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STRAIN DISTRIBUTION IN ECAP PROCESS WITH VARIOUS FRICTION CONDITIONS – NUMERICAL MODELLING

1. INTRODUCTION

Forming methods based on large plastic deformation (SPD – Severe Plastic Deformation) makes possible to get metal samples with strongly size reduced microstructure, which are ready to further processing. Such materials are characterized by high mechanical properties with high ductility and crack resistance (in fragile materials case) kept [1].

In this paper was analysed friction influence on distribution and value of effective strain [2, 3] in ECAP (Equal Channel Angular Pressing) method deformed samples, which consists in pushing metal by angular channel die with specified shape. Tools were designed in that way, to obtain in one forming treatment four material pathways (according to C model [1]) through channel die bend: A, B, C and D (Fig. 1). There was settled that ECAP process parameters that may control are friction factor, pathway number and distance between channel die bends.

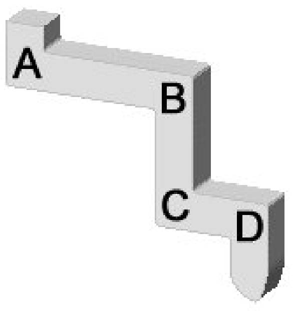

Fig. 1. *The shape from ECAP process: A, B, C, D – bends of die channel*

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2. NUMERICAL CALCULATIONS

For numerical calculations were used commercial programme QForm2D/3D based on finite elements method and plastic flow theory. Initial stock temperature was equal 1100 °C, tools temperature 500 °C and punch velocity 50 mm/s. Physico-chemical properties of deformed metal were accepted according to data for unalloyed steel 0.2% C contains, visco-plastic body model was taken into consideration [3]. Channel's die cross-section was accepted as square with 10 mm side and constant on whole length. Internal and external radius of all bends are equal 1 mm. The die construction enables four bends A, B, C and D about 90° angle in each channel, according to Figure 2. Length of following channel die is reduces about cross-section side width. To evaluation of friction influence on strain distribution in used deforming method were accepted three values of friction factor: 0.05, 0.4 and 0.8. Numerical calculations were done with assumption of plane strain state.

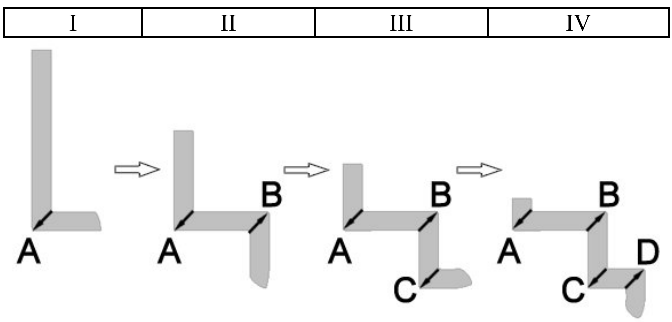

Fig. 2. *ECAP process stages: A, B, C, D – bends of die channel*

Friction factor influence on effective strain distribution and value was studied. Effective strain measurements were done in points lying along channel die bend angles bisectors A, B, C and D, separately for four process stages (Fig. 2). For each angle ten values of effective strain were read out. Selection and numeration idea of following points is shown in Figure 3a (bends A and C) and Figure 3b (bends B and D).

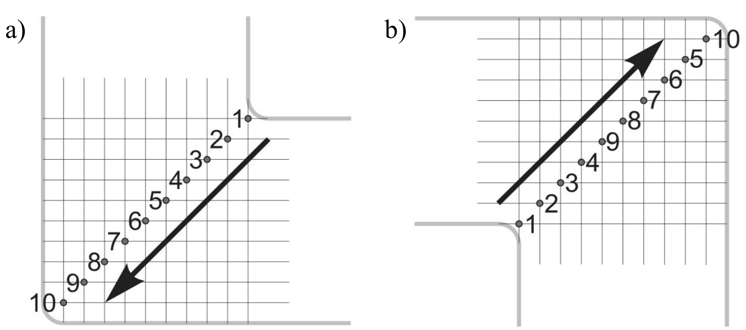

Fig. 3. *The position of measuring points to bends of die channel: A and C (a) and B and D (b)*

3. ANALYSIS OF NUMERICAL CALCULATIONS RESULTS

In discussed ECAP process various factors are friction conditions and channel length. On effect of deformation process in each following channel bent to previous about 90^{o} angle also has influence the number of previous bends. Calculations results which take to account above dependences are presented in Figures 4 to 8.

