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USING SEVERE PLASTIC DEFORMATION TO OBTAIN ULTRA FINE GRAIN SIZE AL ALLOY BY ECAP TECHNOLOGY

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ABSTRACT

Method of equal channel angular pressing is used for obtaining of new properties of metallic materials. Extrusion of aluminium alloy has been verified experimentally with focus on acquisition of basic findings about behaviour of material flow in extrusion channel, about magnitude of deformation resistance, deformability and structural changes in extruded piece.

The results of experiments have been described and compared with the values obtained and normal direct extrusion. The experiments brought new findings. Practical use of the method ECAP consists in possibilities of obtaining a fine-grain structure in extruded pieces and to make use of it at subsequent super-plastic forming.

Keywords: severe plastic deformation, equal channel angular pressing, stress-strain state, metal flow, structure

1. INTRODUCTION

Research and utilisation of equal channel angular pressing has been intensively investigated in important scientific working sites and universities all over the world (Soul, Fukuoka, Los Angeles, Grenoble, Los Alamos, etc.). Technology of equal channel angular pressing (ECAP) offers possibilities for obtaining a fine-grain structure. The method ECAP makes it possible to achieve high plastic deformation in extruded material, moreover without change of original cross-section of the input semi-product. The basic arrangement of tools for realisation of the ECAP technology is demonstrated in the Fig. 1

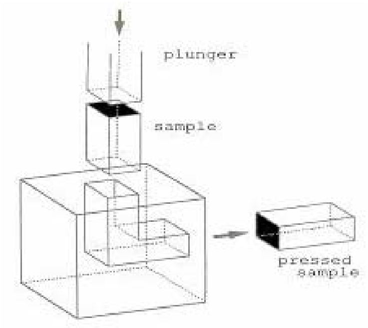

Figure1. Principle of ECAP process

The equipment for realisation of the method ECAP has been designed and installed at the Technical University of Mining and Metallurgy in Ostrava (VŠB – TU Ostrava), where there have been performed basic tests with use of the following materials - Pb, Al, Mg. The aim of these tests was acquisition of basic findings about deformation behaviour of these materials, as well as determination of thermo-mechanical parameters of extrusion. The basic concept of utilisation of the ECAP is aimed at acquisition of new findings in the area of deformation resistance, states of stress on materials’ deformability, and their use for obtaining of nano-structures. The solution will result in deepening of knowledge about deformation behaviour of metallic materials, influence of plastic deformation structure and mechanical properties, and project of broader application of the ECAP technology in industrial practice [1]. The technology ECAP makes it possible to obtain an ultra-fine grain in larger volumes, when extrusion itself does not reduce the original cross-section of the sample. It is possible to use the obtained materials in automotive industry, in military and aerospace industries. The products manufactured by this technology meet also the basic pre-requisites for their subsequent utilisation at super-plastic forming [1].

2. EQUAL CHANNEL ANGULAR PRESSING (ECAP)

Many works were devoted to investigation of the ECAP technology, however only few of these works dealt with its use for obtaining of nano-structural materials. The products obtained by the ECAP technology can be characterised by specific properties and uses, and they are determined for manufacturing in comparatively small quantities. Applications of products characterised by high strength and precisely defined properties comprises namely the fields of transport, electrical engineering, aerospace and submarine technology, but also consumer industry, sports utensils, etc.

Plastic deformation realised with use of the ECAP technology represents a complex process, which depends on great number of factors, such as homologous temperature of deformation Th, (Th = Ttav/Tt), grain size dz, strain rate $\dot{\varepsilon}$, magnitude of octahedral stress at deformation σ8, particularly in relation to the magnitude of the modulus of elasticity E (σ8/E represents homologous stress), but also on density of structural surfaces (particularly dislocations; vacancies), on purity, etc. ECAP cold deformation is significantly dependent on the latter factors.

Influence of magnitude of plastic deformation on characteristics of the alloy AlCuMg is at the use of technology ECAP connected with increase of internal energy. Internal energy increases till the limit value, which depends on method of deformation, purity, grain size, temperature, etc. Increment of internal energy is directly related to the quantity and character of lattice defects in extruded alloy, i.e. that volume of energy absorbed by structure at deformation increases with contamination of the matrix, with reduction of grain size, with drop of deformation temperature [2,3].

As a result of non-homogeneity of deformation at the ECAP (selected planes and direction of slippage) the internal energy increment at different places of the formed alloy is also different. For example value of internal energy is different at slip planes, at the boundaries and inside the cells. It is possible to observe higher internal energy also in proximity of precipitates, segregations and hard structural phases. For usual technologies, pure metals, medium magnitude of deformation and temperature the value of the stored energy is said to be of approx. 10 $Jmol^{-1}$ [6]. Density of dislocations, concentration of vacancies and total surface of walls of cell structure increases at cold extrusion in proportion to magnitude of plastic deformation, see Fig. 2.

