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Increase of efficiency of the ECAP technology at grain refinement of the alloy AlMn1Cu

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ABSTRACT

Purpose: The foundation of the resolved problem consists of verification of influence of temperature and also geometry of the ECAP tool on obtaining of required amount of deformation which substantially influences grain size. Research was realised with use of the alloy AlMn1Cu. Verification concerned influence of change or route of deformation on amount of deformation aimed at obtaining of required grain refinement.

Design/methodology/approach: At the first stage of solution mathematical simulation was used for determination of conditions for obtaining the required amount of material deformation. Experimental part of the work was then made on the basis of results of the mathematical simulation.

Findings: Route of deformation was changed by deflection of horizontal part of the ECAP channel by 10 and 20°. Obtained results were compared with conventional ECAP process without deflection of the channel. Increased efficiency of the ECAP process was confirmed unequivocally.

Practical implications: Practical application of the obtained results at forming of the given alloy in the company AlInvest Břidličná will bring economy of forming operations, as well as operations of heat treatment of that alloy.

Originality/value: The obtained results will be verified by designing of new device enabling forming of strip of sheet. This type of alloy is used for production of strip of sheet by technology of successive rolling to the required thickness with required mechanical properties with preservation of the required formability.

Keywords: ECAP process; Mathematical simulation; Channel geometry; Effective strain; Effective stress; Microstructure

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Preparation of materials with ultra-fine-grained structure to nano-structure with mean size of grain below 1 μm, [1] is one of progressive technologies, which has been for last approx. 20 years in the centre of interest of basic and applied research. It is expected that such materials will have high strength properties, as well as good forming parameters, overcoming the properties of currently produced classical materials. This brings at their use also an important economic effect. Such materials will find their use particularly at such applications, where obtaining of high strength will reduce mass of construction, while good toughness will contribute to safety of the given structure (steels and alloys in automotive industry, aluminium and magnesium alloys in aircraft industry). Some types of ultra-fine-grained (UFG) alloys have already been implemented into mass production, whereas required properties are achieved by formation of fine-grained structure and its stabilisation. At the same time further intensive research of completely novel production technologies is carried on [2, 5]. It runs out that one of the ways for obtaining ultra-fine-grained structure or nano-structure consists in use of severe plastic deformation of materials, i.e. amount of deformation, which cannot be obtained by classical deformation processes [3].

2. Enhancement of properties of materials processed by methods of SPD (severe plastic deformation)

It is known that grain refinement improves mechanical strength, it is therefore obvious that UFG materials have very high strength. Moreover, these materials have at the beginning high density of dislocations. UFG materials can after SPD process achieve higher strengthening [4]. This process, however, usually reduces ductility. Strength and ductility are the key mechanical properties of each material, but they are typical antagonistic properties. Materials can have very good strength or ductility, but they can have both properties only very rarely [5]. Recent investigations have shown that UFG materials uniquely combine high strength and ductility (Fig. 1), but this success requires original approach. Conventional cold rolling of copper and aluminium increases yield value, but it decreases ductility due to reduction of material cross section [6, 7]. Two connecting lines in the diagram represent this dependency for Cu and Al. Percentage marking in the nodes denotes percentage reduction of the mean grain size after individual passes through the ECAP tool. Unlike this, extremely high strength and ductility of nano-crystalline Cu and Ti evidently differentiates these materials from coarse-grained metals (CG) [8, 9].

3. Current state of development of simulation of multiple plastic deformation

Simulation enables investigation of behaviour of the formed material in real, accelerated or decelerated time. After creation of geometric model and completion of simulation calculation it is then possible to simulate in few minutes the development of the whole operation [10, 11]. Already the experience gained at preparation of the simulation model can lead to proposal for optimisation of the forming technology. That is to say that creation of simulation model is not possible without thorough analysis of investigated problem which can reveal at the very beginning of processing of the given task considerable reserves [12]. Simulation offers a complex viewing of investigated problem and it enables therefore its analysis based on multiple criteria. It is possible to change one of design-technological parameters and to observe thus its influence on behaviour of the formed material, on development of technological operation and on possible defects of the product.

