14th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2010, Mediterranean Cruise, 11-18 September 2010

INFLUENCE OF CHANGE OF THE ECAP TOOL CHANNEL GEOMETRY WITH INSERTED HELIX FOR STRAIN HARDENING OF THE SEMIS MADE OF AL AND AL ALLOYS

Stanislav Rusz, Lubomir Cizek,
Stanislav Tylsar, Jan Kedron
VSB – Technical University of Ostrava
708 33 Ostava – Poruba
Czech Republic

Tibor Donic
Technical University of Zilina
010 26 Zilina, Velky Diel
Slovakia

Marcin Knapinski
Technical University of Czestochowa
42-200 Czestochowa
Poland

ABSTRACT
Technology ECAP is at present the most verified technology for manufacture of UFG and nano-materials. Dependencies of impact of geometry of the ECAP channel on gradual achievement of high degree of deformation (ε ≈ 4 – 5) are well known. For achievement of this high deformation it is necessary to choose also an optimum type of passes through the ECAP tool in dependence on the formed material. The paper analyses influence of changes of the deformation routes on magnitude of intensity of deformation and intensity of stress. Change of route of deformation is realised by new geometry of horizontal channel, which consists of classical square cross section followed by helix, while the outlet has also a square cross section. On the semis made of Al we have achieved an increase of intensity of deformation by 25-30% at individual passes. Mathematical simulation was realised in the program Simufact Forming. The obtained results were mutually compared. Efficiency of the SPD process was substantially improved from the viewpoint of the required grain refinement.
Keywords: severe plastic deformation, new type of ECAP process, hardness, microstructure

1. USE OF SEVERE PLASTIC DEFORMATION FOR CREATION OF ULTRA-FINE GRAINED (UFG) STRUCTURE

The process itself of severe plastic deformation, which leads to structure refinement, depends on several factors. Apart from already mentioned structure of lattice there are also:

- Structure before deformation (grain size, micro-structure)
- Particles of the second phase
- Strain rate and temperature of deformation
- Magnitude of deformation, route of deformation

Initial grain size influence to a great extent the refinement process, together with particles of another phase in structure (in case of light metals presence of precipitates). The refinement gets more difficult with decreasing grain size, since creation of shear planes and therefore also splitting of grains becomes more difficult. The finest structures can be achieved at low temperatures and corresponding strain rates. Higher temperature can be on the contrary used at controlled re-crystallisation, however, size of grains obtained at this process varies in the range from 1 to 5 μm (Al alloys). The structure is therefore not assessed as UFG structure. At the deformation intensity ε > 5 gradual breaking of thin elongated grains to shorter segments was observed, till creation of UFG structure, which is homogenous in greater part of material volume. When sub-micrometric width of grains is achieved, then the rate of creation of further grain refinement is very low. This is given by the fact that elongated grains are very stable and they do not split even at big deformations. Further splitting could be possible only by change of the route of deformation, nevertheless the route Bc appears to be the most efficient and from the viewpoint of another change of the deformation rout is not efficient. New method called "twist extrusion" (TE) at present expands very intensively [1]. The principle of the TE method consists in creation of intensive shear deformation by extrusion of material through the tool, in which a helix was created, and where therefore occurs shear deformation (see Fig. 1)

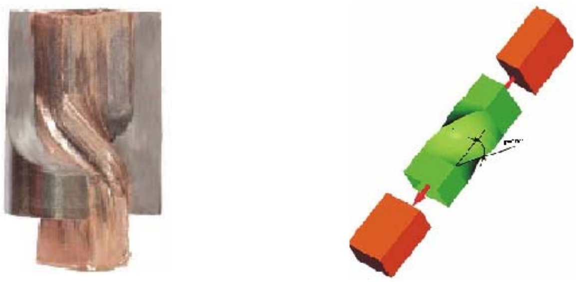


Figure 1. Principle of the "twist extrusion" method

Shape of material along the axis of extrusion does not change. The condition of constant shape before the process and after it is also fulfilled, so it is possible to make repeated extrusion and thus accumulation of plastic deformation. The sample can be extruded with use of push broach or by use of hydrostatic pressure. Shear deformation is not distributed equally at the place of twisting of the sample (in cross section) [2]. The biggest deformation is achieved in the most distant part of the sample, perpendicularly to the axis of extrusion, the smallest deformation is on the other hand in the axis. This fact is given by the tool geometry, material in the centre of the sample in cross section is twisted only minimally. Average magnitude of deformation can be expressed by the relation 1.

