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DAMAGING OF AL-MG ALLOYS SEVERELY PLASTIC DEFORMED BY EQUAL CHANNEL ANGULAR PRESSING

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Abstract: *The evolution of damaging for a difficult-to-work Al-Mg alloy during Equal Channel Angular Pressing (ECAP) was investigated. Conducted most expeditiously at room temperature, using a die with a channel angle of 90°, the ECAP may lead to the cracking of the billet. Finite Element Analysis (FEA) was performed for three different die designs to study the influence of die geometry on billet damaging. The results show that cracking may be reduced or eliminated by inner fillet corner of the die channels. It is demonstrated that the predicted results are in good agreement with experimental date obtained for 5052 aluminum alloy.*

Keywords: *damage, deformation, simulation, aluminum*

1. INTRODUCTION

ECAP is one of the main processing techniques to produce ultrafine-grained materials. In ECAP, a billet is pressed through a die that contains two equal cross-sectional channels meeting at an angle ϕ, with or without fillet corner corresponding to an angle ψ (see Fig.1). Because the cross-section of the billet remains the same during extrusion, the process can be repeated until the accumulated deformation reached a desired level.

Obviously, achieving a large amount of strain during ECAP is essentially for grain refinement. The material must withstand repeated high strains, without cracking. Unfortunately there are no criteria which ensure a guaranteed successful SPD process. A good workability of the material is a necessary condition but not sufficient. Inherent failures of ECAP if not made a correct process design were reported, especially billets damages due to the cracking on their upper surfaces (Kim, 2006). As the microstructure and the mechanical properties of the severely plastic-deformed material are directly related to the deformation, most researches are focused on deformation behaviour in terms of strain distribution or working load level (Li et al., 2004). There is lack of systematic studies to understand damaging in ECAP

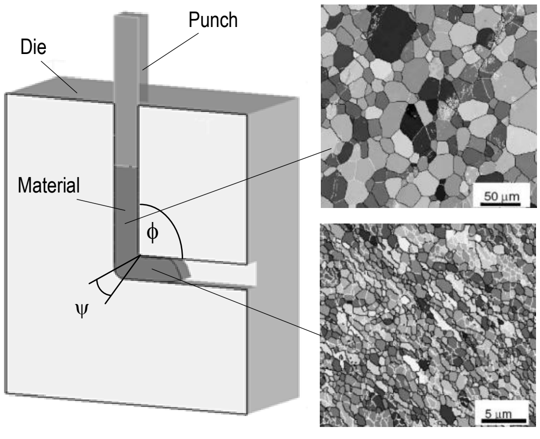

Fig. 1. Principle of ECAP, die geometry and refinement of the structure by severe plastic deformation (SPD)

In this paper, a FEA is performed to evaluate the damage during ECAP, depending on die geometry and process parameters. The results of damage prediction were confirmed by experimental data for AA5052. In the future, we must optimise the die designs using damaging analysis in order to accurately predict the material behaviour in SPD processes.

2. MATERIAL AND PROCEDURE

A commercial non heat-treatable AA5052 with a composition, in wt.%, of Al-2.8%Mg-0.2%Cr was used in experiments. Specimens with dimensions of 10x10x60mm were machined from as-received alloy. The experiments were conducted at room temperature with a ram speed of 8.75mm/s, using dies with channel angle ϕ of 90° with and without fillet corner of the channels.

Commercial finite element code DEFORM 3D was used for the simulations. The workpiece was discretized in 8000 tethraedral elements. The friction coefficient 0.12, Poisson's ratio 0.33, and Young's modulus 69GPa together with isotropic strain hardening of the material were assumed. The tolerance, positioning of the workpiece and top/bottom die, convergence criteria, re-meshing conditions, and boundary conditions were specified before the execution of the simulation process.

Three design scenarios are analyzed by FEA to reveal the deformation behaviors and their relationship with the design configuration (90_R_r, where R and r are outer and inner corner radius of the two die channels, respectively):

A – die with no arc transition R, r = 0 mm; (90_0_0)

B – die with outer arc transition R = 4 mm; r = 0 mm (90_4_0)

C - die with inner arc transition R = 0 mm; r = 2 mm (90_0_2).

To estimate the damage, the Cockcroft-Latham model was used. According to this model, a damage factor (D_f) is defined by the following relationship (Figueiredo et al., 2007):

$$D_f = \int_0^{\bar{\varepsilon}_f} \frac{\sigma_T}{\bar{\sigma}} d\bar{\varepsilon} \qquad (1)$$

where σ_T is the maximum principal tensile stress, σ^- is the effective stress, $d\varepsilon^-$ is the effective strain increment and the integral is evaluated from zero strain to the final effective strain, ε^-_f. The effective strain for one ECAP pass is (Iwahashi et al., 1998):

$$\bar{\varepsilon} = \frac{1}{\sqrt{3}}\left[2\cot\left(\frac{\phi}{2}+\frac{\psi}{2}\right) + \psi\csc\left(\frac{\phi}{2}+\frac{\psi}{2}\right)\right] \qquad (2)$$

where the significance of terms is revealed in Fig.1.

This form of the Cockcroft–Latham relationship is generally considered to provide a good prediction of the fracture of metals during ECAP.

To determine the critical damage D_f^* corresponding to the failure of the material, a compression test was performed for AA5052. It reveals that accumulated damage at failure was $D_f^* = 0.310$. When D_f exceeds D_f^*, the cracking takes place.