3.1. Numerical analysis of the ECAP process

Analyses of effects of various conditions of material flow were effected with use of computer simulations of deformations using finite element method (FEM). None of the previous analyses took into consideration mechanical strengthening of material by micro-structure during development of extrusion through equal angular channel (ECAP). Grain refinement to critical plastic deformation is related to development of dislocations [13, 14]. That’s why enhancement of micro-structure and macroscopic behaviour during ECAP requires also an analysis of density of dislocations and variation of distribution of dislocations [15].

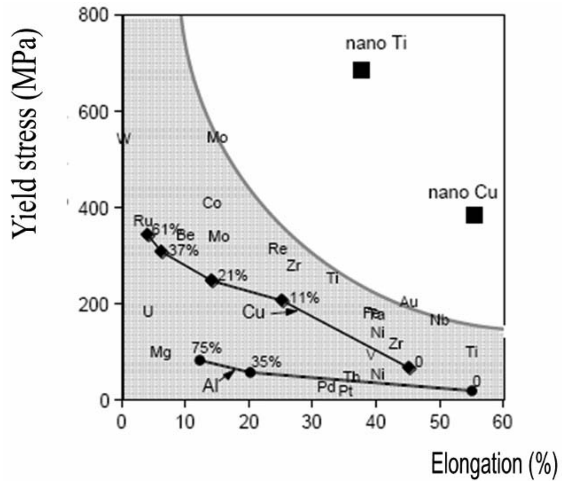


Fig. 1. Comparison of yield value of UFG and CG materials

3.2. Mathematical simulation of forming process in the program QForm

This product has been based on advanced software and forming technologies. It is not necessary to define numerical parameters of simulation. Total volume of input data is limited to the absolutely necessary minimum [5]. Results of simulation are displayed simultaneously with progress of simulation. Model of metal forming realised in the QForm program corresponds to real forming process. Simulation gives complete information about distribution of flows, temperatures and deformation in material, about force, energy and other parameters of the forming process. Programm QForm helps to the tool designer with selection of semi-products, evaluation of the shape of press, optimisation of shapes of performs, a in case of tools – select an appropriate temperature of the semi-product, suggest the relevant bleed, analyse strain in the tool and influence of friction on tool material and select suitable lubricant, etc.

3.3. Simulation of forming of the alloy AlMn1Cu by ECAP process

This material (Table 1) is stronger than pure aluminium and at the same time it preserves high formability, good chemical resistance and very good resistance to corrosion. It is very easily weldable by all welding methods. It is used in soft state or as cold rolled.

Table 1.
Chemical composition of AlMn1Cu

Element	Si	Fe	Cu	Mn	Other	Other – total	Al
[%]	0.6	0.7	0.05-0.20	0.10	0.05	0.15	rest

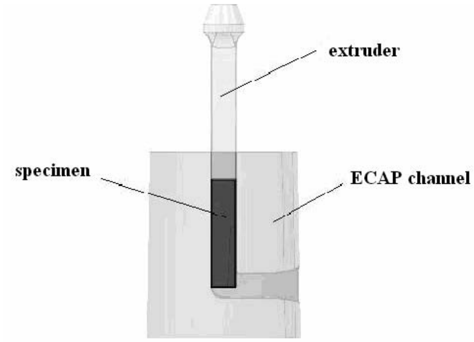


Fig. 2. Assembly of the ECAP forming tool

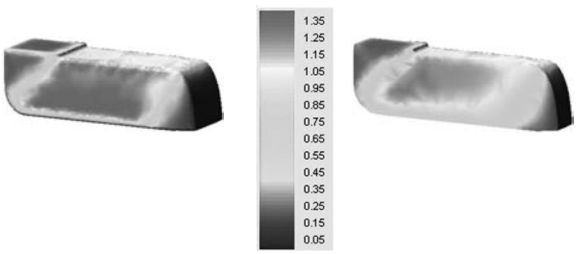
Boundary conditions of simulation process:

tool temperature	T_{tool} = (20, 350) [°C]
semi-product temperature	T_{semi} = (20 a 350) [°C]
ambient temperature	T_o = 20 [°C]
tool material	Dievar
sample material	AlMn1Cu
friction coefficient	f = 0.1 [-]
rate of extrusion	v = 0.5 [mm/s]

The following assembly of the ECAP tool was created for mathematical simulation (see Fig. 2).

