Achievements in Mechanical and Materials Engineering
COMMENT Worldwide Congress on Materials and Manufacturing Engineering and Technology
16th - 19th May 2005
Gliwice-Wisła, Poland
COMMITTEE OF MATERIALS SCIENCE OF THE POLISH ACADEMY OF SCIENCES, KATOWICE, POLAND
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, GLIWICE, POLAND
ASSOCIATION OF THE ALUMNI OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, MATERIALS ENGINEERING CIRCLE, GLIWICE, POLAND
13th INTERNATIONAL SCIENTIFIC CONFERENCE
ON ACHIEVEMENTS IN MECHANICAL AND MATERIALS ENGINEERING

Mathematical Modeling for ECAP Technology of Multiple Forming

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Abstract: The technology, ECAP – Equal Channel Angular Pressing, belongs to technologies of accelerated development and represents top items of R&D agenda in the world. Aluminium alloys of super fine granularity structure are basic intermediate products realised by ECAP technologies. The state of super fine granularity facilitates forming of material in the so-called 'super plastic state'. The achievement of the desired structure depends primarily on the tool geometry, number of passages through the die, magnitude and speed of deformation, process temperature, and lubrication mode.

Keywords: Severe plastic deformation, Nanostructure, Grain size

1. INTRODUCTION

The principle of the ECAP (Equal Channel Angular Pressed) technology has been known since the nineties of the past century. Nevertheless concrete utilisations of this technology for nanostructure material developments have been rather rare. This paper informs on ECAP technology investigations that have been oriented by overall objectives of acquiring new knowledge concerning deformation resistances, stress condition impacts, and physical/technological conditions as decisive factors of material formability processes that provide for nano-sized grain structures of very high plasticity, and very good mechanical properties.

Better understanding of the whole process and developments of ECAP technology applications for practical industrial use will be final outcomes of the project.

The ECAP technology provides for large volume ultra-fine grain structures at which point the extrusion does not reduce original cross section profiles. Especially automobile, military, and space industries are principal beneficiaries of this technology.

2. PRINCIPLE OF MULTIPLE PLASTIC DEFORMATIONS

High plastic deformations are achieved by extruding the sample through a special L-shaped channel-die (see Fig. 1). If the angle between two L-shaped channels equals 90°, the worked sample is under shear as it passes from the input channel to the next [1]. It is obvious that the sample has been extruded without any change of its original cross section size. This makes this process unique in comparison to common processes of metal forming like for example rolling or extrusion that are typically accompanied by reducing of transverse profiles. In practice it is useful to define individual planes within the sample as subject of ECAP technology application. Fig. 1 illustrates these planes: Plane, X, is perpendicular to lengthwise axis; and planes, Y and Z, run parallel to sample side and upper face from the point defined by the sequence of extrusion. Maintaining the sample profiles constant throughout the whole channel demonstrates that the only aim of repeated deformations is attaining of high deformation degrees. It is an option to turn the sample about between individual extrusions so that shears are affected differently, and there are some references to this effect. Currently four different passes through the channel are commonly distinguished that are described as type extrusions, A, BA, BC, and C (see Fig. 2). Type A means that the sample is extruded without any turning action; B denotes a quarter turn between each extrusion phase; BA and BC concerns reversing or maintaining extrusion direction respectively. Type C is reserved for half turn action between each extrusion phase. Current references point to the fact that BC (zero direction reversing) is considered to be the best ECAP extrusion type, which provides for deformation maximum by each pass. Nevertheless this type is applicable only for materials with very good formability parameters.