In Figure 4 is shown the local effective strain distribution in cross-section, which characterize accepted principle of getting ECAP process effect. To assign the effective strain values, cross-section on boarder of two adjacent channels was choosen. It is make strain values comparison possible in following process stages in relation to various boundary conditions. The maximal values in particular stages and for specified die bends A, B, C and D are localized between 6 and 9 measure points at friction factor m = 0.05 and m = 0.4. For the lowest friction factor effective strain is relatively uniformly splitted on diagonal length. Friction factor increase causes increase of effective strain gradient, what the most visible is in B cross-section, specially for friction factor m = 0.8.

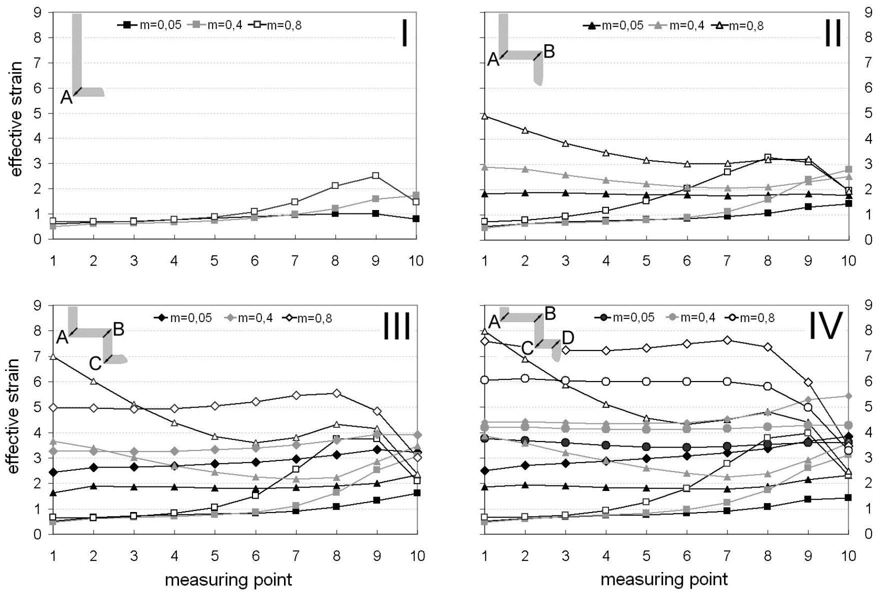

__Fig. 4.__ Value of effective strain in ECAP process: I, II, III and IV – stage of the process (according to Fig. 2). A, B, C, D – bends of channel die

The most strain uniformity, at simultaneously the lowest effective strain value occurs at friction factor m = 0.05 and kept up on almost stable level in all four ECAP process stages. In real ECAP process friction factor is equal about m = 0.4. The numerical calculated distribution of effective strain in bend A in following process stages, for this value of friction factor is shown in Figure 5. In all process stages at friction factor m = 0.4 effective strain to half of diagonal plane distribute uniformly. Near external surface in stage I sets on 1.7 level and increase about twice for II, III and IV process stages.

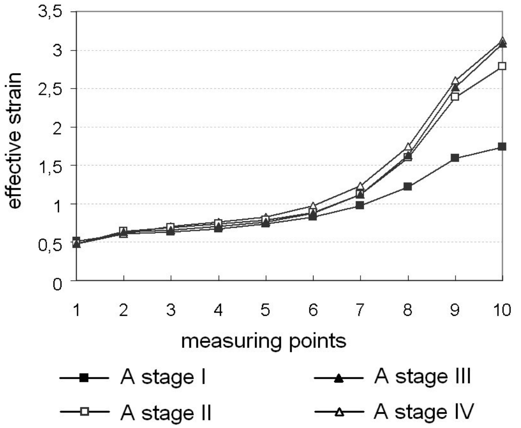

Fig. 5. *Effective strain distribution in A bend in following process stages for friction factor m = 0.4*

In Figures 6–8 is shown the effective strain distribution in particular stages of ECAP process. This distribution in more uniformity for calculations with friction factor equal *m* = 0.05 (Fig. 6). Friction increasing results in effective strain non-uniformity increase (Fig. 7). The most effective strain value gradient was obtain for friction factor value equal 0.8 (Fig. 8). External evidence of strain non-uniformity induced by friction is frontal part shape of material pushed by the channel die. In case of stage IV, connected with pass by channel die bend (marked as D), end and frontal part of deformed material influence on effective strain value in measuring points.