3.4. Obtained magnitude of effective strain in the alloy AlMn1Cu at 1 and more passes at 20 °C – classical shape of the ECAP channel

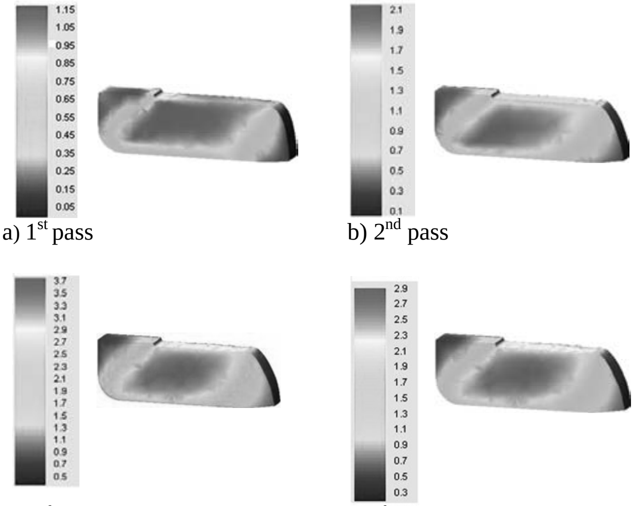
Results of mathematical simulation are evaluated at the half of the sample cross section, since deformation and strain is greater on the surface than inside the sample (deformation and strain do not run evenly in full volume of materials). Another reason is the fact that their magnitude increased at the borders due to friction between the channel and the tool



a) full section; b) 50% of the section

Fig. 3. Effective plastic strain after the 1st pass of the type Bc

Comparison of amount of deformation at the passage of the sample through the tool (R1 = 4 mm, R2 = 0.5 mm, Ψ = 90˚ and Φ = 90˚) on the sample surface and on the half cross-section (Fig. 3) shows obvious influence of the given friction.



a) 1st pass b) 2nd pass c) 3rd pass d) 4th pass

Fig. 4. a, b, c, d Effective plastic strain of the alloy AlMn1Cu at 20°C and 4 passes

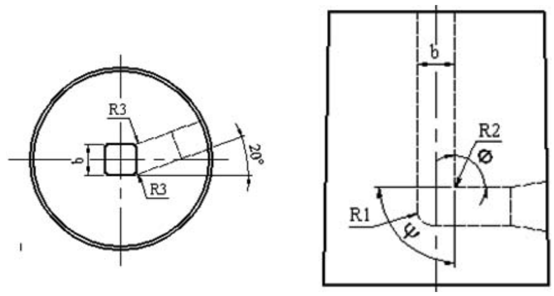


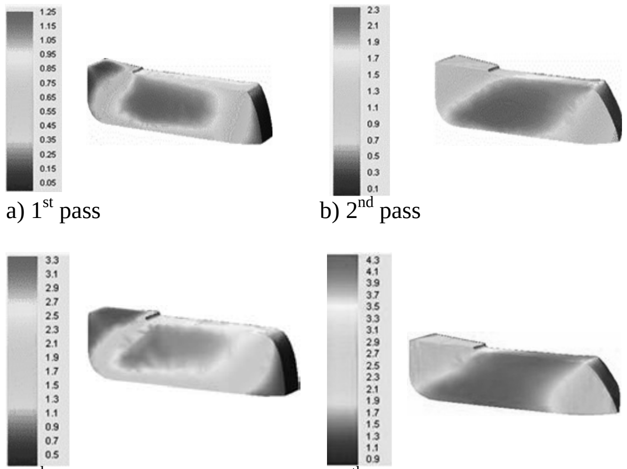
Fig. 5. ECAP tool with deflection of 20°

Magnitude of deformation intensity at 20°C and use of the proposed tool achieves after the first pass the value ε_i = 1.1 (Fig. 4 a). The value of deformation intensity after the second pass is ε_i =2.1 (Fig. 4 b). After the third pass it is ε_i = 2.9 (Fig. 4 c), and after the fourth pass the value is maximum ε_i = 3.7 (Fig. 4 d).

