NUMERICALLY INVESTIGATING EFFECTS OF CHANNEL ANGLE, FRICTION AND RAM VELOCITY ON STRAIN HOMOGENEITY IN ECAP

Serkan ÖĞÜT[1], Aykut KENTLİ[2]
[1](Marmara University Mechanical Engineering Department, Marmara University, Istanbul TURKEY
Email: serkan.ogut@marmara.edu.tr)
[2] (Marmara University Mechanical Engineering Department, Marmara University, Istanbul TURKEY
Email: akentli@marmara.edu.tr)

ABSTRACT

Equal channel angular pressing (ECAP) is a powerful severe plastic deformation (SPD) method proposed by Segal et al. Although it enables high values of strain to be imposed, it does not always provide homogenous strain distribution. Within this study, effects of the process parameters on the strain distributionwere investigated.To that end, 3D finite element simulations fordifferent combination ofchannel angle, friction coefficient and ram velocity values were performed. As a result of the finite element simulations, it is seen that the highest mean effective plastic strain can be obtained with channel angle of 90^0, friction coefficient of 0.15 and ram velocity of 5 mm/s. The lowest coefficient of variance of strain inhomogeneity can be achieved with channel angle of 105^0, friction coefficient of 0.1 and ram velocity of 3 mm/s.

Keywords*-ECAP, FEM, Strain Homogeneity, Ti Alloys*

1. INTRODUCTION

Equal channel angular pressing (ECAP) is a novel severe plastic deformation (SPD) methodwhich allows inducing intense strainto bulkmaterialsin order to obtain ultrafine grained (UFG) materials [1].As it described in the study of Valiev and Langdon, UFG materials are defined as polycrystals having very small grains with average grain sizes less than 1 µm [2].ECAP is extensively used in order to obtain better microstructure and mechanical properties thanks to its advantages over the conventional manufacturing methods. These advantages are stated in the study of Valiev and Langdon [2]. The most important advantages of ECAP and the other SPD methods like high pressure torsion (HPT) and twist extrusion (TE) over the traditional manufacturing methods is re-applicability. Thanks to this advantage, more strain can be obtained in the material, thus the average grain size can be reduced into nanosize. In SPD processes, the microstructure and the mechanical properties of the workpiece are considerably related with the amount of strain brought on and strain homogeneity accomplished [3]. Therefore, the recent interests in the ECAP studies tend to attempts to maximize the total strain induced and strain homogeneity obtained. Mahallawy et al. investigated the effect of number of passes and route on strain homogeneity [4]. Using 3D finite element analysis,Balasundar and Raghu compared the coulomb and shear friction model in terms of their effects on the strain distribution obtained during ECAP [5].Cerri et al. investigated the effect of friction, corner angle and number of passes on total strain and strain distribution for 6082Zr and 6082ZrSc Aluminum alloys [6].Djavanroodi and Ebrahimi investigated the effects of channel angle, friction and back pressure on level of strain and strain homogeneity for commercial pure aluminum [7]. Yoon et al. examined the effects of corner angle and strain hardenability of the processed material on deformation homogeneity using finite element analysis [8].Djavandroodi et al. investigated the effects of channel angle and corner angle on strain distribution for pure aluminum using 3D finite element analysis [9]. At the end of the study, they determined the optimum channel angle and corner angle giving the best strain uniformity [9].

In the present work, the effects of channel angle (∅), friction coefficient (µ) and ram velocity (V) on the strain homogeneity of Ti-5Al-2.5 Sn alloy was investigated using 3D finite element analysis. Simulation results were compared with the analytical results to validate the finite element models.

2. ANALYTICAL SOLUTIONS FOR THE EFFECTIVE PLASTIC STRAIN

During ECAP processes, workpieces are divided into four regions namely tail, plastic deformation zone (PDZ), steady-state zone and head. These regions can be seen in Fig.1 taken from finite element simulation carried out forvalidation.Head region is beginning part of the workpiece and tail region is behind part of the workpiece. Strain distribution is non-uniform for both regions.PDZ region is located in the junction part of the die and plastic deformation starts in this region. Finally, steady-state zone is the region located between head and tail regions. Effective plastic strain distribution is uniform over this region along the extrusion axis.

