NEW GEOMETRY OF ECAP CHANNEL

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NOVÁ GEOMETRIA ECAP KANÁLA

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Abstrakt

Na tvorbu ulrajemnej štruktúry (UFG) štruktúr pomocou intenzívnych plastických deformácii bolo vyvinutých viacero spôsobov. Equal channel angular pressing (ECAP) metóda patrí medzi najvýznamnejšie IPD metódy, vďaka jej jednoduchosti a produktivite omnoho väčších vzoriek než u ostatných. ECAP metóda prešla rozsiahlym konštrukčným vývojom, ktorý sa fokusoval na zníženie kontaktného trenia a na zvýšenie intenzity plastickej deformácie na jeden prechod. Konštrukčné zmeny boli zamerané na zmenu uhla medzi kanálmi, na pohyb jednotlivých stien ECAP matrice a na viacnásobné zalomenie kanála v rámci jednej ECAP matrice. Konštrukčné zmeny tvárniacich nástrojov je možné realizovať pomocou numerických simulácii v rôznych softvérových produktov. Distribúciu a intenzitu φ_{ef} v ECAP procese je možné geometricky ovplyvniť uhlom Φ, uhlom ψ a geometrickým tvarom priečneho prierezu vzorky. Najčastejšie používaný priečny prierez je kruh a štvorec, taktiež obdĺžnik, prípadne iné tvary ktoré sa približujú k finálnemu tvaru výrobku. Predmetom príspevku je konštrukčný návrh (modifikácia) ECAP kanála a jeho funkčné overenie pomocou numerických simulácii v softvérovom programe Deform 3D. Modifikácia ECAP kanála využíva obdĺžnikový tvar priečneho prierezu vzorky, ktorý umožňuje zmenu v orientácií priečneho prierezu medzi vstupom a výstupom z matrice. Z numerických simulácií vyplýva, že v modifikovanom ECAP kanále je distribúcia φ_{ef} oveľa vyššia a s vyššou homogenitou ako v klasickom ECAP kanále (kruhový, pravouhlý priečny prierez), pretože kov pri pretlačovaní tečie v zóne plastickej deformácie dvoma smermi v osovom a radiálom.

Abstract

For generation of ultra fine grained (UFG) structure by intensive plastic deformation (IPD) several ways have been developed. Equal channel angular pressing (ECAP) method is one of the most important methods of IPD, thanks to its simplicity and productivity of much larger samples than others. ECAP method has undergone extensive design development, which was focused on the reduction of contact friction and on the increase of the intensity of deformation during one pass. Design changes were aimed at change of the angle between the channels, the movement of each ECAP die wall and multiple crank of channel within a single ECAP die. Design changes of shaping tools can be implemented using numerical simulation in various software products. Distribution and intensity φ_{ef} in the ECAP process can be geometrical affected by the angle Φ, ψ angle and by geometric shape of a sample cross-section. The most commonly used cross-section is a circle and square, also a rectangle or other shapes that are close to the final shape of the product. The subject of paper is the engineering design (modification) of ECAP channel and its functional verification using numerical simulation in the software product Deform 3D. Modification of ECAP channel uses a rectangular cross-sectioned sample, which allows a change in cross sectional orientations between input and output of the matrix. The numerical simulations show that for the modified ECAP channel distribution of φ_{ef} is much higher and more homogeneous than for conventional ECAP channel (circular, rectangular cross-section) because the extruded metal is flowing in the zone of plastic deformation in two directions, in axis and radially direction~~s~~.