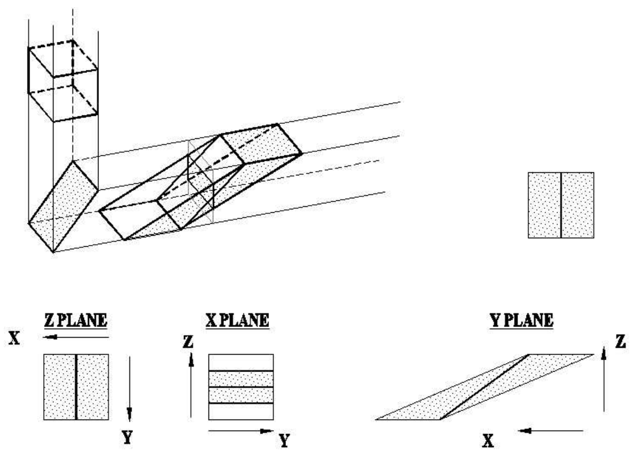


Figure1. ECAP technology principle

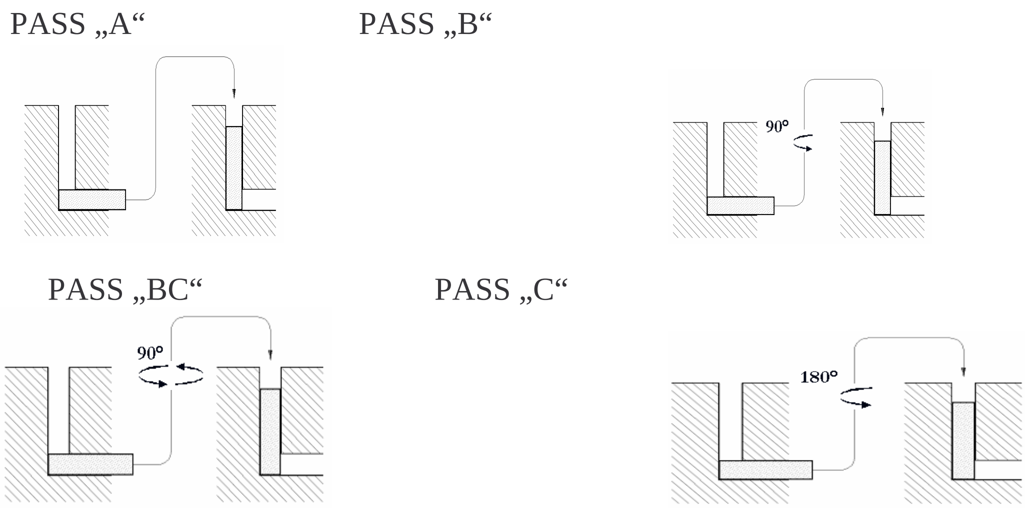


Figure 2. Extrusion types

The ECAP method of forming essentially consists in extruding cylindrical or prismatic samples through specific geometry channels. An ideal cycle renders only shear stresses in the material when it passes through the channel angulation. Various angles provide for varying degree of deformation. Angles from 90° to 120° are common. Von-Mises [1] comparative elongation by single deformation cycle can be specified as follows:

$$\Delta\varepsilon = \frac{1}{\sqrt{3}} \cdot 2 \cdot \cos\phi \qquad (1)$$

As the outlet channel has the same dimensions as the input one, samples can be extruded as frequently as needed. The extrusion cycle number defines total deformation. Plastic deformation is a complex process influenced by a lot of parameters like deformation temperature, T, especially concerning melting temperature, T_t, average granularity, d; deformation speed; strain values as especially regards modulus of elasticity. It also depends on structural fault density (especially dislocations), material purity, and other factors [3]. Deformations accomplished by ECAP cold processes are particularly sensitive to the latter. Internal energy ratios, which are defined by deformations modes, purity, granularity, temperature, etc., rise to their maximums. The number and quality of lattice faults in the worked alloy directly influence internal energy accretions. Volumes of energy absorbed by the structure during deformation increase with fouling of the forming tool, decreasing granularity and decreasing deformation temperatures [2]. Fine-grain structures add to material plasticity, and in some cases even ‘super plastic condition’ deformations are possible. Achieving of required structures in the worked samples primarily depends on tool geometries, number of extrusion cycles, magnitude and speed of deformation, as well as temperatures.

3. MATHEMATICAL MODELLING FOR ECAP TECHNOLOGY

The investigation principal goal consisted in analysing of the ECAP technology mathematical modelling concerning AlCu4Mg2 alloy sample extruded by passing through channels of different radii of inner and outer walls, R1 = 2.4 mm, R2 = 0.2 mm, and constant channel width, b = 8 mm (Fig. 3).

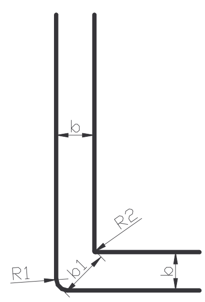


Figure 3. ECAP dimensions

2.1 Impact of Varying ECAP Tool Inner and Outer Radii

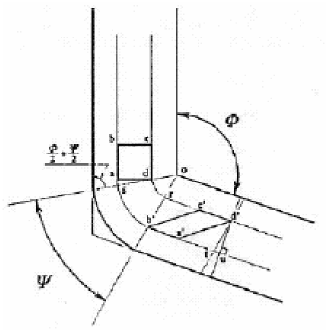
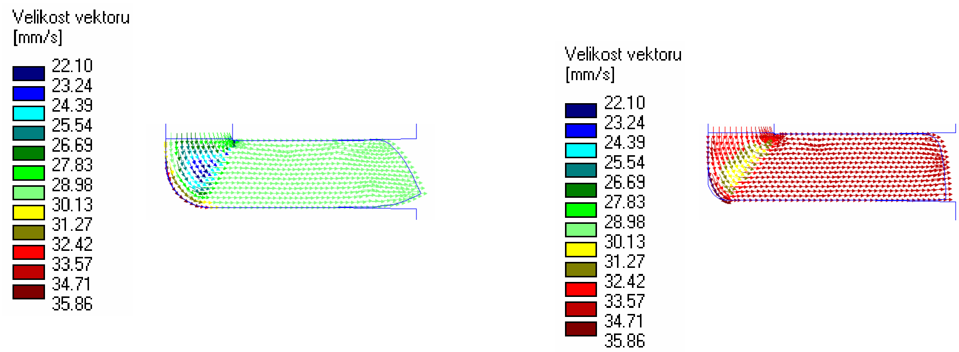


