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Refining of structure of the alloy AlMn1Cu with use of multiple severe plastic deformation

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Analysis and modelling

ABSTRACT

Purpose: Substance of the investigated issue is analysis of the obtained medium grain size, mechanical properties and formability of the alloy AlCu1Mn by the process of multiple severe plastic deformation.
Design/methodology/approach: Comparison of results obtained by pressing through the classical channel geometry and through the channel with modified geometry.
Findings: This alloy is used for manufacture of strips. Obtaining of the required grain refinement during initial forming operations will substantially change the existing production technology and increase its efficiency.
Research limitations/implications: Increase of amount of deformation will fundamentally increase efficiency of the process of multiple severe plastic deformation.
Practical implications: New findings will be applied into production technology at the company AlInvest Bridlicna, Czech Republic.
Originality/value: New solution of geometry of the ECAP channel is original, as well as findings, which will be used at severe plastic deformation".
Keywords: Computational material science; Process severe plastic deformation; Geometry of the ECAP tool; Alloy AlCu1Mn; Structural analysis; Analysis of basic mechanical properties.

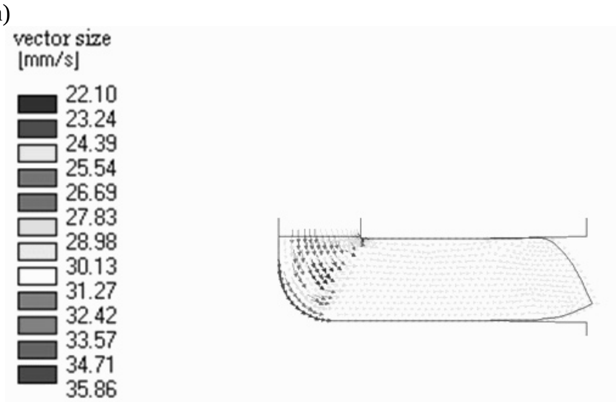
1. Introduction

1.1. Classical geometry of the ECAP tool

In the first stage an influence of the tool geometry on obtained degree of intensity of amount of deformation (effective strain) of the available alloy AlMn1Cu at the first and the second pass through the ECAP tool was verified by simulation with use of the software FormFem in a 2D space. At the same time influence of magnitude of the radius R1 on non filling of the tool with material at the channel arc was analysed [1,3,10] . Figure 1 shows as an example the analysis of the vector of material in the channel of the ECAP tool flow rate from the viewpoint of documentation of non filling of material at the place, where vertical part of the channel passes to the horizontal part.

Next, another example show influence of the change of the outer radius of the channel (R1) on obtained magnitude of effective strain at the first pass of the sample through the ECAP channel. Influence of the radius R1 was not analysed, since according to all accessible literature references its value can be minimal and it does not influence the forming process as such. For this reason the value R1 = 0.2 mm was chosen as the constant value. On the Fig. 2 is summarise the obtained values of the effective strain $\varepsilon_{i,}$ as the main factor influencing the extent of grain fragmentation after individual passes of the sample through the ECAP channel with different radii R1 and identical angles ϕ and ψ obtained by mathematical simulation

a)



b)

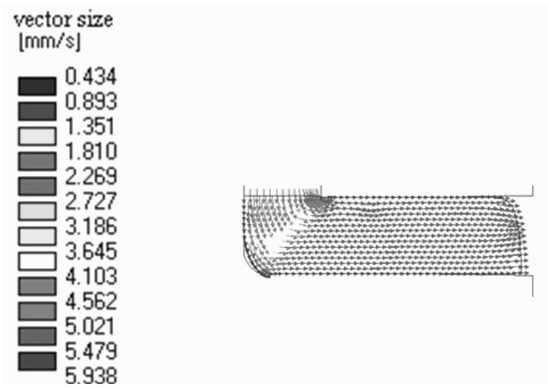


Fig. 1. Development of magnitude of the vector of material flow rate
a) for radii of the channel R1 = 5.5 mm, R2 =0,
b) for radii of the channel R1 = 2.4 mm, R2 =0,2mm

The following values of the forming parameters were achieved: Vector of material flow rate for radii R1 = 5.5 mm, R2 = 0.2 mm, with tool angles ϕ= 90 °,ψ = 90°, achieves the value - v = 28.98 mm.s-1.

For radii R1 = 2.4 mm, R2 = 0.2 mm with tool angles ϕ = 90°, ψ = 90°, the vector of materials flow rate achieves the value - v = 5.021 mm.s-1. Non-filling of material is caused by incorrect selection of the rounding angles of transitions of the tool channel (Table 1).