$$\varepsilon_{stř} = \frac{tg\gamma_{\max} + (0,4 + 0,1 \cdot tg\gamma_{\max})}{2} \qquad (1)$$

Extrusion can be realised hydro-mechanically. Pressure of 1500 MPa created by hydraulic press (4000 kN) can be used for extrusion. Hydrostatic pressure is in this case used for creation of back pressure of approx. 700 MPa. Advantage of hydro-mechanical extrusion consists in achievement of high plasticity, creation of low friction between the tool and material, and also use of various values of speed of tool.

2. NEW GEOMETRY OF THE ECAP TOOL WITH IN-BUILT HELIX IN ITS HORIZONTAL CHANNEL.

The tool differs from the basic concept of the ECAP geometry by created helix part in horizontal area of the channel with a helix angle γ=10°. The basic objective of use is the helix. Helix geometry was to simulate the back pressure and thus to increase the extrusion force. The tool was made form the top quality tool steel made by Böhler-Uddeholm with trade name HOTVAR.

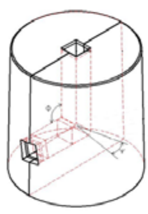


Figure 2. Diagram of the ECAP tool with modified geometry

2.1 Layout of the working site

Experiments were realised at the department of mechanical technology, Faculty of Mechanical Engineering, Technical University of Mining and Metallurgy in Ostrava (VŠB-TU Ostrava). Hydraulic press DP 1600 kN K with servo operated valve enabling smooth regulation from control panel and with temperature regulator was used for extrusion.

Figure 3. Working site for verification of new geometry of the ECAP tool

The press can be controlled manually via the control panel or by PC software via PC card. it is thus possible to monitor and record the courses and developments of deformations, forces and stresses in dependence on time or route. Possible reheating of the ECAP tool is possible with use of a heating sleeve, when temperature of the sleeve and of the tool is controlled by temperature regulator (see Fig. 3). The maximum extrusion force was limited by structural strength of the tool to 200 kN. Extrusion was performed at the rate of extrusion of 0.5 mm.s-1 and strain rate 1.10-2 s-1.

Table 1. Chemical composition of Al99.5%

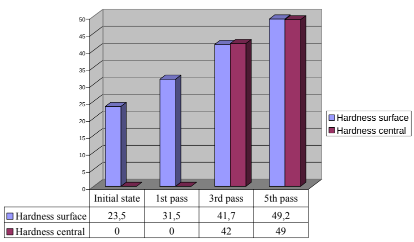
Si	Fe	Ti	Mg	Cu	Mn	Al	Rest
0.25%	*0.40%*	*0.05%*	*0.05%*	*0.05%*	*0.05%*	*99.5%*	*0.03%*

Table 2. Chemical composition of AlMn1Cu

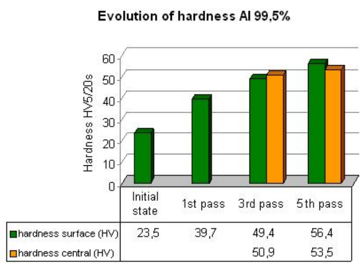
Mn	Fe	Si	Cu	Al
1.1%	*0.45%*	*0.55%*	*0.15%*	*rest*

Pure aluminium (99.5%) - EN AW-Al-99.5 and AlMn1Cu - EN AW-AlMn1Cu (hereinafter only Al99.5% and AlMn1Cu) were used for experiments. Aluminium was formed by 5 passes through the ECAP tool. Dimensions of the samples: 15x15, length 60 mm. Chemical composition and basic mechanical properties of aluminium are given in tab.1 and in tab. 2. The alloy AlMn1Cu was formed by 7 passes through the ECAP tool with modified geometry.