Figure 4. ECAP tool diagram, where Φ represents channel passage angle, and Ψ provides for the passage corner roundness

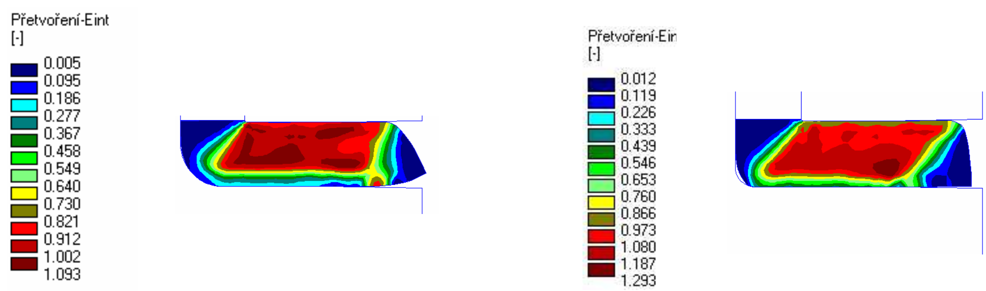
General conditions ECAP see Fig. 4. Assumed parameters: R1=2.4mm, R2=0.2mm; and R1=5.5mm, R2=0.2mm. ECAP process simulations for the assumed parameters led to a conclusion that flow inadequacies depend on unsuitable channel dimensions whereby the channel width is constant, 8mm, in radial directions of the passage. From the point of view of the flow vector, it has been explicitly demonstrated that larger radii make for better fillings of the channel. Fig. 5 illustrates vector values for material flow speeds.



a) b)

Figure 5. Vector values for material flow speeds; a) Channel radii: R1=5.5 mm, R2=0.2mm; b) Channel radii: R1=2.4 mm, R2=0.2mm

2.2 Deformation Intensity vis-à-vis Varying Radii and Constant Angles, ϕ, ψ



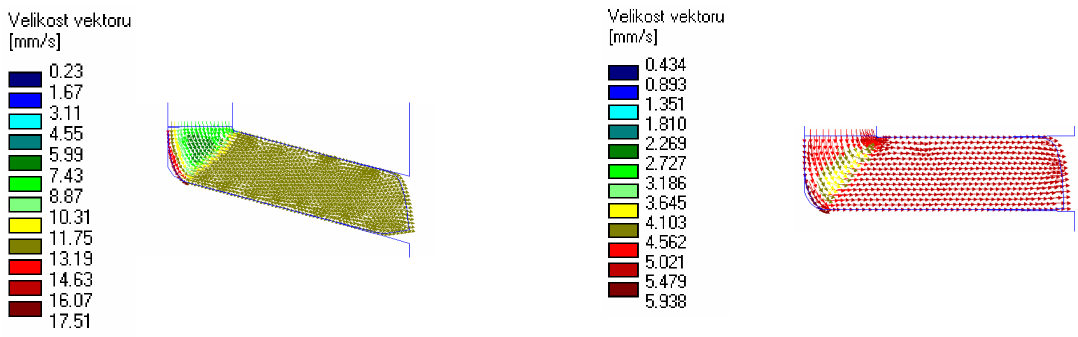
a) b)

Figure 6. Deformation intensity a) Channel radius: R1=5.5 mm, R2=0.2mm
b) Channel radius: R1=2.4 mm, R2=0.2mm

Deformation intensity investigations proved that values, ε_i, are higher for smaller radii as compared to values produced by larger ones. The outcome deformation intensity for R1=5.5 mm, R2=0.2 mm, with tool angles: ϕ = 90°, ψ = 90° has the value, ε_i = 1.09. By the radius of R1=2.4mm, R2=0.2 mm; tool angles, ϕ = 90°, ψ = 90°, the deformation intensity reaches the value of ε_i=1.29. The inner radius, R2=0.2 mm is identical for both channels. Fig. 6 provides for deformation intensities.