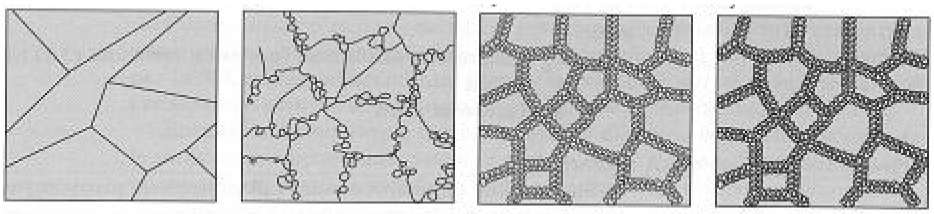

Figure2. Charge of dislocation sub-structure after cold forming

If no softening processes occur at forming, then dislocation density depends linearly on magnitude of plastic deformation in accordance with the well-known equation:

$$\rho = \rho_o + K \cdot \varepsilon \tag{1}$$

ρ_o is initial dislocation density, K is a constant, ε is magnitude of deformation. Flow stress, which is necessary for continuation of deformation is a function number of of lattice defects, particularly of dislocations, and it can be expressed by the equation [4]:

$$\tau = \tau_o + k \cdot G \cdot b \cdot \rho^{\frac{1}{2}} \tag{2}$$

τ_o is value of initial flow stress, k is a constant, G, b is modulus of elasticity in shear, Burgers' vector. Size of sub-grains and magnitude of deformation are in direct relation, when size of sub-grains decreases with increased deformation [6]. We have designed a tool and proposed a procedure for verification of development of structure at equal channel angular pressing. AlCuMg alloy was used for manufacturing of the input semi-product. Our target was to obtain after extrusion the semi-products with a fine-grain structure. Such a structure on one hand increases strength properties and plasticity, and on the other hand it is possible to use it at selected cases for subsequent deformations under conditions of „super-plastic state". Obtaining of the necessary structure in extruded samples depends primarily on the tool's geometry, number of passes through the die, obtained magnitude of deformation, temperature, etc.

3. EXPERIMENTAL VERIFICATION

The experiments were aimed at verification of functionality of the proposed equipment, determination of deformation resistance, deformability and change of structure at extrusion of the alloy AlCuMg. The experiments were made on the equipment, which is demonstrated in Figures 3 a, b [5]. The contents of individual elements in the alloy corresponded approximately to the standard. Original input examples were made of hot-formed semi-products. Square section of the input samples was 8 x 8 mm. The samples were extruded at the temperature of approx. 20°C. In order to increase deformation in the volume of the sample, the samples were turned after each internal extrusion around the longitudinal axis by 90° and extruded again.

a) b)

Figure 3 a) Overall view of the forming equipment and die
b) Detailed view of the extruding punch for ECAP process

The average grain size in cross direction was determined by quantitative metallographic methods. It varied around 150 μm. The basic mechanical properties were determined by tensile tests: strength R_m = 220 MPa, ductility A_5 = 15 % and hardness HB (2,5/62/30) ~ 70.

4. OBTAINED RESULTS AND THEIR ANALYSIS

In order to increase efficiency of plastic deformation and its influence on properties of structure of the used alloy, the samples passed at extrusion by the ECAP method repeatedly through a rectangular channel. After individual passes there occurred accumulation of deformation strengthening. So e.g. at extrusion with the radius of rounding of inside edges (R = 0,1 až 0,4) the initial deformation resistance varied in the range of approx. σ_{max} = 650 MPa and it increased gradually in such a way, that at the fourth extrusion it achieved the value of σ_{max} = 1050 MPa. Deformation resistance at extrusion through a die with smaller radii of rounding achieved at the first extrusion the values around σ_{max} = 780 MPa, and at the third extrusion the values of σ_{max} = 1560 MPa [5] .

5. CONCLUSIONS

1. The ECAP process is an efficient tool for refining of grain in poly-crystalline metals. These procedure makes it possible to obtain e.g. in pure aluminium the grain size of approx. 1 μm [5].
2. The micro-structure obtained by the equal channel angular pressing depends on individual experimental conditions:

   (a) for obtaining of an optimum micro-structure it is necessary to use more passes and turning of the sample between the individual extrusions by angle of 90° in the same sense of rotation

   (b) it is advantageous to extrude by at least 4 or more passes in order to obtain high-angle boundaries of sub-grains.
3. The most suitable angle between horizontal and vertical part of the extrusion channel varies around 90°. Radii of rounding of the working parts of the extrusion channel must correspond to conditions for steady flow of metal.
4. Extrusion speed in the range of strain rates $\dot{\varepsilon} = 10^{-2} \div 10^{-1} s^{-1}$ has only partial influence on deformation resistance, and comparatively small influence on micro-structure.

6. ACKNOWLEDGEMENT

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