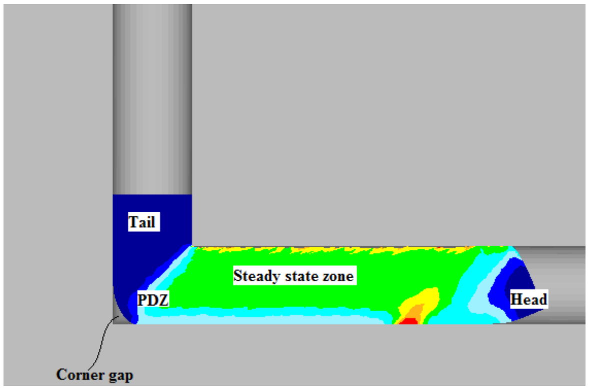

Figure 1. The overview of the different regions occurred during ECAP process

To investigate the influences of the ECAP parameters on total strain and strain distribution, it is a must to have information about the analytical solutions of the effective strain. Segal et al. [10] proposed an analytical model giving effective strain in dies with sharp corner:

$$\varepsilon_p = \frac{N}{\sqrt{3}} 2\cot\left(\frac{\emptyset}{2}\right) \qquad (1)$$

where N is number of pass and$\emptyset$ is channel angle.

The more inclusionary equation was proposed byIawashi et al. [11] and can be seen in Eq.2. With this equation, effective strain can be calculated in dies withround corner:

$$\varepsilon_p = \frac{N}{\sqrt{3}} \left(2\cot\left(\frac{\emptyset+\Psi}{2}\right) + \Psi\mathrm{cosec}\left(\frac{\emptyset+\Psi}{2}\right)\right. \qquad (2)$$

where Ψ is corner angle.

It is important to note that the effects of friction, deformation gradient and strain hardening are neglected in these analytical solutions.

3. 3D FINITE ELEMENT SIMULATION

Within this study, 3D finite element analyses were performed in order to approximate ECAP process. The punch and the die geometry were assumed as rigid parts since there is no deformation in these parts. The workpiece geometry has the length of 55mm and diameter of 10mm and it is modeled as plastic material. The initial element number of workpiece was determined as 30000 and re-meshing was used in order to accumulate large strains induced during ECAP process. The material properties of Ti-5Al-2.5 Sn alloy were taken from the library of the used finite element software. Half portion of punch, die and workpiece were used in modelling since the process is symmetrical about the middle plane.The ambient temperature was chosen as 20 ^{0}C and temperature effect in the process was ignored.Three parameters were used in the finite element simulations namely channel angle, friction coefficient and ram velocity. There are three levels for all parameters; 90^0, 105^0 and 120^0 for channel angle, 0.1, 0.2 and 0.3 for friction coefficient and 1 mm/s, 3 mm/s and 5 mm/s for ram velocity.

To validate simulation results, theoretical values were compared with simulation results. Since the effect of friction coefficient is neglected in the theoretical model, three finite element models with friction coefficient of 0.01 were generated for validation. Thus, analytical results and simulation results were compared for three channel angles and this comparison can be seen in Table.1. Within the verification stage, effective plastic strain values of FEM analysis were calculated by averaging the strain values taken from 50 points scattered over the steady state region.

Table 1. Effective strain comparison between theoretical and FEM values

	φ=90^0	φ =105^0	φ =120^0
Theoritical	1.154	0.886	0.666
FEM (μ=0.01)	1.137	0.873	0.649

4. RESULTS AND DISCUSSION

To investigate the influences of channel angle, friction coefficient and ram velocity on effective strain and strain distribution 27 finite element analyses were performed. After calculation stage in all analysis, effective strain values were taken from 50 points in the transverse plane. For each analysis, mean effective strain value was calculated by averaging this 50 strain values. Also Coefficient of Variance of effective plastic strain (CVε_p) valueswas calculated for each analysis in order to see strain inhomogeneity in transverse plane.CVε_p is proposed by Basavaraj et al.[12] to quantify strain inhomogeneity and as follows:

$$CV\varepsilon_p = \frac{Stdev\varepsilon_p}{Av\varepsilon_p} \qquad (3)$$

whereAvε_P is average plastic strain and Stdevε_P is standard deviation of plastic strain in the transverse plane.

