude of transition R1 = 2.4 mm and R2 = 0.2 mm and R1 = 5.5 mm and R2 = 0.2mm. Simulation of the ECAP process with these parameters proved that amount of incomplete flow is influenced by unsuitable selection of the channel dimensions, when channel width has constant value 8mm (in radial directions of transition).

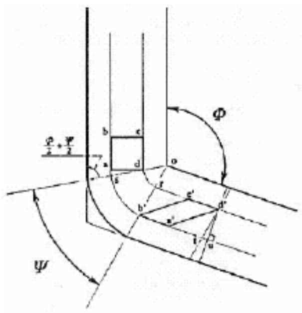


Figure 2. Dimensional parameters of the ECAP extruding channel

3.2. Development of the magnitude of deformation intensity at various radii and identical angles ϕ, ψ

Development of the magnitude of deformation intensity proved that the values ε_i are in case of the smaller radius higher in comparison to the values with bigger radius.
The final value of deformation intensity for the radius R1 = 5.5 mm, R2 =0.2 mm with tool angles ϕ = 90°, ψ = 90° - is ε_i = 1.09 .
For the radius R1 = 2.4 mm, R2 = 0.2 mm, with tool angles ϕ = 90°, ψ = 90° the deformation intensity achieves the value ε_i = 1.29. Internal radius R2 = 0.2 mm is identical for both channels.

3.3. Development of magnitude of the vector of material flow rate at various radii and angles ϕ = 105°, ψ = 60°, 90°

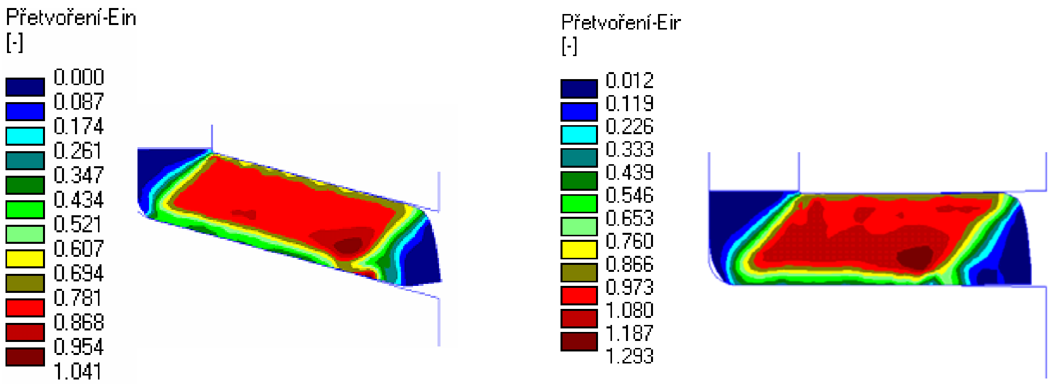
For the radii R1 = 1.85 mm, R2 = 0.2 mm and angles of transition ϕ = 105°, ψ = 60°, the magnitude of the vector of material flow rate achieves the value v = 13.19 $mm.s^{-1}$.
For the radii R1 = 2.4 mm, R2 = 0.2 mm with angles ϕ = 90°, ψ = 90°, the magnitude of the vector of material flow rate achieves the value v = 5.02 $mm.s^{-1}$. The magnitude of the vector of material flow rate is 3x higher than ion the tool with channel angles ϕ = 90°, ψ = 90°.

3.4. Development of deformation intensity deformace at various radii and the angle ϕ = 105°, ψ = 60°, 90°

The following values of forming parameters were achieved:
At the channel angles ϕ = 105°, ψ = 60° with radii R1=1.85 mm and R2 = 0.2mm, deformation intensity achieves the value ε_i = 1.04.
At the channel angles ϕ =90°, ψ = 90° with radii R1 = 2.4 mm and R2 = 0.2mm, deformation intensity achieves the value ε_i = 1.29.
Development of deformation intensity is smaller by 10% for channel parameters ϕ = 90°, ψ = 60° with radii R1 = 2.4 mm and R2 = 0.2mm than in parameters ϕ = 105° and ψ = 60°.
Schematic diagram is shown in Fig.3

4. CONCLUSIONS

It follows unequivocally from the results of mathematical modelling that tool geometry at multiple plastic deformation (ECAP technology) influences the obtained amount of deformation and also magnitude of stress intensity. From the viewpoint of forming of structure with ultra fine-grained composition, which is characterised by high plasticity with preservation of very good mechanical properties, it is necessary to achieve the highest possible deformation at individual passes through the tool channel. The values of deformation after the first passage though the forming tool matrix achieved at mathematical modelling the magnitudes of 1.2 – 1.3 at the angle ϕ =90° and the value 1-1.05 at the angle ϕ = 105°. From the viewpoint of obtaining of the grain size of the order of (150-200) nm it is necessary to achieve the amount of deformation ε_i > 4, which requires realisation of four repeated passages through the matrix with the channel angle ϕ =90°, or 5-6 passages with the channel angle ϕ = 105°. This angle is suitable for extrusion of materials, the forming of which is difficult.



a) ***b)***

Figure 3. Dent of deformation intensity
a) for channel radii R1 = 1.85 mm, R2 = 0.2 mm and channel angles ϕ = 105°, ψ = 60°
b) for channel radii R1 = 2.4 mm, R2 = 0.2mm and channel angles ϕ = 90 °, ψ = 90°

New finding is influencing the stress condition by use of various values of the angle ψ (angle of the channel external rounding). During modelling after one passage at the angle ψ = 60° lower intensity of stress was achieved than at the angle ψ = 90°, while filling of transitions by material from vertical into horizontal part of the channel was optimal at the smaller angleψ. Material flow was more uniform. From the viewpoint of possible formation of internal defects use of the smaller angle ψ appears to be more appropriate. Results of mathematical modelling were verified by experimental tests of extrusion of the AlCu4Mg2 alloy. Comparable values of the forming forces and also amount of deformation during one passage thorough the channel. Modelling of the second and other passages is under development with special attention paid to exact definition and modelling of changes of the deformation route in next passages.

5. REFERENCES

[1] T. Hebesberger, A. Vohauer, R. Wadsak, H.P. Stuwe, R. Pippan: Výroba, struktura a vlastnosti nanokrystalických kovových materiálů vyhotovených vysokou deformací [Production, structure and properties of nano-crystalline metal materials prepared by severe deformation], BHM, 147.Jg. (2002), No. 11, pp.358-363.

[2] P.B Bearbon, Z. Horita, M. Nemoto, T.G.Langdon: Influence of pressing speed on microstructure development in Equal-channel angular pressing, Metallurgical and material transactions, vol. 30A, 1990, pp.4005-4010

[3] Y. Inwahashi, J. Wang, Z. Horita, M. Nemoto, T. G. Langdon: Principle of equal–channel angular pressing for processing of ultra–fine grained materials, Scripta Materiallica, vol. 35,1995, pp.143-147

The work was financed by aim of GAČR of the Czech Republic GA-101/08/1110 and sponzored by projects MSM 6198910015