4. Modification of geometry of the ECAP channel aimed at increase of amount of deformation

Used tool had the same geometry as classical solution of ECAP (R1 = 4 mm, R2 = 0.5 mm, Ψ = 90˚, Φ = 90˚ and b = 10 mm), but connection of horizontal and vertical channels is made with a rounding R3 = 5 mm. Horizontal part of the ECAP channel ECAP is deflected by o 20° and lightly extended at the end, as it is shown in the Figure 5. Amount of deformation at 20°C and use of tool with deflection of 20° achieves after the first pass the value ε_i= 1.25 (Fig. 6 a). After the second pass the value of deformation intensity increases to ε_i =2.3 (Fig. 6 b). After the third pass it is ε_i = 3.3 (Fig. 6 c), and after the fourth pass it achieves the maximum value ε_i = 4.3 (Fig. 6 d).

Obtained values of deformation intensity are given in the Table 2. They prove a distinct difference between the values of deformation intensity at increasing number of passes. This means that there occurs strengthening by deformation and change of material structure (change of grain size). Bigger difference in magnitude of deformation intensity was manifested at use of the tool with deflected horizontal channel by 20° in comparison to the classical ECAP channel, which is in conformity with theoretical assumptions. It is therefore obvious that obtaining of higher deformation requires necessarily modification of the tool.



a) 1st pass b) 2nd pass c) 3rd pass d) 4th pass

Fig. 6. a, b, c, d - Effective Plastic Strain of the alloy AlMn1Cu at 20°C and 4 passes, channel deflection 20°

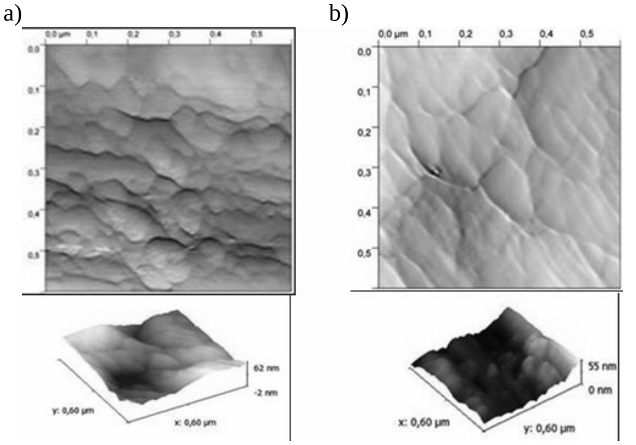


Fig. 7. Micro-structural analysis a) after the 1st pass, b) after the 4th pass through the ECAP tool

5. Metallographic analysis on AFM microscope

An entry analysis of structure was made on the AFM (Fig. 7) microscope for the angle of deflection of the ECAP tool – 20° (1st to 4th pass). Initial mean grain size varied within the interval 150-200 μm. Grain is considerably refined after individual passes. At this stage of research works only entry analysis was made. Considerable disintegration of structure occurs after the 4th pass through the ECAP tool, when the mean grain size varies from 150 to 200 nm.

Table 2.
Magnitudes of effective plastic strain achieved after the 1st to 4th passes through the classical ECAP channel and through the channel with deflection of 20°

–	Temperature / channel deflection	Passage „Bc“			
		1.	2.	3.	4.
Deformation [-]	20°C	1.1	2.1	2.9	3.7
	20°C / 20°	1.25	2.3	3.3	4.3

6. Conclusions

It may be stated on the basis of obtained results of mathematical simulation and micro-structural analysis that the proposed novel concept of the channel of the ECAP tool had proved fully successful. In comparison with classical solution of the ECAP tool it brings substantial increase of the amount of deformation at individual passes and leads thus to higher efficiency of the process of „severe plastic deformation“. From the viewpoint of obtaining of the required UFG structure in the alloy ALMn1Cu it leads to reduction of number of passes through the ECAP tool in comparison with classical geometry of the ECAP channel.

Next research works will be focused on observation of changes of mechanical and forming properties after individual passes through the ECAP tool with modified geometry.

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