4.1. Effect of channel angle on effective plastic strain:

The effect of channel angle on effective strain can be determined by examining the mean effective strain vs. channel angle graphs. According to Fig.2-Fig.4, mean effective strain value decreases while channel angle increases. This relation between channel angle and effective strain is compatible with the one in the analytical solution shown with Eq. (2).

4.2. Effect of friction coefficient and ram velocity on effective plastic strain:

WhenFig. 2- Fig.4are examined, it can be seen that an increase in friction coefficient leads to an increase in effective plastic strain. This can be attributed to the strain increase in the outer surface of the workpiece. On the other hand, it can be said that there is no significant effect of ram velocity on level of effective plastic strainwhen Fig.2-Fig.4 are taken into consideration.

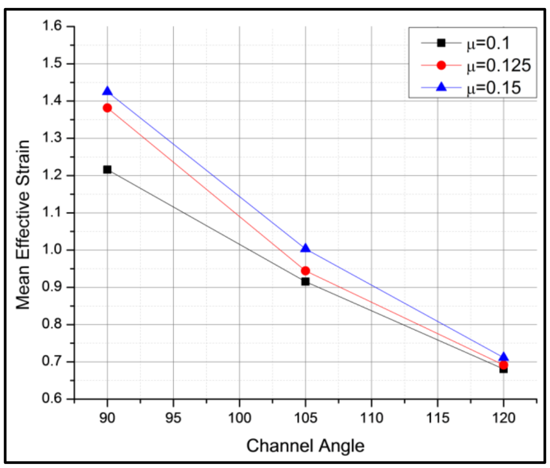

Figure 2. Mean Effective Strain for V=1 mm/s

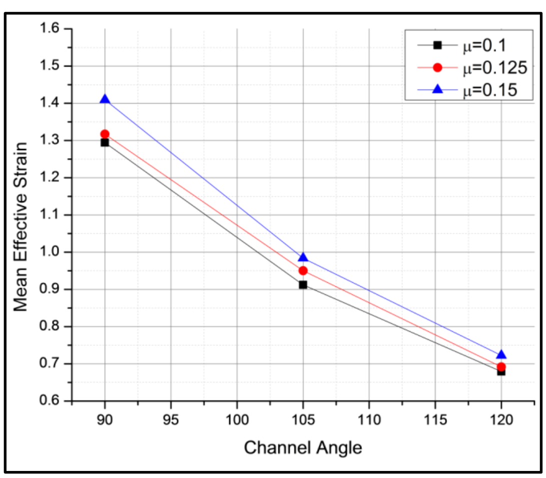

Figure 3. Mean Effective Strain for V=3 mm/s

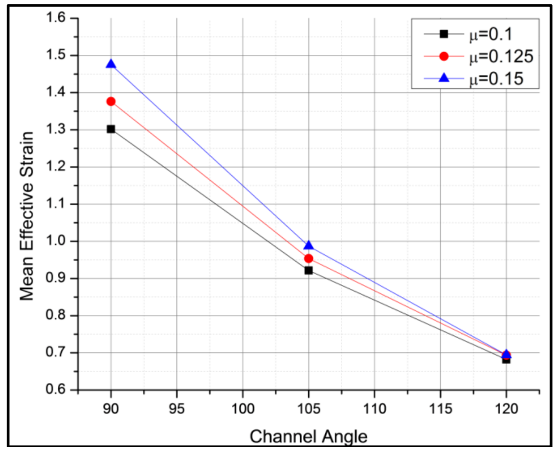

Figure 4. Mean Effective Strain for V=5 mm/s

4.3. Effect of channel angle on effective plastic strain inhomogeneity:

According to Fig. 5-7, strain inhomogeneity in effective plastic strain tends to decrease with the increasing channel angle. For all ram velocity and friction coefficient values, the least strain inhomogeneity value can be obtained by channel angle of 105^0.