Keywords: ECAP, numerical simulation, effective strain

1. Introduction

ECAP as one of „the most effective" Severe Plastic Deformation (SPD) method [1 to 5] has undergone several constructive changes, or modifications since its origin. Segal [1] dealed with the friction between sample and ECAP channel. To reduce the friction he suggested ECAP matrix with floating wall on the outside of the output channel and the outside of the entrance channel. Markushev et al. [2] patented "passing through a narrow outlet channel", in which there is a reduction of cross sectional samples and increased plastic deformation. Stecher and Thomas [1] presented a ECAP matrix equipped with cylindrical surface, which replaces the outer wall of the exit channel and reduces friction. Design modifications that improve the performance of ECAP equipment are very important for industrial application [3]. Direct entry of samples into multiple successive channels at different angle Φ increases plastic deformation in one ECAP pass. Such shape of ECAP die may be S-shaped curve (which is equivalent to route C), or U-shaped curve (which is equivalent to rout A). Using the multiple crank of ECAP channel leads to increase~~s~~ of the extrusive force on one pass, but considerably there is an increase in ECAP equipment productivity. To reduce manual operation between the individual passes special multifunctional ECAP matrix called "rotary ECAP die", in which the sample is extruded through a matrix of four mutually perpendicular channels in one plane, was proposed. The same sample is alternately extruded beyond that channels [4]. Distribution and intensity of φ_{ef} in the ECAP process can be affected by the three main geometrical parameters: (1) angle Φ, (2) angle ψ, or inner r and outer R radius, (3) geometric shape of a sample cross-section. The first and second parameter is now fairly well described and technically controlled. The most commonly used form of a sample cross-section is a circle, a square or a rectangle. The importance of the rectangle was described in works [6 to 8] as a way to ensure geometric semi pretreatment of a specific constructive application. In that description the sample with a rectangular cross-section was extruded through a channel that did not alter its shape or orientation of a cross-section~~al~~. Sample with a rectangular cross-section can be defined as the “blockstone” with dimensions $a \neq b \neq l$. Extrusion of sample in the form of “blockstone” allows you to use another dimension, a cross-sectional orientation of the input to output transverse section. The proposed modification of the ECAP channel uses unsymmetrical shape of a sample~~s~~ cross-section, permitting a change in cross-sectional orientations between input and output of the matrix. In **Fig. 1** a modified ECAP channel scheme is shown. Rectangular sample with cross-section a x b changes its orientation during extrusion to the plane in which lies the vertical and horizontal axis of channel to b' x a'.

Flow of metal in the modified ECAP channel is different from the flow of metal in classical ECAP channel, because the deformation zone is changing orientation of a cross-section *a* x *b* to *b'* x *a'*, while the material flows in the forward and transverse direction relative to the output of the horizontal channel. Such extrusion increases the intensity of deformation φ_{ef}, extruded sample is getting the original shape, allowing the extrusion process to be repeated. ECAP channel geometry can be constructed in two versions:

a) model 1 - cross-section of input channel is defined as: $a < b$ a and output $a´ > b´$

b) model 2 - cross-section of input channel is defined as: $a > b$ and output $a´ < b´$.

