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MATHEMATICAL SIMULATION OF CHANGE OF DEFORMATION PROCESS AT SEVERE PLASTIC DEFORMATION

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ABSTRACT
Development of materials with ultra-fine structure, i.e. nano-structural materials, belongs nowadays to front-end areas of research of materials and forming technologies all over the world. This topic is also one of the leading themes of the EU 7th Framework program. Substance of this process consists in obtaining of grain size of tested material under 1 μm. Sub-microcrystalline materials with average grain size from 50 to 200 (nm) are characterised by very high formability with preservation of their very good strength properties. Important part of works of existing research centres deals with issues of strengthening in the course of plastic deformation. Main content of work will consist of verification of new technology of manufacturing of nano-structural materials by so called EHSD method - Extrusion with High Stage of Deformation with use of Al alloys. Moreover there will be made a comparison of the obtained results with currently published research works in this area, as well as mathematical modelling of this technology

Keywords: severe plastic deformation, high amount of deformation, mathematical simulation, stress-strain state, metal flow, UFG structure

1. INTRODUCTION
Materials with ultra-fine grain structure and their development with use of technologies of multiple plastic deformation belong to front-end areas of research all over the world. Research is focused primarily on forming of non-ferrous metals and their alloys. Non-ferrous metals can be recycled very well and they replace steels more and more. Overall interest in nano-structural materials increased tremendously during last two decades. During that period technologies for their production were also developed. These materials will find their application e.g. in machinery, metallurgy, automotive, military and space industries. Nano-structural materials are characterised by exceptional mechanical properties. They have very high strength and resistance to fatigue and at the same time they can be formed very well. Structural components made of these materials can carry much higher loads and they thus increase safety of whole constructions. The required structure can be obtained in dependence on temperature-deformation conditions, tool geometry, number of passes, optimum magnitude of strain rate and lubrication conditions.

2. TECHNOLOGY ECAP
Principle of the ECAP technology is schematically shown in Fig. 1. The tool is designed with two angular channels in cross-section, which is interested by angle □ and also additional angle □, which defines angle of arc of curvature in section of two channels. Deformation generated in the sample, in its individual places of passage inside the channel, depends primarily on the angle Φ between two separated parts pf the channel. Dependence on the angle Ψ in top outer part of the curvature arc at the place of intersection of both channels is also very important [1].

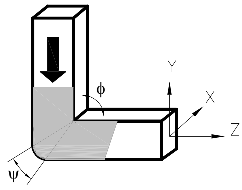


Figure 1. Principle of ECAP technology

Due to the fact that surface area of cross section of the sample is constant at individual places during passage through the channel, it is obvious, that repeated extrusion is effected in order to achieve very high degree of deformation. In practice it is possible to turn the sample between individual extrusions, which activates different shearing system [2, 3].

3. MATHEMATICAL SIMULATION OF EXTRUSION PROCESS ECAP

Plastic deformation represents a complex process dependent on great number of factors, such as temperature of deformation T, particularly in relation to the melting temperature Tt at mean size of grain d, strain rate, magnitude of stress namely in respect to magnitude of modulus of elasticity. It depends also on density of structural defects (namely dislocations), on purity of materials, and on other factors. Deformation realised with use of cold ECAP technology depends significantly on the last mentioned factors [8].

Simulation of forming process was made with use of the program Superforge. This program was introduced to the market by the company MSC Software. MSC.SuperForge is very strong tool for a 3D simulation of forming processes. It is successfully used fro analysis of processes of bulk forming. The program can be efficiently used for evaluation of effect of conditions that are characteristic for forming process on material flow and final shape and properties of the forged piece [4]. Simulation is in this program based on method of final volumes (Volume Element Method = VEM). MSC.SuperForge was developed on the basis of Euller network, when these network is applied to a surface composed of triangle surfaces. These surfaces are geometric entities, which serve for reading of material surface and afterwards these elements are converted into volume elements [4].

Materials used for simulation of the ECAP process in program SuperForm

Material of tool and material for experimental tests:

Material Dievar was used for simulation. Dievar is Cr-Mo-V alloyed high-strength steel for hot work with very high resistance against formation of fissures and bigger cracks due to thermal fatigue, and with high resistance to hot wear.

