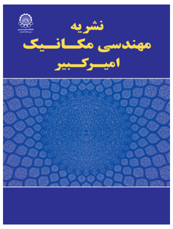

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(8) (2021) 1115-1118
DOI: 10.22060/mej.2021.18754.6883

Theoretical Analysis of Equal Channel Angular Pressing Process by Upper Bound Method and Its Experimental Investigation in Condition of Circular Cross-Section Channel

R. Naseri[1*], M. Kadkhodayan[2], M. Shariati[2]

[1] Department of Mechanical Engineering, Technical and Vocational University, Tehran, Iran,
[2] Department of Mechanical Engineering, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

ABSTRACT: The equal channel angular pressing process is one of the most effective severe plastic deformation processes to produce ultrafine grained steels metals. Also, the upper bound theory is one of the reliable theoretical tools to forecast deformation strain and forming load. In this research, analysis of equal channel angular pressing technique in an arbitrary channel and corner angles using upper-bound theory was performed and a general and user-friendly equation for predicting the forming force is proposed according to the geometry of process and elastic-plastic properties of work-piece material. By comparing the amount of obtained theoretical load with experimental forming force resulted from applying process on 7075 Al alloy, has been observed very good agreement between the results. This guarantees the reliability of the achieved general equation for equal channel angular pressing force. According to the results of the present research, experimental and theoretical forming load of equal channel angular pressing process on this material under conditions of channel angle 135°, corner angle 20°, billet diameter 10 mm, and billet length 90 mm were obtained equal to 48 kN and 55.04 kN, respectively. Furthermore, by increasing the channel angle from 60 to 150 under a constant corner angle of 20°, process load is decreased equal to 41.3% from 86.4 kN to 50.7 kN. In addition, by increasing the corner angle from 0° to 40° under a constant channel angle of 135°, the negligible reduction of a load equal to 2.5% was observed from 56 kN to 54.6 kN.

Review History:

Received: Jul. 20, 2020
Revised: Jun. 30, 2021
Accepted: Jul. 03, 2021
Available Online: Jul. 14, 2021

Keywords:

Equal channel angular pressing
Upper-bound theorem
Elastic-plastic properties
Forming load

1. INTRODUCTION

The Equal Channel Angular Pressing (ECAP) process is one of the most important and effective processes of Severe Plastic Deformation (SPD) processes for producing ultrafine or nano grained structures and consequently enhancement of static and dynamic mechanical properties of pure and alloy metals. In this process, high strains are introduced to the workpiece due to the existence of shear stress in the deformation region [1]. In a forming process to optimization of die design, determination of required load and applied strain prior to performing of the process is very essential. Nowadays, analytical and numerical methods are generally used to predict these parameters in a forming process. Upper-bound theorem as an analytical method is one of the most conventional, accessible, and reliable techniques for forecasting load and strain [2, 3].

Literature review shows that most researches have focused on utilize of the upper bound method in the ECAP process with square and circular cross-section channels and under the angle of 90 degrees [4, 5]. It is clear that the use of the upper bound method in investigating of deformation and forming load of ECAP with a circular cross-section with an arbitrary or general channel angle has been neglected. In this regard, the use of this method in the analysis of the ECAP process with a circular cross-section and at arbitrary geometric angles is innovative. Hence, there is a need to achieve a comprehensive and user-friendly equation for forecasting of forming load and this equation was obtained in this research. Furthermore, the experimental test has been performed for validation of this obtained theoretical relationship.

2. Methodology

2.1. Analysis of deformation

The understanding of the geometry of the deformation zone and the velocity discontinuity surfaces of material are the most important matters in analyzing the deformation in forming processes. In this research, based on these items, the development and extension of relationships obtained by Paydar et al [5] were used for the analysis of deformation in the ECAP process with arbitrary channel angle. Hence, the required force (F) and pressure (P) were obtained according to Eq. (1) and Eq. (2):

