Comparison of workpiece geometry and its effects on ECAP process by FEA

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ABSTRACT

Equal channel angular pressing (ECAP) is a well-known severe plastic deformation (SPD) method. Generally circular or square cross-sectional workpieces are investigated in this process. Both of the geometries have some advantages and disadvantages. In this study, one circular and one square cross-sectional workpieces having equal cross-sectional areas were investigated as numerically by the help of finite element analysis software. All of the boundary conditions and material properties are kept same at the two analyses, so effect of the geometry is investigated and results are compared for each case. In order to compare results; pressing force, maximum stress in material while pressing, effective strain, and strain inhomogeneity were selected as parameters. At the end of the processes, it will be determined which one has more strain and strain homogeneity. Also, it will be decided which case need how much force for the processes.

Keywords *- ECAP, FEA, SPD.*

1. INTRODUCTION

By the developing technology and industry, all machines and devices become more compact. Their sizes decrease gradually while functionality of them increases. From automotive to aerospace industry, electronical devices to food industry, construction material must be more strength to deformation. Produced material by traditional methods becomes weak and insufficient to supply required properties. Application of old-style procedures in order to increase strength of material also increases brittleness in the meantime. This is not a desired property in design because it causes sudden failures in critical zones. In order to prevent unexpected failures the material must has more strength and ductility. To reach this aim, severe plastic deformation (SPD) methods have been developed, so by this way materials gain more strength together with ductility. By the increase of ductility, toughness of material also increases so it will resist to high force and the fracture will be delayed. In order to see the effect of SPD method, true stress–strain curves can be compared before and after SPD processes. It will show firstly high increase in yield strength and secondly there will be significantly less strain hardening, though ductility will be high level [1].

In recent time, many SPD methods are developed and some of these have become most common and developed increasingly. The most popular ones are can be ordered as; equal channel angular pressing (ECAP)[2], high pressure torsion (HPT)[3],repetitive corrugation and straightening (RCS)[4], accumulative roll-bonding (ARB)[5], cyclic extrusion compression (CEC)[6], multi-directional forging (MDF)[7], tube channel pressing (TCP) or tubular channel angular pressing (T-CAP)[8, 9], and twist extrusion (TE)[10]. Besides, ECAP is seen as most studied and developed method among of them in literature. For instance expansion equal channel angular extrusion (Exp-ECAE) is generated by a spherical cavity is provided at the junction of the ECAE channels [11]. As workpiece cylindrical and square cross sectional solid geometries are widely used in ECAP method. Both of the geometries have some advantages and some disadvantages. Squared geometry is useful for applying different route on a workpiece because the route angle must be certain value such as 90 or 180 degree around y-axis. However, in square cross sectional geometry, deformation or cracks can occur at the sharp edges in low pressing temperature. The cylindrical cross sectional geometry is suitable for pressing process but at the different route application, determining the certain angle becomes more difficult.

Selecting the right geometry is very important in engineering design such that results can be affected from geometry while under the same conditions [12, 13].

In this study, ECAP process is simulated for square and cylindrical cross sectional workpieces by using finite element analysis (FEA) methods. In the analyses same material (Al-5052) and equivalent cross sectional area is chosen with same length in workpieces. Therefore the comparison of both geometries is made and the differences in parameters like applying load, stress, strain, etc. is presented. In section 2, finite element analyses are explained in detail with modelling, meshing, and boundary conditions. In section 3, the results of FEA are explained and comparison of two cases is done with graphs and tables, and then the differences will be discussed. Section 4 will be comprised of conclusions.

2. FINITE ELEMENT ANALYSIS

In this section of paper, general information will be given about finite element analysis of the two cases. The generation of CAD models, meshing of workpieces, boundary conditions, and assumptions are explained in this section. Special software which is developed for plastic deformation simulation is used in finite element analyses.

2.1. CASES

Two cases are investigated in this study: the first one is square cross-sectional workpiece and the second case is circular cross-sectional workpiece geometries. Channel angle (ϕ) is 90° while outer corner angle (ψ) is decided as 20° in both of the cases because of general acceptance in previous ECAP studies. Shear friction coefficient between workpieces and dies is taken zero due to validation of analytical calculation in which the strain (γ) equations [Eq.1] of Agwa M.A. et al. is used and close results were obtained [14].

$$\gamma = 2\tan\left(\frac{\phi-\psi}{2}\right) + \psi \sec^2\left(\frac{\phi-\psi}{2}\right). \qquad (1)$$

Al 5052 alloy is determined as workpiece material in two cases and cold pressing is applied with 20° Celsius of operation temperature.