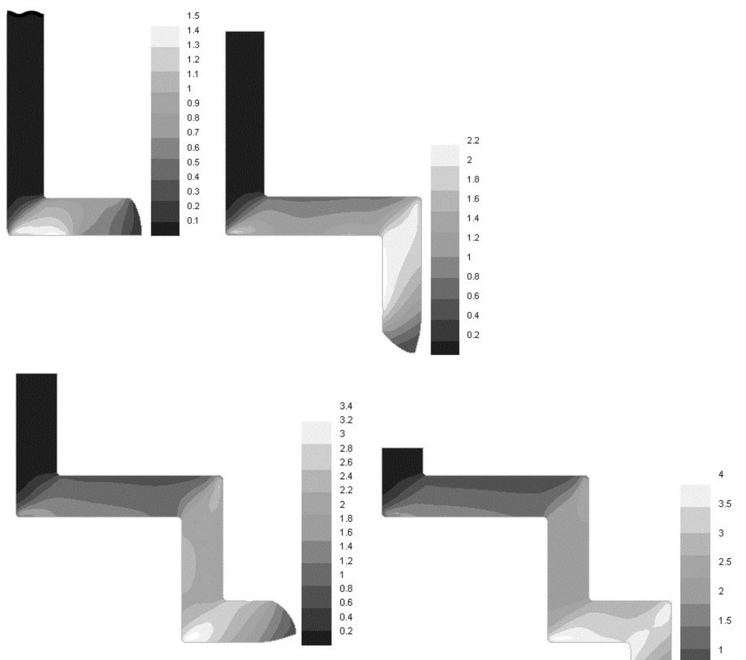

Fig. 6. *The friction factor (m = 0.05) influence on effective strain distribution during ECAP process in analyzed stages*

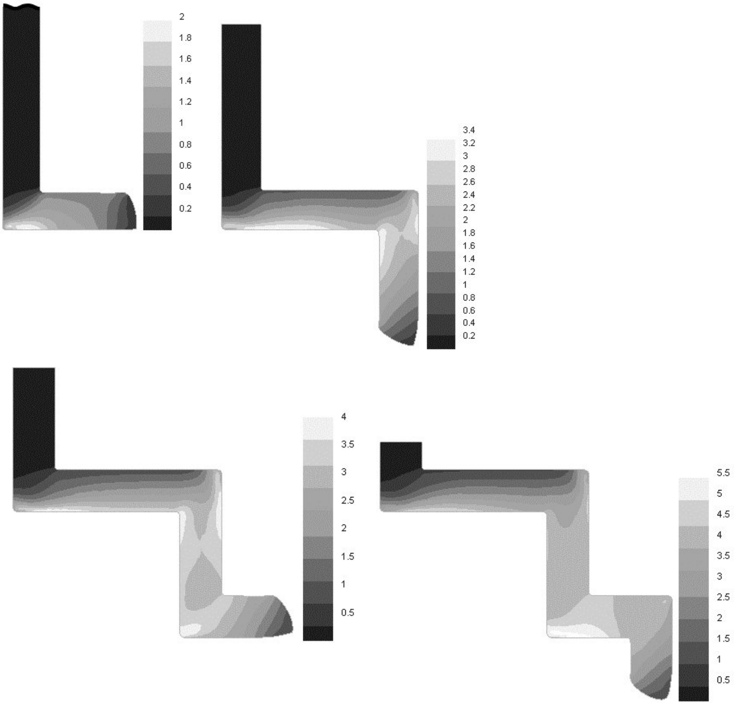

Fig. 7. *The friction factor (m = 0.40) influence on effective strain distribution during ECAP process in analyzed stages*

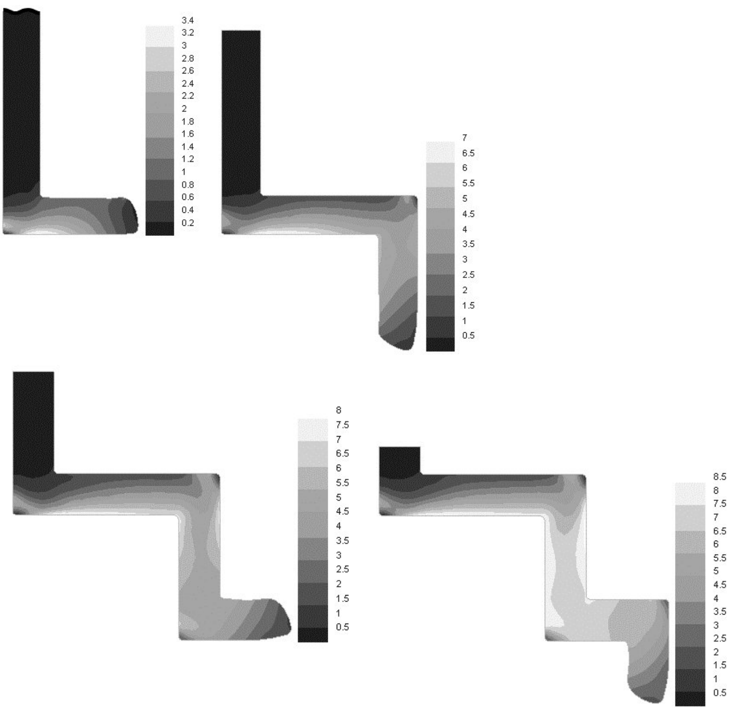

Fig. 8. *The friction factor (m = 0.80) influence on effective strain distribution during ECAP process in analyzed stages*