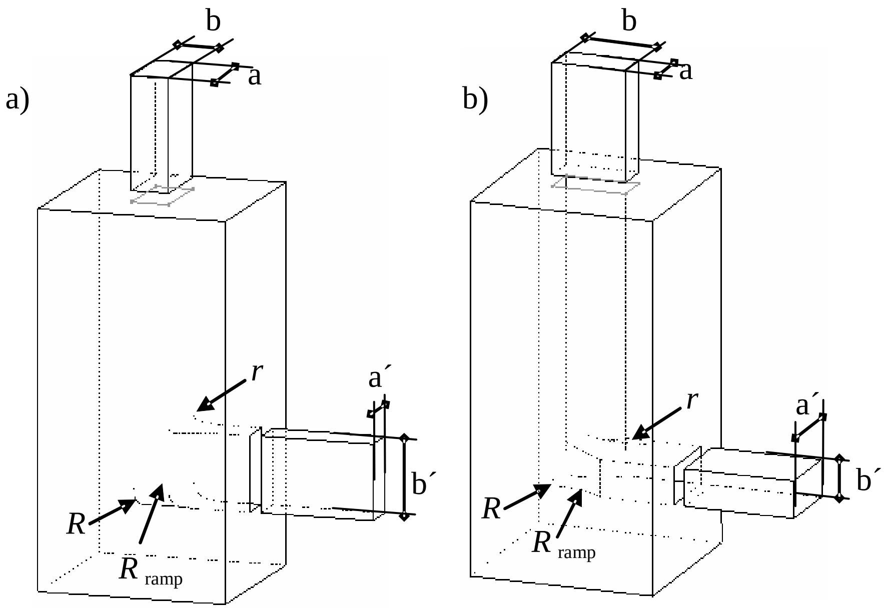

Fig.1 Scheme of modified ECAP channel, for: a) model 1 and b) model 2

2. Numerical simulation and results

The functionality of the modified ECAP channel was tested using numerical simulations in program Deform 3D. Numerical simulations were constructed for both geometries according to the scheme of **Fig. 1**.

The sample was defined as a plastic object with high-purity aluminum material characteristics. The size of the sample was a = 5 mm, b = 10 mm and l = 60 mm Fig. **2a**. Geometry of the sample was described by FEM mesh with 30000 elements. In **Fig. 2b** is displayed ECAP matrix, where a = 10 mm and b = 5mm, R = 2 mm, r = 2 mm and radius of the ramp connecting the vertical channel with horizontal channel is R_{ramp} = 15 mm. In **Fig. 2c** is displayed ECAP matrix, where a = 5 mm and b = 10mm, R = 2 mm, r = 2 mm and R_{ramp} = 15 mm. Ram and ECAP matrix are defined as solid objects. The process of extrusion was simulated at 20 °C with extrusion rate 1 mm.s^{-1}. Friction conditions between matrix channel, ram and sample were defined by *Shear* model with a coefficient of friction f = 0.12 [-] which is responsible for the cold forming tool steels.

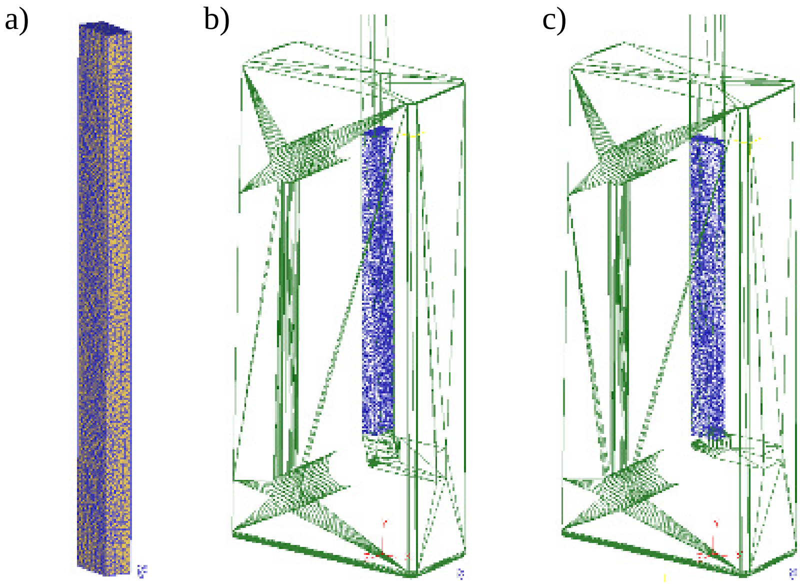

Fig.2 Geometry and mesh: a) workpiece; b) matrix of model 1; c) matrix of model 2.