Workpieces were meshed into 20000 elements and the top die moved along –y direction with 1 mm/sec constant speed while bottom die was fixed. Top die moves 100mm along the pressing which equals to workpieces lengths so the time of processes become identical that is100 second.

2.1.1. Case 1: Square Cross-Sectional Geometry

In this case 10X10 mm square cross-sectional prismatic workpiece with 100 mm length was used for ECAP process. In figure 1, the meshed workpiece is shown as assembled inside of bottom die and under the top die. The workpiece is pressed along the channel by the top die with a constant speed.

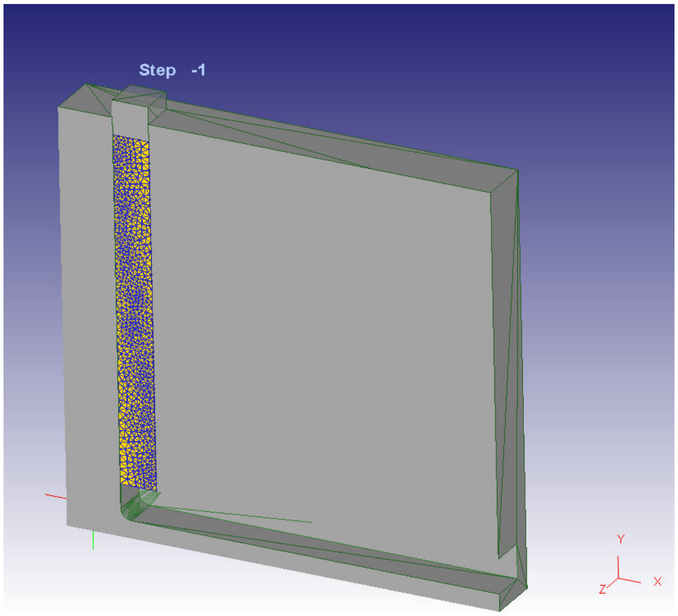

Fig. 1 Square cross-sectional geometry model

2.1.2. Case 2: Circular Cross-Sectional Geometry

In this case a circular cross-sectional cylindrical workpiece is used which has length of 100 mm and a radius of 5.642 mm (fig.2) so it has same cross sectional area 100mm^2 with case 1.

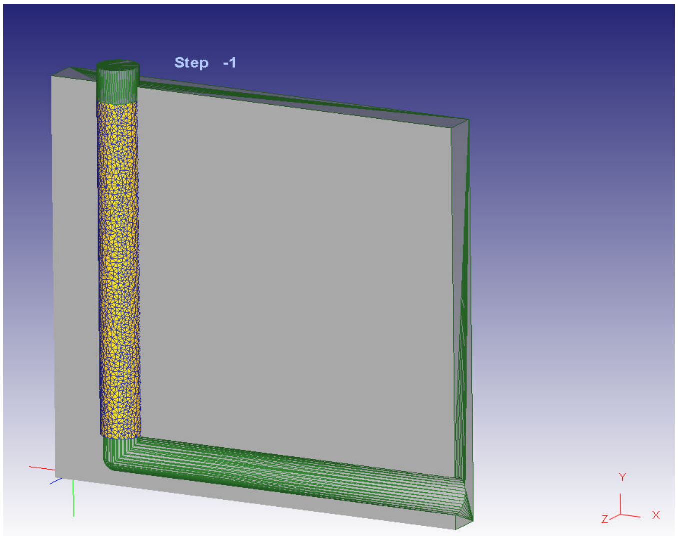

Fig. 2 Circular cross-sectional geometry model

3. RESULTS AND DISCUSSION

In the final of the analyses, the material flowed along the channel so the strains and effective strains of them changed. Effective strain is the one of the most important parameters in ECAP processes. The increase in the effective strain shows the efficiency of the ECAP process. Also, the smallness of strain inhomogeneity shows the increase of homogeneity of steady state zone by approaching to zero. In literature, for analytical calculations of effective strain and inhomogeneity, several formulas were derived from equation of Segal et al. [Eq.2]. In this paper, for analytical calculation of strain the Eq.1 was used by dividing $\sqrt{3}$ in order to find effective strain (ε).

$$\varepsilon = \frac{2}{\sqrt{3}} \cot\left(\frac{\phi}{2}\right) \quad (2)$$

Table 1 Strain results of cases

Case	Effective Strain (ε) (Analytical)	Effective Strain (ε) (FEA)	Strain Inhomogeneity (FEA)
Circular	1.108	1.240	0,0810
Square	1.108	1,273	0,0247

The effective strains and strain inhomogeneity were calculated by taking 15 point on steady state zone and compared with Eq. 1 results as shown in table1. The sample points were taken from vertical symmetry surface of steady state zones. The high value of effective strain indicates the increase of hardness property.