2.3 Speed Vector Values for Material Creep by Varying Radii and Angles, ϕ = 105° and ψ = 60° a 90°

By R1=1.85mm, R2=0.2mm and with transience angles, ϕ=105°, ψ=60°, the speed vector for material creep attains the value of v=13.19mm.s^{-1}. By R1=2.4mm, R2=0.2mm with angles, ϕ=90°, ψ=90°, the speed vector for material creep is v= 5.02mm.s^{-1}. The material creep speed vector is three times greater than that for channels with angle, ϕ= 90°, ψ=90° (Figure 7).



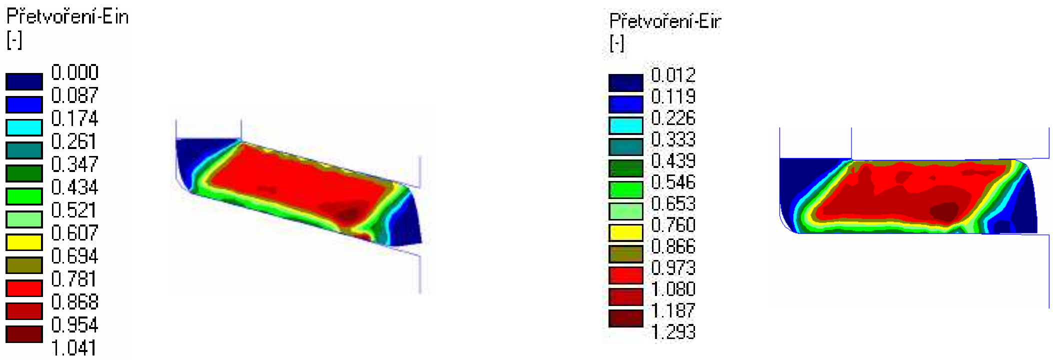
a) b)

Figure 7. Speed vectors for material creep

a) Channel radii: R1=1.85mm, R2=0.2mm; Channel angles: ϕ=10 5°,ψ=60°

b) Channel radii: R1=2.4mm, R2=0,.2mm; Channel angles: ϕ=90°, ψ=90

2.4 Deformation Intensities for Varying Radii and Angle, ϕ = 105° a ψ = 60° a 90°



a) b)

Figure 8. Deformation intensities

a) Channel radii: R =1.85mm, R2=0.2mm; Channel angles: ϕ=10 5°,ψ=60°

b) Channel radii: R1=2.4mm, R2=0.2mm; Channel angles: ϕ=90°,ψ=90

The following forming parameters have been achieved (Figure 8.):

For channel angles of ϕ=105°, ψ=60° with radii of R1=1.85mm and R2=0.2mm, the deformation intensity attains the value of ε_i=1.04. For channel angles of ϕ=90°, ψ=90° with radii of R1=2.4mm and R2=0.2mm, the deformation intensity attains the value of ε_i =1.29. Deformation intensity is lower by 10% for channel parameters of ϕ=90°, ψ=60° with radii of R1=2.4mm and R2=0.2mm than that for parameters of ϕ=105° and ψ=60°.

3. CONCLUSION

The mathematical modelling data clearly demonstrate that it is the tool geometry that provides for decisive factors of multiple plastic deformation processes (ECAP technology), concerning both deformation and strain intensities. Achieving of ultra fine-grain structures, which demonstrate both high plasticity and very good mechanical properties, is conditioned by keeping maximum deformation rates for each passage through the tool channel. The deformation parameters after the initial passage though the forming tool reached the values of 1.2 – 1.3 by angle, ϕ=90° and then, by angle of ϕ=105°, the amounts reached values of 1-1.05. From the point of view of achieving granularity about 150-200 nanometers, it is necessary to employ deformation, $\varepsilon_i > 4$, which asks for quadruple passage through the tool at an angle of ϕ=90° or, if the channel angle is ϕ=105°, that 5 to 6 passages are applied for the worked sample. New knowledge has been provided by a finding that strain conditions can be affected by varying the values of the angle, ψ (channel outer edge roundness). Modelling a single passage condition, lower strain values have been attained for ψ=60° than for ψ = 90°, whereby the material filling optimum by its coming from vertical to horizontal parts of the channel was achieved with angles under the value, ψ. More consistent flows of material have been observed here. Taking into account likelihood of inner fault formation, employment of smaller ψ-angle values seem to be more advantageous. The mathematical modelling results have been verified by experimental test of alloy, AlCu4Mg2. Comparable values of forming forces and deformation ratios have been achieved by single passages through the channel.

ACKNOWLEDGEMENT

The work was performed within the frame of Grant projects N° 106/04/1346 under assistance of Grand Agency of the Czech Republic, MPO IMPULS FI IM/033 and with assistance of the project CEEPUS PL-13.

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