*Corresponding author's email: rnaseri@tvu.ac.ir

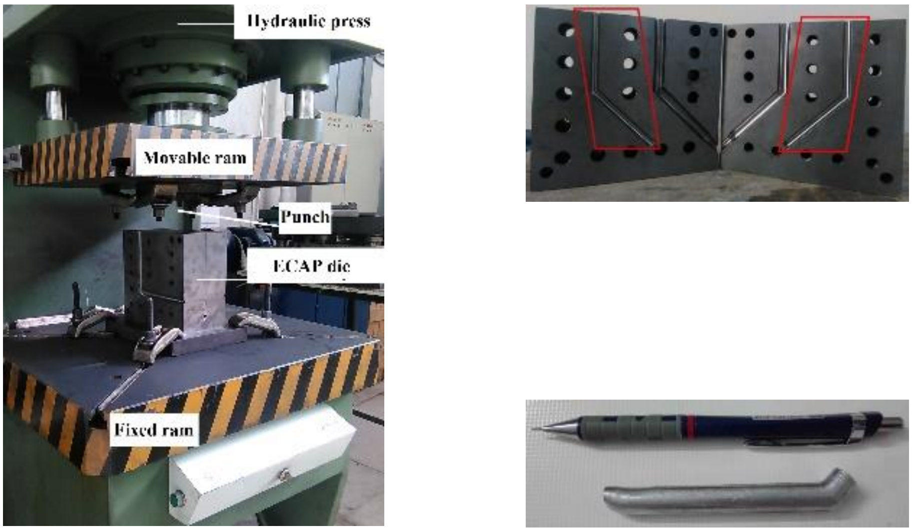

Fig. 1. The real view of (a) set-up of process and (b) ECAP die and used channel with an angle of 135 degrees, corner angle of 20 degrees, and diameter of 10 mm (shown in the red box)

Table 1. Strain-hardening properties of annealed Al-7075

Annealed metal	Strain hardening $\sigma = c\,\varepsilon^{n}$		Mean shear stress (MPa)
	c (MPa)	n	$\bar{k}$
Al-7075	592.99	0.2133	169.836
True strain		True stress (MPa)	
Yield	Ultimate	Yield	Ultimate
ε_Y	ε_U	σ_Y	σ_U
0.004108	0.082505	191.737	317.667

Table 2: Input and output parameters and how to obtain them in the determination of forming force

Input parameters								
φ	ψ	a	L	m	c	n	ε_Y	ε_U
Die and work-piece geometry				*	Uniaxial tensile test			
Output parameters								
l			$\bar{k}$		$\bar{\sigma}_Y$		F	
$l = L - 2a$			Eq. (4)		Eq. (3)		Eq. (1)	

*1- Ring compression test, 2- Finite element simulation of ring compression test and using the calibration curve [7, 8]

$$F = \pi a^2 \bar{k}\left[\psi + 2\cot\left(\frac{\varphi+\psi}{2}\right) + \frac{4m}{\pi}\psi\csc\left(\frac{\varphi+\psi}{2}\right) + 4m\cot\left(\frac{\varphi+\psi}{2}\right) + \frac{2ml}{a}\right] \quad (1)$$

$$P = \bar{k}\left[\psi + 2\cot\left(\frac{\varphi+\psi}{2}\right) + \frac{4m}{\pi}\psi\csc\left(\frac{\varphi+\psi}{2}\right) + 4m\cot\left(\frac{\varphi+\psi}{2}\right) + \frac{2ml}{a}\right] \quad (2)$$

2.2.Materials and experimental procedures

Al-7075 alloy was chosen as the material to apply ECAP. This material was machined as a rod with a length of 90 mm and an approximate diameter of 10 mm and then for annealing was inserted into a furnace at a temperature of 415 °C for one hour and then cooled in a closed furnace [6]. In addition, the elastic-plastic properties of the annealed metal before and after ECAP were obtained according to the ASTM E 8M-00.

To compare the forming load in ECAP in two methods of the experimental and bound theorem, one pass of ECAP was performed on the Al-7075 billet under diameter of 10 mm, die angle of 135°, corner angle of 20°, and ram speed of 9 mm/s. Fig. 1 demonstrates real views of ECAP die and setup and Also, the billet after applying one pass of ECAP under mentioned condition.

3. RESULTS AND DISCUSSION

3.1. Mechanical properties

The true stress-strain diagram of annealed Al-7075 obtained from the uniaxial tensile test shows that the power equation σ=592.99 $\varepsilon^{0.2133}$ has been fitted on the strain-hardening region of the diagram. Amounts of strains in yield and ultimate points are 0.004108 and 0.082505, respectively. Using these values and the power relationship reported in the strain-hardening region, the mean shear yield stress ($\bar{k}$) according to the Eq. (3) and Eq. (4) and Table 1 was obtained equal to 169.8 MPa.

Therefore, by relationship obtained from the upper bound theorem, Eq. (1), and using the geometric properties of die and the mechanical properties of the billet material, the forming force can be calculated analytically and this value should be compared with the results of the experimental test for validation.