Table 1.
Simulation of non-filling of material

Magnitude of non-filling of material in the channel with radii R2=0.2 mm and R1=2.4 mm	Magnitude of non-filling of material in the channel with radii R2=0.2 mm and R1=5.5 mm [
0.398 [mm]	0.106 [mm]

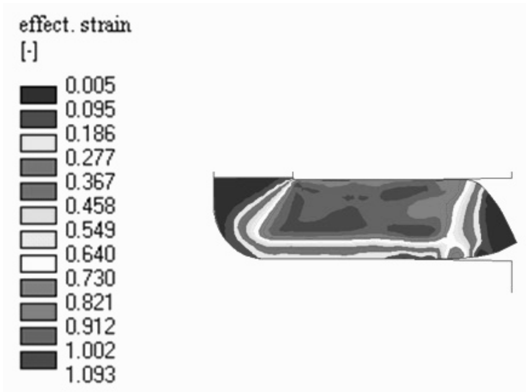
2. Deformation – strained condition at various geometry of the ECAP tool

It was proven from the development of the values of the effective strain, that the values εi are higher at the smaller radius in comparison to those at the bigger radius.

Resulting value of the strain intensity for the radius R1 = 5.5 mm, R2 = 0.2 mm, with tool angles ϕ = 90°, ψ = 90°, is ε_i= 1.080.

For the radius R1 = 2.4 mm, R2 = 0.2 mm, with tool angles ϕ = 90 °, ψ = 90°, the average value of the effective strain after the first pass of the samples through the ECAP tool is εI = 1.150. The inner radius R2 = 0.2 mm is identical for both channels. Figure 2 shows the results obtained by simulation,

a)



b)

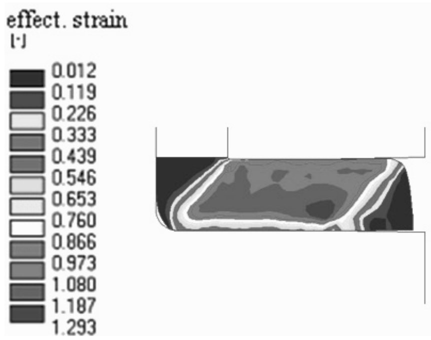


Fig. 2. Development of the effective strain, a) for the channel radii R1 = 5.5 mm, R2 = 0.2mm, b) for the channel radii R1 = 2.4 mm, R2 = 0.2mm

2.1. Influence of the negative angle Φ on the obtained value of the deformation intensity at individual passes obtained by mathematical simulation.

Figure 3 fives as an example the values of the effective stress and strain at the 1st pass through the ECAP tool.

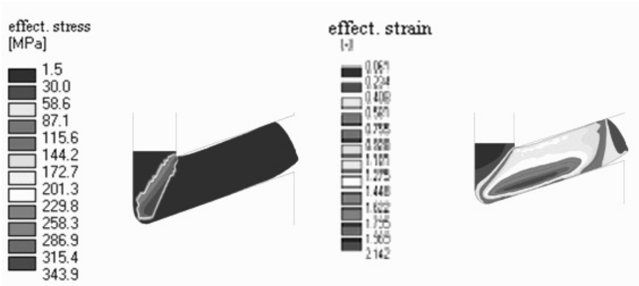


Fig. 3. Development of the effective stress and strain at negative angle ϕ

The following findings resulted from mathematical simulations followed by experiments with the channel geometry of the ECAP tool:

- If the rounding radius of the channel R1 is reduced from 5.5 mm to 2.4 mm, effective strain εi slightly increases from 1.080 to 1.150 (see the Fig. 2).
- If the angle ϕ is changed (increased), effective strain decreases approximately by 10% after each pass. Material flow is at the same time more fluent, which creates a pre-requisite for use of the bigger angle for materials that are difficult to form [4,5,6].
- When smaller outer radius of channel rounding was used R1 = 2.4 mm, the sample was during experiments ruptured at the 4th pass through the tool, i.e. the magnitude of the amount of deformation required for expected refining grain was not achieved.
- When so called "negative" angle ϕ was used (75°), mathematical simulation showed that there occurred substantial increase in effective strain ε_i at individual passes. The given channel geometry can be used only for easily formable of the type of pure Al or Cu [2,7,8,9]. In other materials deformation strain steeply increases and hence also load of the tool, which leads to its rupture.