2.1 Analysis of numerical simulations by a modified ECAP channel the first model

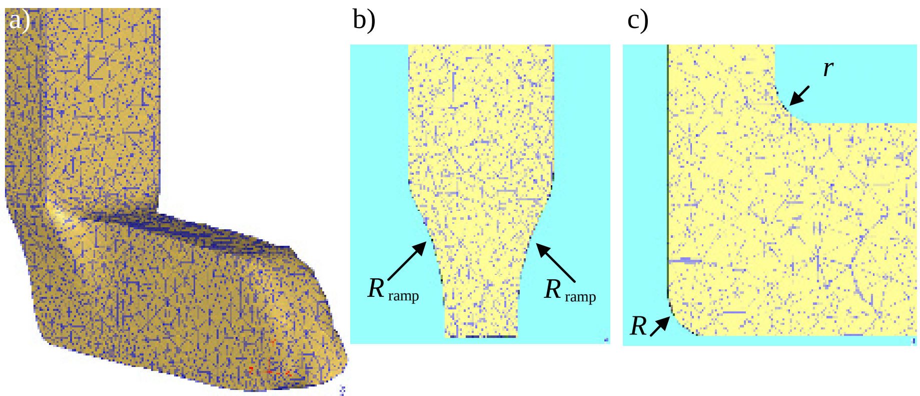

Fig.3 The filling of modified ECAP die: a) the sample is in the process of extrusion b) cut along the vertical matrix channel, c) cut along the horizontal matrix channel.

Fig. 3 shows the filling of a modified ECAP channel. The figure shows that the channel is completely filled with extruded material, which makes the sample obtain the original shape. Distribution and intensity of plastic deformation φ_{ef} across cross-section of the sample is shown in Fig. 4, where the increase can be seen along the length of the sample (**Fig.4a**) from φ_{ef} = 1.9 [-] to φ_{ef} = 2.5 [-]. The graphical dependence shows that the distribution of φ_{ef} measured across the sample thickness of the bottom-up is in the front and the body of sample spread very evenly, where $\Delta\varphi_{ef.\ max.} \approx 0.07$ [-]. Also across the width of the sample (**Fig. 4b**) in the bottom, middle and upper part a high homogeneity of φ_{ef} can be observed. Where $\Delta\varphi_{ef.\ max.} \approx 0.004$ [-] which is completely a negligible value.

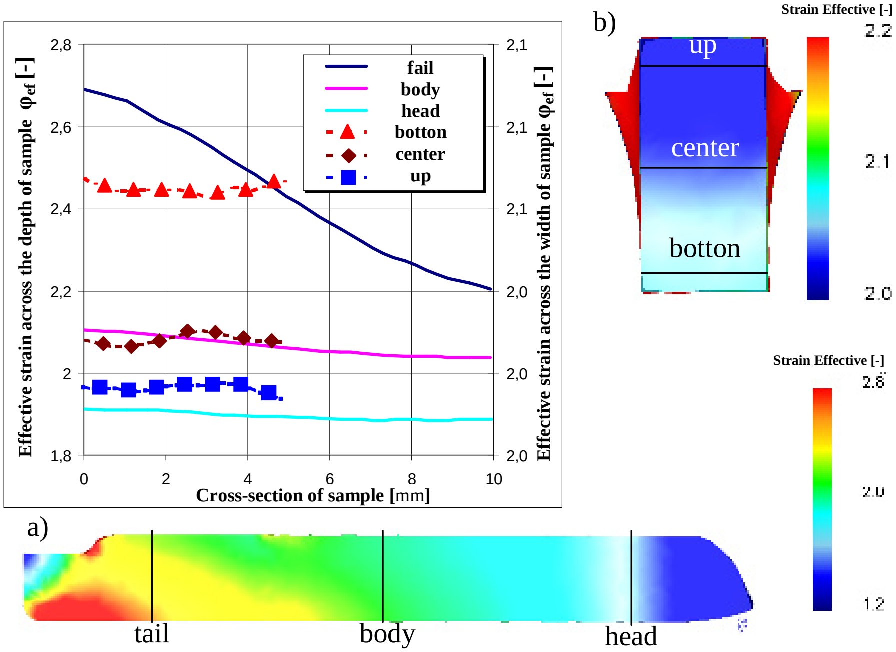

Fig.4 Distribution intensity of plastic deformation on a) longitudinal section of the sample, b) cross section of the sample in the sample body

2.2 Analysis of numerical simulations by a modified ECAP channel the second model

Fig. 5 shows the filling of a modified ECAP channel. The figure shows that the channel is not completely filled with extruded material, which means that the sample does not acquire the original shape.