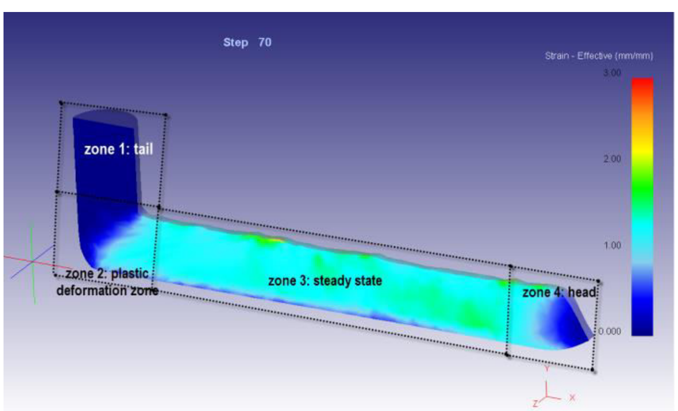

Fig. 3 ECAP zones and effective strain distribution

At the table 1, it is shown that analytical effective strain is equal for both cases due to using same parameters and formula. However, in FEA results of the effective strain for circular case is higher than square case while inhomogeneity much smaller for square one.

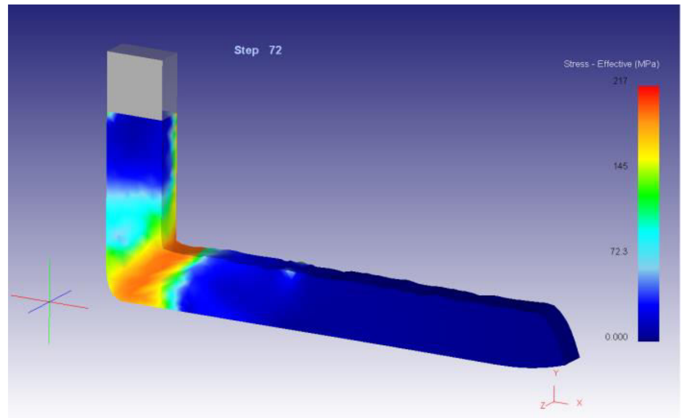

Fig. 4 Effective stress distribution from vertical symmetry surface while pressing

The effective strain distribution is shown in fig.3; it is extreme and has nearly homogeny distribution in steady state zone while it is zero at the tail and head zone. In fig.4 effective stress distribution is presented in which the maximum value is shown in plastic deformation zone with 45° angle with x-axis and the load value is 217 MPa.

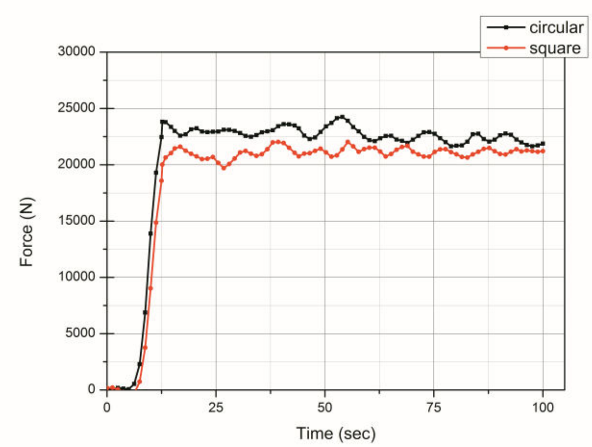

Fig. 5 Applied force vs time graph for two cases

The above graph shows that although the both of workpieces have equal cross-sectional area and under the equal conditions the required force is higher for circular case fig.5. Besides, the variance of curves is similar to each other.