4.4. Effect of friction coefficient and ram velocity on effective plastic strain inhomogeneity:

Fig.5-Fig.7 show that strain inhomogeneity increases due to the increase in friction coefficient. This can be attributed to the strain increase in the outer surface of the workpiece. While effective plastic strain increases in outer parts of the workpiece, it does not change in central parts of the workpiece. This leads to an increase in strain inhomogeneity. When Fig.5-Fig.7 are analyzed from the viewpoint of ram velocity, it is seen that there is no significant effect of ram velocity on effective plastic strain inhomogeneity.

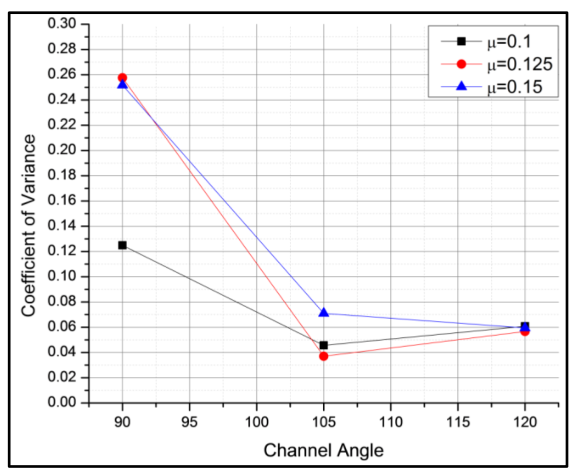

Figure 5. Inhomogeneity in strain for V=1 mm/s

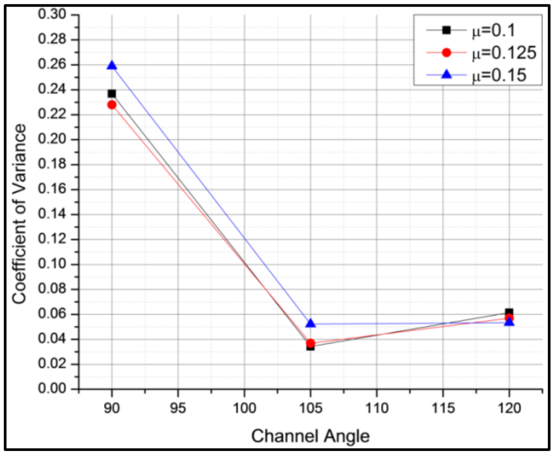

Figure 6. Inhomogeneity in strain for V=3 mm/s

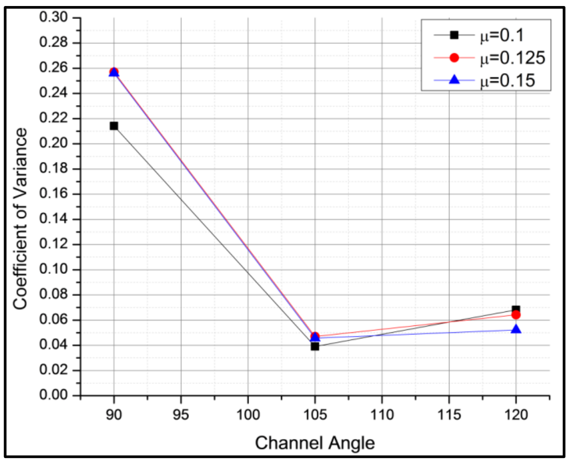

Figure 7. Inhomogeneity in strain for V=5 mm/s

5. CONCLUSION

The deformation behavior of Ti-5Al-2.5 Sn alloy processed by equal channel angular processed was simulated using 3D finite element method within this study. Thanks to this simulation, the effects of die channel angle, friction coefficient and ram velocity on strain homogeneity and total strain level were investigated. The obtained conclusions as follow:

1. With the increasing die channel angle, strain level decreases. Results show that, highest strain level can be obtained with channel angle of 90^0. On the other hand, increasing channel helps to obtain lower strain inhomogeneity. The lowest $CV\varepsilon_p$ value can be achieved with channel angle of 105^0.

2.Higher magnitude of effective plastic strain also can be obtained by higher friction coefficient. However,increase in friction coefficient leads to increase in $CV\varepsilon_p$ value as well.

3. Finally, it has been seen that the ram velocity does not have a significant effect on level of effective plastic strain and effective plastic strain inhomogeneity.

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