Distribution and intensity of plastic deformation φ_{ef} on transverse and longitudinal section of the sample is shown in **Fig. 6**. The figure shows that the distribution of φ_{ef} along the length of the sample (Fig. 6) increases from φ_{ef} = 1,6 [-] up to φ_{ef} = 2,5 [-]. Distribution of φef across the thickness and width of the sample is in the front and the body of sample evenly distributed, where $\Delta\varphi_{ef.\ max.} \approx 0.1$ [-].

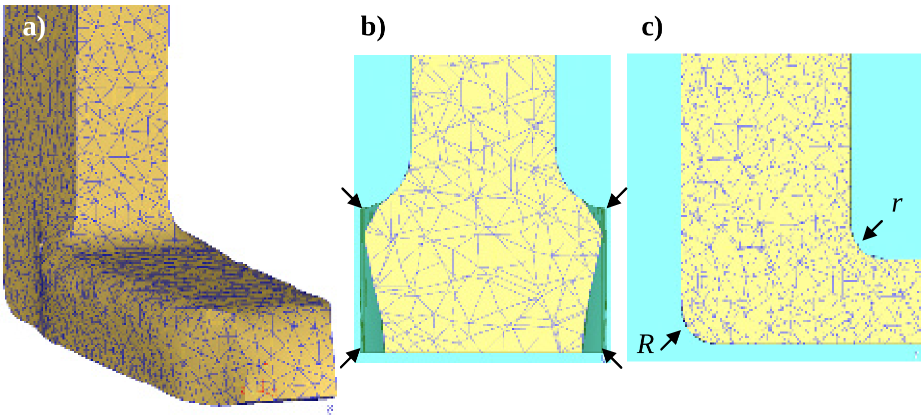

Fig.5 The filling of modified ECAP die: a) the sample is in the process of extrusion b) cut along the vertical matrix channel, c) cut along the horizontal matrix channel

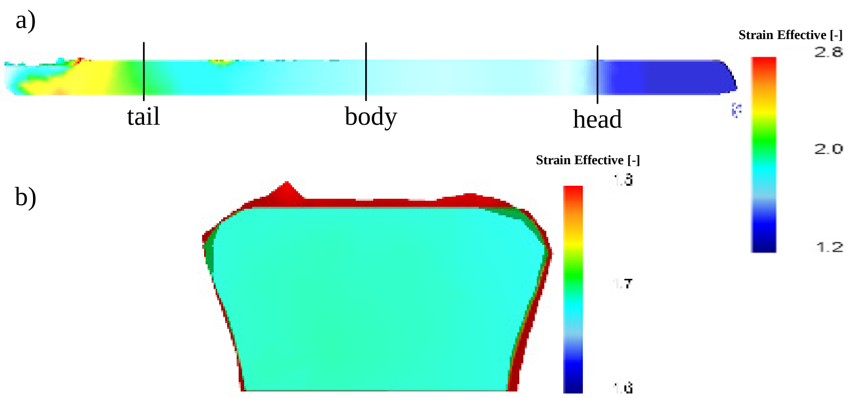

Fig.6 Distribution intensity of plastic deformation on a) longitudinal section of the sample, b) cross section of the sample in the sample body.

3. Conclusion

From these numerical simulations for both modified ECAP channels results that φ_{ef} intensity of plastic deformation is much more higher and homogeneous than in classical ECAP channel (circular, rectangular). In ECAP matrix with circular cross-section cumulated effective deformation in samples after the 1st pass is $\varphi_{ef} \approx 1{,}1$ [-] [9]. Higher values for the plastic deformation are caused by the extruded metal flowing in the zone of plastic deformation in two directions (the axial and radial). The practical importance has only the geometry model 2 because extruded material perfectly fills the channel matrix and the sample obtains the original shape, allowing the process to be repeated several times. This geometry of the ECAP channel is much more favorable than the geometry of circular or square cross-section because by a single pass higher and more homogeneous plastic deformation intensity φ_{ef} is achieved.

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