Table 3. Forming force in ECAP technique in experimental and upper-bound methods

ECAP	Channel angle	Corner angle	Channel diameter
	φ (°)	ψ (°)	$2a$ (mm)
	135	20	10
Billet length	Friction factor	Maximum load	
L (mm)	m	F (kN)	
		Analytical	Experimental
90	~ 0.1	55.04	48

By fitting the Holloman power equation ($\sigma = c\varepsilon^n$) to the strain-hardening region, with a coefficient (c) and power (n), the mean yield stress ($\bar{\sigma}_Y$) is obtained using Eq. (3), where, ε_Y and ε_U are yield and ultimate strains, respectively. Therefore, using von-Misses criteria, the mean shear yield stress ($\bar{k}$) is determined by Eq. (4) [4]:

$$\bar{\sigma}_Y = \frac{1}{\varepsilon_U - \varepsilon_Y}\int_{\varepsilon_Y}^{\varepsilon_U} c\,\varepsilon^n d\,\varepsilon = \frac{1}{\varepsilon_U - \varepsilon_Y}\frac{c}{n+1}\left(\varepsilon_U^{n+1} - \varepsilon_Y^{n+1}\right) \tag{3}$$

$$\bar{k} = \frac{\bar{\sigma}_Y}{\sqrt{3}} \tag{4}$$

3.2. Forming load analysis

The experimental tests show that the required forming load for one pass ECAP of under mentioned conditions was 48 kN. All input and output parameters and how to obtain them were presented in Table 2. According to the amounts of geometrical characterization of setup (Table 3) and mechanical properties of the material (Table 1) and also Eqs. (1), (3), and (4), the required force will be obtained equal to 55.04 kN using the upper-bound theorem.

s can be observed from comparing the amount of forming force obtained from analytical (55.04 kN) and experimental (48 kN) methods, there is a very good agreement between the results from the upper bound method and the real value, which means high reliability to Eq. (1) to predict the forming force in ECAP process. The greater amount of analytical force than the experimental one can also be attributed to the upstream prediction in the upper limit analytical method. The amount of analytical force is more than the experimental result, which can be attributed to properties of upper-bound analysis in predicting with a higher value.

4. CONCLUSIONS

The qualitative and quantitative results of the present study include the following:

· In this study, using the elastic-plastic properties of the work-piece material and the upper bound theory, a general, comprehensive, and user-friendly relationship was obtained to predict the amount of required force to apply the ECAP process with circular cross-section channel and also arbitrary die and corner angles.

· Comparison of ECAP forces obtained from upper-bound analytical method (55.04 kN) with the experimental result (48 kN) on the annealed Al-7075 alloy in channel angle of 135°, corner angle of 20°, billet length of 90 mm, and diameter of 10 mm, have demonstrated that it can be trusted to the relationship obtained in this study based on the upper-bound theorem analysis.

REFERENCES

[1] R. Naseri, M. Shariati, M. Kadkhodayan, Effect of work-piece cross section on the mechanical properties of commercially pure titanium produced by Equal Channel Angular Pressing, Modares Mechanical Engineering, 15(6) (2015) 157-166.

[2] K. Abrinia, M.J. Mirnia, A new generalized upper-bound solution for the ECAE process, International Journal of Advanced Manufacturing Technology, 46(1-4) (2010) 411-421.

[3] F.R.F. Silva, N. Medeiros, L.P. Moreira, J.F.C. Lins, J.P. Gouvêa, Upper-bound and finite-element analyses of non-isothermal ECAP, Materials Science and Engineering A, 546 (2012) 180-188.

[4] A.R. Eivani, A. Karimi Taheri, An upper bound solution of ECAE process with outer curved corner, Journal of Materials Processing Technology, 182(1-3) (2007) 555-563.

[5] M.H. Paydar, M. Reihanian, R. Ebrahimi, T.A. Dean, M.M. Moshksar, An upper-bound approach for equal channel angular extrusion with circular cross-section, Journal of Materials Processing Technology, 198(1) (2008) 48-53.

[6] M.H. Shaeri, F. Djavanroodi, M. Sedighi, S. Ahmadi, M.T. Salehi, S.H. Seyyedein, Effect of copper tube casing on strain distribution and mechanical properties of Al-7075 alloy processed by equal channel angular pressing, Journal of Strain Analysis for Engineering Design, 48(8) (2013) 512-521.

[7] F. Fereshteh Saniee, I. Pillinger, P. Hartley, Friction modelling for the physical simulation of the bulk metal forming processes, Journal of Materials Processing Technology, 153-154 (2004) 151-156.

[8] E.M. Mielnik, Metalworking science and engineering, 1st ed., McGraw-Hill College, 1991.

HOW TO CITE THIS ARTICLE

R. Naseri, M. Kadkhodayan, M. Shariati, Theoretical Analysis of Equal Channel Angular Pressing Process by Upper Bound Method and Its Experimental Investigation in Condition of Circular Cross-Section Channel, Amirkabir J. Mech Eng., 53(8) (2021) 1115-1118.

DOI: 10.22060/mej.2021.18754.6883