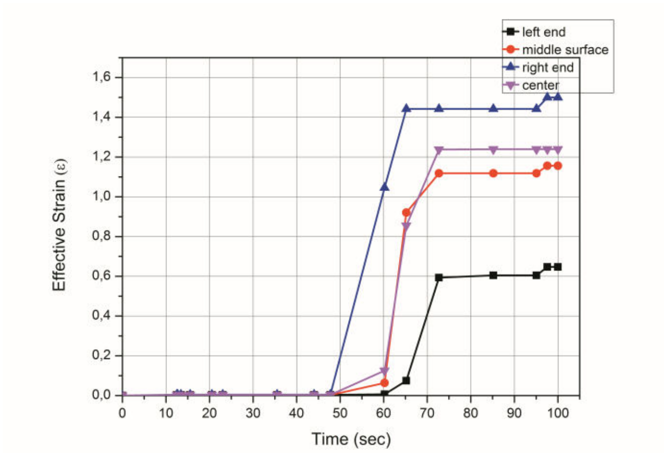

Fig. 5 Effective strains of circular case versus time

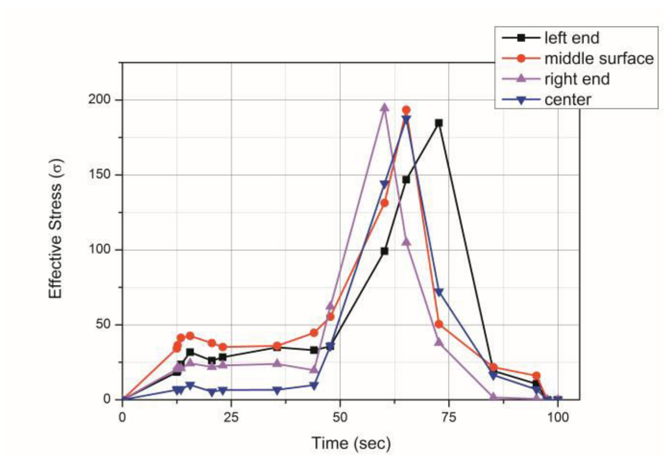

Fig. 6 Effective stress of circular case versus time

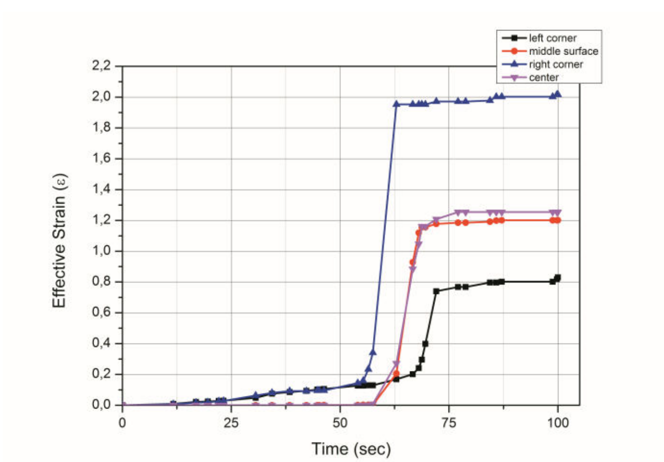

Fig. 7 Effective strain of square case versus time

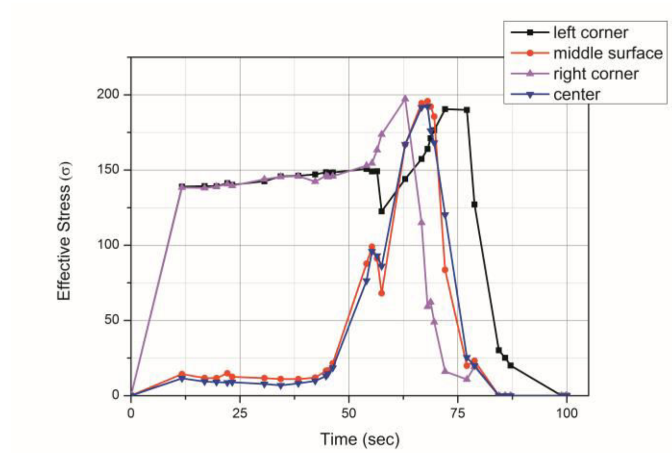

Fig. 8 Effective stress of square case versus time

Effective strain and effective stress distribution of two cases are presented above (fig.5-fig.8). For each graph, 4 points were detected from middle length of workpieces: three of them on surface and one of them at the center of workpieces. The above graphs show the effective strain and stress variance of these points along all pressing time. Strain graphs (fig.5, fig.7) show maximum strains are on right ends while minimum strains are on left ends. Also on middle surface and in center the values are seen close to each other and among ends values. In stress graphs (fig.6, fig.8), there is minor stress till reaching to plastic deformation zone (PDZ) despite this value is greater for square case at the corners. Moreover effective stresses reach to maximum values at PDZ and then immediately fall to minimum levels.