3. MEASUREMENT OF HARDNESS OF Al



a)



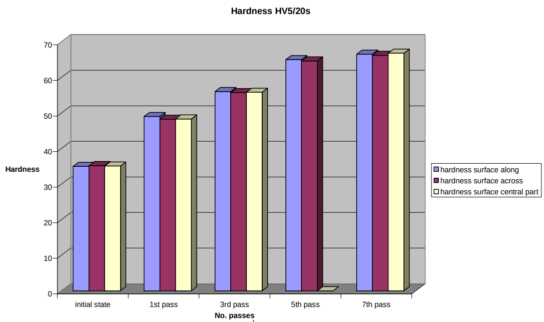
b)

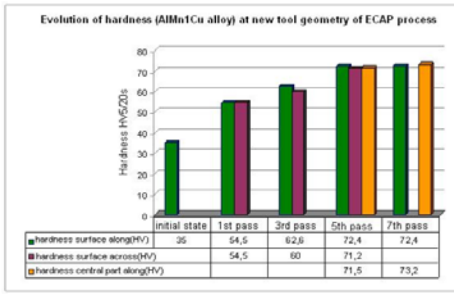
Figure 4. Achieved values of hardness, initial state and state after individual passes (Al), a)classical geometry of ECAP tool, b)new geometry of ECAP tool with helix

Hardness on pure aluminium 99.5% was measured after the 1st, 3rd and 5th pass through the tool, and at the same time hardness on initial sample was also measured. The measurement itself was made in a

longitudinal direction on the surface and in the centre of the sample. It is obvious from the obtained results (see Fig. 4), that the most significant increase was achieved after the 1st pass through the tool. After that the hardness did not increase so much. After the 5th pass an average hardness of 56.4 HV was achieved on the sample surface, which represents a double increase in comparison to the initial state.
Samples extruded through the ECAP tool with a helix 10° show more pronounced increased at the same number of passes in comparison to the classical geometry.

3.1. Measurement of hardness of AlMn1Cu





a) *b)*

Figure 5. Achieved values of hardness, initial state and state after individual passes (AlMn1Cu), a) classical geometry of ECAP tool, b) new geometry of ECAP tool with helix

In the alloy AlMN1Cu a significant increase of the values of hardness was achieved at extrusion with new geometry of the tool. The process can be therefore assessed from the viewpoint of the obtained hardness as highly efficient. It can be unequivocally concluded from comparison of the values hardness achieved for the same alloy formed by the classical ECAP channel that new geometry of the tool significantly increases the achieved hardness, and the most notable increase is achieved already after the 1st pass through the tool.

4. CONCLUSIONS

Measurements of hardness of Al and AlMn1Cu after individual passes through the classical ECAP channel and through the channel with modified geometry (helix), confirmed unequivocally an increase in efficiency of the SPD process with new geometry of the ECAP tool. Metallographic analysis of the samples of Al and SAED by use of diffraction lattice has proven an average grain size of the order of 300-350 nm in case of the new ECAP geometry in comparison to 550-600 nm in case of classical geometry. In the samples from the alloy AlMn1Cu the average grain size of the order of 200-250 nm was achieved by the new geometry in comparison to 400-450 nm in case of the classical geometry of the ECAP tool. Future research will be focused on further modifications of the ECAP tool geometry in order to achieve the required grain size at lower number of passes.

Acknowledgements
The work was performed within the frame of Grand Agency of the Czech Republic GA 101/08/1110

5. REFERENCES

[1] Orlov, D., Beygelzimer, Y., Synkov, S., Variukhin, V., Horita, Z. - Evolution of Microstructure and Hardness in Pure Al by Twist Extrusion, *Materials Transactions,* vol. 49. no.1. 2008.
[2] Mazurina, I., Svidkov, O., Kaibyshev, R. and Miura, H. Effect of deformation temperature on microstructure in 2219 aluminium alloy during ECAP, *Rev. Adv. Materials Science and Forum,* vol. 559, December 2007