3. Proposal of the new concept of the ECAP tool from the viewpoint of increasing of the amount of deformation at the first pass of material through the ECAP tool

Proposal of new geometry of the forming tool was based on results of experiment with simulation of homogeneity of distribution of the sample deformations in its volume during the ECAP forming, realised at the VSB-Technical University of Ostrava. Design of the new tool for the given technology was prepared on the basis of results obtained with the classical geometry. This concerns first of all change of route of deformation at the first pass through the ECAP channel [10,11,12]. It results in increased amount of deformation leading to higher refining of grain and therefore to overall enhancement of efficiency of the process of multiple severe plastic deformation. Change of design concerns the horizontal channel, which is deflected by 10° and 20° in respect to the horizontal axis.

a) b)

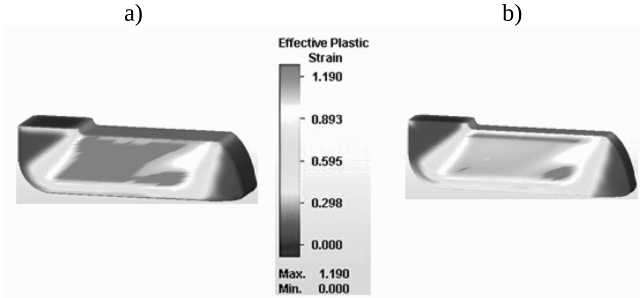
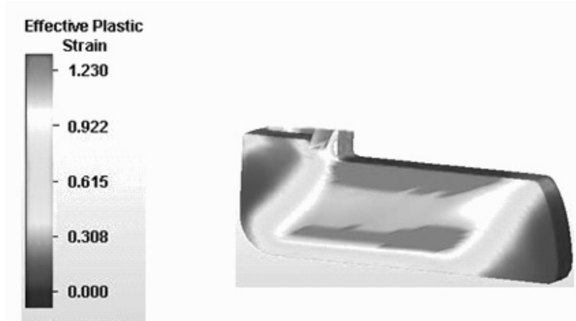


Fig. 4. Comparison of the obtained amount of effective strain and homogeneity of distribution of deformations from the sample edge to its central part, a) at the sample edge, b) at the sample central part

a)



b)

c)

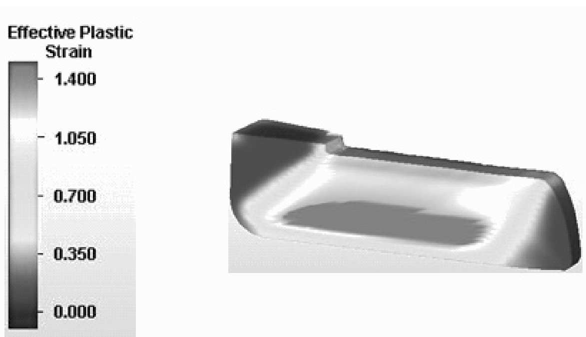


Fig. 5. Development of the effective strain, a) without the channel axle offset, b) with the channel axle offset by 10°, c) with the channel axle offset by 20°

It was unequivocally proven by comparison of the deformation intensity for the radius R1 = 5.5 mm, R2 = 0.2 mm, with tool angles ϕ = 90° and ψ = 90° in the program SuperForm, that at the sample edge, where material contacts the tool, the zone of deformation is distinctly bigger than at the cross section of the sample at the half of its width after pressing (see the Fig. 4 a, b), at identical value of the effective strain $\varepsilon_I = 1.19$. The obtained results of the amount of deformation confirm unequivocally the influence of friction forces in the channel lateral walls on distribution of deformation [11,12,13,14]. During experimental works it will be necessary to further modify the channel geometry, namely by relief of the lateral walls approx. by 1° in horizontal direction.

On the basis of these results design of new geometry of the pressing channel of the ECAP tool was developed (see the Figure 5 a, b, c, Table 2).

Table 2.
Effective strain at different ECAP channel axle offset

Axle offset of the output part [°]	Deformation intensity [-]
0	1.23
10	1.25
20	1.4

4. Conclusions

It was proven with use of mathematical simulation (program Superform), that deflection of the channel in the horizontal part leads to significant increase in deformation intensity at the first pass of the sample through the ECAP channel.

For the purposes of experimental confirmation of the results of mathematical simulation new design of the ECAP tool was prepared and afterwards new inserts into the ECAP tool with the given axle offset were manufactured. Future research will be realised particularly with stress on enhancement of the efficiency of the process of severe multiple plastic deformation.

Acknowledgements

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