3. RESULTS AND DISCUSSIONS

Using damage factor (D_f), as defined in Eq. (1), Fig.2 shows damage distributions for the three scenarios. The highest level of damage (0.850) corresponds to 90_0_0 die. Outer fillet corner of the die channels (90_4_0 die) determines only a small decreasing of maximum damage (0.654). A significant change takes place for inner fillet corner of the die channels (90_0_2 die) when the level of damage down to the value of 0.230, due to increasing compressive deformation component (Yoon & Kim, 2008).

In accord with failure condition ($D_f > D_f^*$), the damage should appear for the first two cases (A and B). Indeed, experimental data confirm this hypothesis. Fig.2 shows massive billets segmentation on upper surfaces of the billets for 90_0_0 and 90_4_0 scenario.

The nature of cracking on upper surfaces of the billets can be depicted from stress distribution. As it is shown in Fig.3, the maximum principal stress was registered on the upper surface of the billet. Furthermore, stress distribution gives an understanding of Cockcroft–Latham model. As we can see from Fig.3, the outer arc transition between channels increases σ_T (187MPa) but the damage factor slowly decreases from 0.850 to 0.654. In opposition, inner arc transition between channels both decreases σ_T (91.4MPa) and D_f (0.230). Regarding σ_T, between 90_0_0 and 90_0_2 scenario, small differences are registered, but material behavior is dramatically changed. This means that σ_T itself is not an absolute damage criterion, while normalized σ_T/σ^{-} gives the real measure of the failure in ECAP. In this way, the maximum principal stress distribution gives the explanation of cracks on upper surfaces of the billets (Figueiredo et al., 2007).

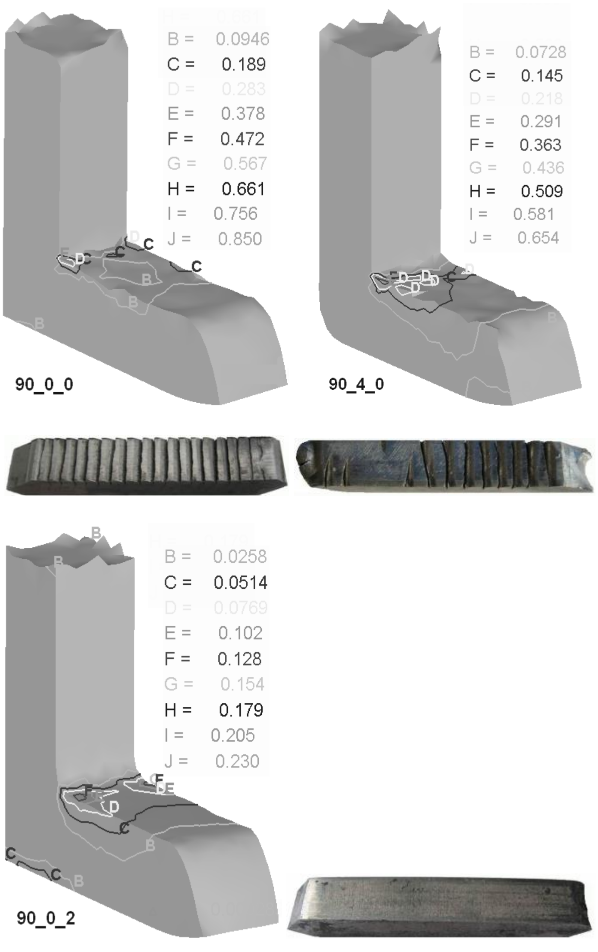

Fig. 2. Damage distribution and failure of specimens in ECAP

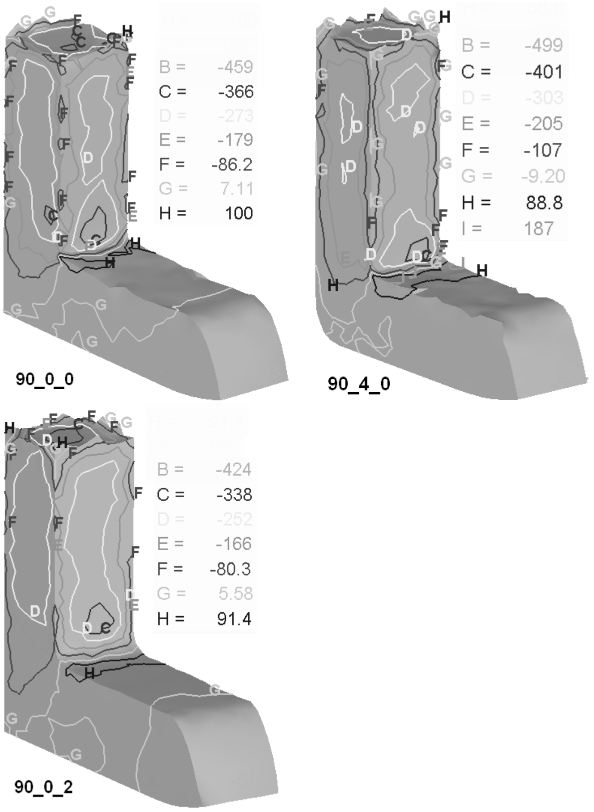

Fig. 3. Stress distribution for the three ECAP scenarios

4. CONCLUSIONS

The evolution of damage during ECAP of 5052 Al-Mg alloy was investigated by FE simulation. The damage was studied for different tool designs.

It was found that inner fillet corner of the die channels has the most significant influence on damaging in ECAP. The results were confirmed by experiments. It is also explained the cracking of the billets by stress distribution on upper surfaces of the workpieces. The paper leads to more accurate design of the dies taking into account the material behaviour according to the predict damage. The next step in our research plan will be to correlate the results of damaging prediction with process design to ensure the success of severe plastic deformation.

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