4. CONCLUSION

As a conclusion, two different cross-sectional geometries (circular and square) with equal areas were analyzed in ECAP process by FEA method. The analyses results were compared within cases for different zones. Also the behavior of parameter compared between cases for same zones. The results show that, circular workpieces needs more force for ECAP process. Maximum effective stress and strain occurs on right ends (at the inner channel angle side) while the minimum values at left ends (outer corner angle side). It can be deduced from this, more hardness can be obtained for desired surface by arranging it at the right end (inner channel angle side).Strain inhomogeneity is almost four times bigger in circular case than square one. It indicates that square cross-sectional workpiece has more homogeny effective strain texture in steady state zone.

REFERENCES

[1]Valiev, R.Z., R.K. Islamgaliev, and I.V. Alexandrov, Bulk nanostructured materials from severe plastic deformation. Progress in Materials Science, 2000. 45(2): p. 103-189.

[2] V.I. Kopylov, Application of ECAP - Technology for producing nano- and microcrystalline materials, Investigations and Applications of Severe Plastic Deformation, 80 (2000) 23-27.

[3] J. Zrnik, S. Scheriau, R. Pippan, Ultrafine Grain Structure of Medium Carbon Steel Prepared by Hpt Severe Plastic Deformation Method, Nanocon 2009, Conference Proceedings, (2009) 96-100.

[4] Y.T.T. Zhu, J.Y. Huang, H.G. Jiang, T.C. Lowe, Processing of bulk nanostructured copper by Repetitive Corrugation and Straightening (RCS), Innovations in Processing and Manufacturing of Sheet Materials, (2001) 175-182.

[5] Y. Saito, H. Utsunomiya, N. Tsuji, T. Sakai, Novel ultra-high straining process for bulk materials - Development of the accumulative roll-bonding (ARB) process, Acta Materialia, 47 (1999) 579-583.

[6] M. Richert, H.P. Stuwe, M.J. Zehetbauer, J. Richert, R. Pippan, C. Motz, E. Schafler, Work hardening and microstructure of AlMg5 after severe plastic deformation by cyclic extrusion and compression, Materials Science and Engineering a-Structural Materials Properties Microstructure and Processing, 355 (2003) 180-185.

[7] R. Gupta, S. Srivastava, N.K. Kumar, S.K. Panthi, High leaded tin bronze processing during multi-directional forging: Effect on microstructure and mechanical properties, Materials Science and Engineering a-Structural Materials Properties Microstructure and Processing, 654 (2016) 282-291.

[8] G. Faraji, M.M. Mashhadi, H.S. Kim, Tubular channel angular pressing (TCAP) as a novel severe plastic deformation method for cylindrical tubes, Materials Letters, 65 (2011) 3009-3012.

[9] A. Zangiabadi, M. Kazeminezhad, Development of a novel severe plastic deformation method for tubular materials: Tube Channel Pressing (TCP), Materials Science and Engineering a-Structural Materials Properties Microstructure and Processing, 528 (2011) 5066-5072.

[10] Y. Beygelzimer, D. Orlov, V. Varyukhin, A new severe plastic deformation methd: Twist extrusion, Ultrafine Grained Materials Ii, (2002) 297-304.

[11] Sepahi-Boroujeni, S. and F. Fereshteh-Saniee, Expansion equal channel angular extrusion, as a novel severe plastic deformation technique. Journal of Materials Science, 2015. 50(11): p. 3908-3919.

[12] Sordi, V.L., et al., Equal-channel angular pressing: influence of die design on pressure forces, strain homogeneity, and corner gap formation. Journal of Materials Science, 2016. 51(5): p. 2380-2393.

[13] Ayten, A.İ., Ekici, B., and Gulluoglu, A.N., Effect of surface geometry on low-velocity impact behavior of laminated aramid-reinforced polyester composite. Journal of Composite Materials. 2016, Vol. 50(29) 4077–4091

[14] Agwa, M.A., M.N. Ali, and A.E. Al-Shorbagy, Optimum processing parameters for equal channel angular pressing. Mechanics of Materials, 2016. 100: p. 1-11.

[15] Segal, V.M., K.T. Hartwig, and R.E. Goforth, In situ composites processed by simple shear. Materials Science and Engineering: A, 1997. 224(1): p. 107-115.