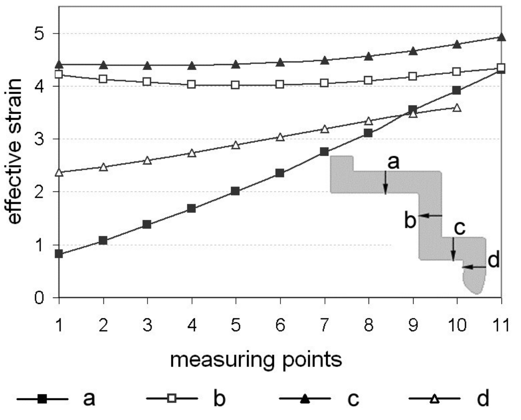

Fig. 9. Effective strain distribution in cross-sections a, b, c and d for stabilized process

Diversification of distance between following bends of die allows to analysis the deformed material way influence on effective strain. On base of obtained results it was found that diversification of effective strain values in whole volume of deformed material. The most strain uniformity in cross-section occurs in small area after entry to another channel. In Figure 9 are shown effective strain distributions in half length of each channel for friction factor m = 0.4. In cross-sections a, b, c and d, the direction of effective strain measurement from 1 to 11 point is marked by arrows. Increase of effective strain values for areas b and c is a result of two adjacent areas interaction. Strains are uniformly distributed along measurement direction – slight smaller values occurs in initial than in final points. The most non-uniformity occurs in a area – nearly five times effective strain value increase is probably result of large metal displacement by this area. In area d lack of interaction of following areas changes strain distribution and favour it's more non-uniformly, in comparison to b and c areas.

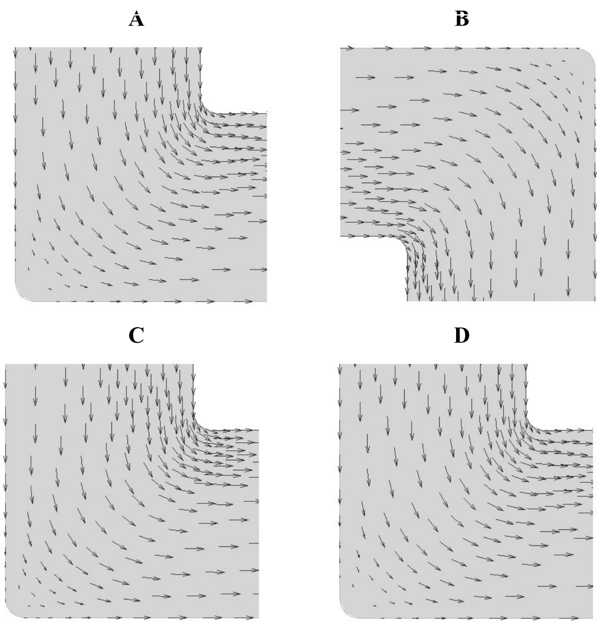

Fig. 10. Distribution of metal displacement vectors in following stages of ECAP process at various material flow directions in channel die

Stereomechanical character of contact is continuously changing. Size of real contact surface increase in relation to getting into contact with new batch of deformed material with changing shape areas. In channel bend area occurs the largest metal flow disturbances caused by violent flow direction and metal flow velocity changes (Fig. 10) and considerable hardening, temperature decreasing and plastic properties deterioration. Large frictional resistances are reason that in some die areas (angle corners) material movement is totally brake, "dead zones" occurs with larger area if the friction factor is higher.

Frictional resistance existence causes mean stresses heterogeneity and occurrence of areas with different deformation degree.

4. CONCLUSIONS

Pushing by angular channel process simulation allows to valuation of friction influence on changes proceeded in material structure. Effective strain accumulation as well as strain release ultrafine grain forming process. It base on general mechanism of dislocation boundaries generating, in result of this follows partition of grains and subgrains [1]. Strain accumulation in following bends they are generated new dislocations boundaries, which provides to very effective grains partition to finest structure domains. If the strain is increasing then distance between dislocation boundaries is getting smaller.

Effect of ultrafine structure generating and grains shape is close to equilibrium, gives the best results at friction factor included between values 0.05 and 0.4 [3]. At boundary friction $m = 0.8$ in channel die corners occurs „dead zones", which testify about large frictional resistance and low ductility.

Acknowledgements

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