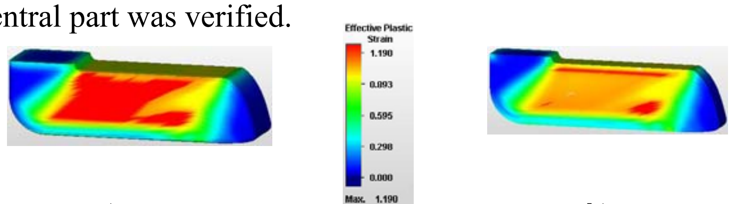
Alloy AlCu4Mg2 was chosen as material for experimental verification of the ECAP technology. This is high-strength hardenable alloy, which is suitable for cold forming after annealing. It is used for various structural purposes, particularly in vehicles and also as fastener. Dimensions of the sample: □ 10 mm x 38 mm.

Entered boundary conditions

Boundary conditions serve for more precise description of the given environment during forming operation. These conditions are entered into the program SuperForge at creation of objects of the given set. Temperature of blank - Tp = 20°C, temperature of tools, Tn = 20°C, ambient temperature T_o = 20 °C, friction coefficient $\mu = 0.05$, mean strain rate achieved the value $\dot{\varepsilon} = 1.2 \cdot 10^{-2}\ s^{-1}$.

RESULTS OF SIMULATIONS

During the first stage a uniformity of distribution of deformations from the border of the sample to its central part was verified.



a) b)

Figure 2. Comparison of achieved magnitude of deformationa) at the sample border, b) in central part of the sample

Comparison of intensity of deformation for a radius R1 = 5.5 mm, R2 = 0.2 mm, with tool angles $\phi = 90°$ and $\psi = 90°$ in the program SuperForm proved unequivocally that at the border of the sample, where it touches the tool (see Fig. 2.5 a), the deformation zone is significantly higher that at cross section of the sample in half of its width after extrusion (see Fig. 2 a, b) – at identical value of deformation intensity $\varepsilon i = 1.19$. Obtained results of magnitude of deformation show unequivocal impact of friction forces in side walls of channel on distribution of deformation. In experimental works it will be necessary to modify geometry of channel by recess of side walls in horizontal direction approx. by 1°.

4. VALUES OF DEFORMATION-STRAIN STATE OF ALLOY ALCU4MG2 OBTAINED AT ONE AND MORE PASSES (WITH USE OF ROUTE REFERRED TO IN LITERATURE AS B_C)

Main target of this stage consisted in analysis of mathematical modelling of the ECAP technology for the sample AlCu4Mg2, extruded through a matrix with various rounding radii of matrix R1 and R2 with constant width of channel b = 10 mm. This dimension is not valid for width of channel between connection of its vertical and horizontal part – marked as b1 (see Fig. 3). Observance of constant width of channel requires that centres of passages must issue form one point, which ensures equal conditions of extrusion.

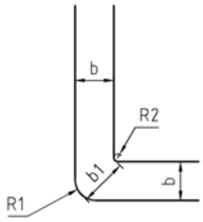
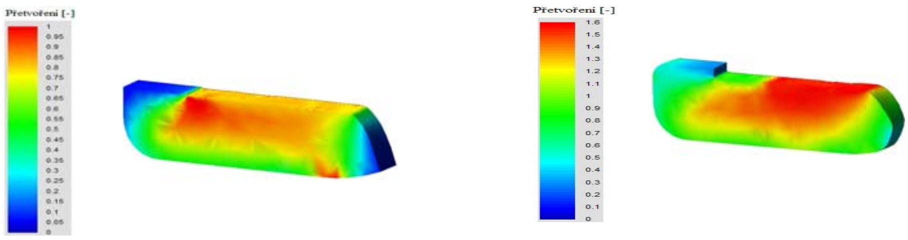


Figure 3. Basic geometry of the ECAP channel

Deformation intensity

For radii R1 = 5.5 mm, R2 = 0.2 mm, with angles of tool $\phi = 90°$ and $\psi = 90°$ the deformation intensity achieves the maximum values $\varepsilon_i \approx 1$ after the first pass through the tool, and the value $\varepsilon_I \approx 1.6$ after the second pass through the tool channel. Courses of deformation intensity are shown in Fig.. 4 a, b.

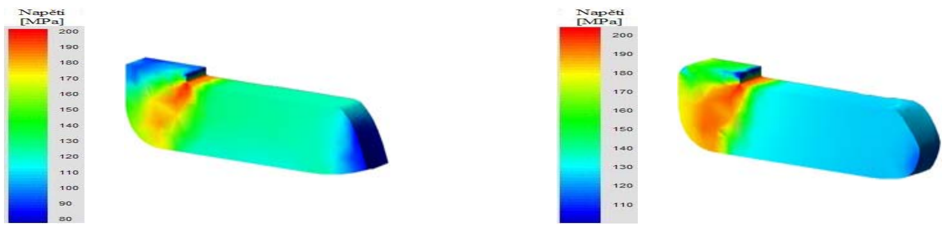


a) *b)*

Figure 4 Courses of deformation intensity a) after the first pass b) after the second pass

Flow stress

The flow stress maximum values for radii R1 = 5.5 mm, R2 = 0.2 mm, with tool angles $\phi = 90°$ and ψ are $\sigma i \approx 200$ MPa after the first pass and $\sigma i \approx 210$ MPa after the second pass through the tool. Courses of flow stress are shown in Fig. 5.



a) *b)*

Figure 5. Magnitude of flow stress a) at the first pass b) at the second pass through the ECAP channel

Contrary to theoretical assumptions no intensive strengthening of materials have occurred, which could have been caused by initial heat treatment. Courses of magnitude of deformation intensity proved that the values εi are at the second pass through the tool higher in comparison to the values after the first pass. According to final parameters after installation passes there occurs accumulation of deformation strengthening. Each extrusion leads to significant refining of mean grain size.

Results obtained by experiments

For radii R1 = 5.5 mm, R2 = 0.2 mm, with tool angles $\phi = 90°$ and $\psi = 90°$ the magnitude of deformation achieves the maximum values $\varepsilon_i \approx 0.9\text{-}0.95$ after the first pass through the tool, and the value $\varepsilon_i \approx 1.4\text{-}1.5$ after the second pass through the tool channel. These results correspond with results of mathematical simulation. The difference in results achieves approx. 5%, which is very positive result. In case of deformation intensity the values after the first pass through the ECAP channel within the range σi ≈ 220-230 MPa, and after the second pass within the range σi ≈ 240-250 MPa. The difference of results is approx. 10%, which is also within the limits of allowable tolerances.

Main target of next research consisted in analysis of mathematical simulation of the first pass through the tool of ECAP technology at change of the route of deformation (deflection of the bottom part of the channel in horizontal direction. Proposed design of new geometry of the tool should bring increased amount of deformation at the first pass through the channel of the ECAP tool and thus to make the whole process more effective.

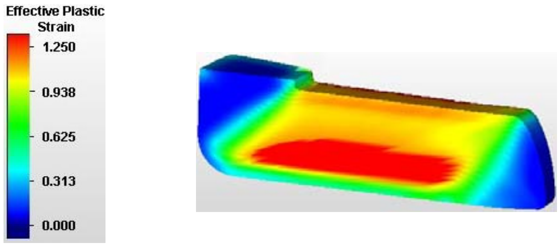


Figure 6. Obtained magnitude of deformation at the first pass through the ECAP channel at change of the route of deformation

Magnitude of deformation.

Final value of deformation for the tool with axle offset of the entry part by 10°, rounding radii R1 = 4 mm, R2 = 0.5 mm, R5 = 5 mm and tool angles $\phi = 90°$, $\psi = 90°$ achieves the max. value εi ≈ 1.25 (program SuperForm) (see Fig. 6). The obtained value is very favourable, since magnitude of deformation was increased in comparison to classical method approx. by 20-25 %.

5. CONCLUSION

Obtained results of mathematical simulation as well as experiments with extrusion of an alloy ALCu4Mg2 through the ECAP tool confirm unequivocally that use of SPD for fragmentation of grain will be much higher in new design of the channel, which uses modification of the route of deformation in the first pass. Thi swill reduce number of pass and thus make the whole process more effective.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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