INVESTIGATING THE EFFECT OF TWO-STEP ANGLE FORMAT IN EQUAL CHANNEL ANGULAR EXTRUSION PROCESS

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Abstract: Equal Channel Angular Extrusion Process (ECAE) is one of the methods of production of microstructure and nanostructure material. In the previous research published, the effect of change in the parameters in the available form of Geometry was evaluated. In this paper new frameworks propose, as a two-stage, for reviewing ECAE process is presented. Therefore, instead of just two channels of input and output, three channels are used. An added channel in fact plays roles of the interface channel for input and output channels in order to divide the angle format. For this purpose, the finite element simulation is used. In the beginning of a Sample process, simulation results are compared with the analytical results and the validity of the theory upper bound on the simulation results is shown. Then with the two-stage target forms, the effect of two-step of angle form on force process and the equivalent plastic obeisance ingot output is checked. Simulations with using the version 6.9 software ABAQUS are performed. The results indicate that the two-step molding angle reduces the maximum force in shaping the ECAE process that is due to breaking the format angle in two stages. Also the two-stage molding angle increases the time to reach maximum force in shaping the process.

Keywords: ECAE Process, Angle of a Two-Level Format, Shaping Force, Equivalent Plastic Strain

1. INTRODUCTION

In recent years, the microstructure and nanostructure materials due to their extraordinary properties such as high strength and low weight have been the attention of many scientific and industrial circles. Extrusion process in the cross-channel angular is one of the methods of production of microstructure and nanostructure material. In the process, ingot is expelled from mold runner due to the compressive force of the punch. It does not change the cross-section of ingot. Due to fractures runner mold, the ingot through the die shear strain is applied and improved mechanical properties Output. Therefore the aim of this process is unlike conventional extrusion, deformation of the billet cross section of the form is not optional. But it is aims to improve the mechanical properties of the product output by applying shear strain. One of the most important characteristics of this method is repeated until to achieve the desired strain. This is due to stable of work piece dimensions during the process. In this process is shown in Figure (1), Form of channels with identical cross sections that together make up the angle Φ, is consisted. Φ called as Angular form in the process. Component of this process is shown in Figure (1), Ingot, The two-section format, and mandrel to move into the ingot mold.

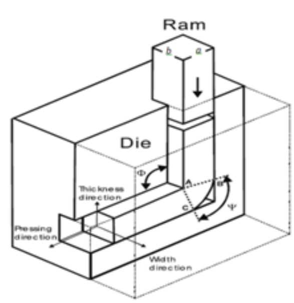


Figure 1. Scheme ECAE process and some geometric parameters such as angles Φ and Ψ and Sides a and b for a rectangular cross-section [1]

Format angle in this process is commonly can be selected between 60° to 135°. Format angle below 90°, because of the dead zone in the input format and output location of encounter and need a lot of pressure to move the piece, is less used. Other influence parameter on the process is external corner radius of the mold. Size of external corner radius of the mold according figure (1), from the internal edge is shows that the collision forms with an angle Ψ. Contributing factor in this process can cited, angle Φ, the shape and dimensions of the cross section of the ingot and mold, friction between the ingot and the mold, ingot material and angle Ψ, In Figure 1, shown.

ECAP process was introduced for the first time by Segal et al in 1981 [2]. Iwahashi et al [3], obtained formula for the relationship between the geometric parameters and the mean effective strain form, Zhang and et al [4], with using three-dimensional simulations and comparisons with experimental results, reviewing the effect of corner radius of the outer form in the multi-path ECAE on processes shaping the force and strain obeisance to ingot. In other research Balasundar and Sudhakara [5], obtained the relationship between the radiuses of the outer edge of the radius from angle Ψ and impact angle in their review process. Neil et al [6], in an analytical research, have studied the effect of friction in a rectangular ingot in a two-dimensional plane strain condition on the shaping force. Then the results are compared with the results of the analytical solution. Nagasekhar et al [7], in a laboratory simulation analysis, a ingot with circular cross section in ECAE process of shaping the force and strain applied to the work piece review and then the simulation results are compared with experimental results and have shown validate of their simulation results.

In this paper, the effect of multi-angle template as a new proposal, evaluated and is compared with format of a single template. In multi-stage molding angle, instead of just two channels of input and output, as in Figure 2 is shown, three channels are used. An added channel in this section plays roles of the interface channel for input and output channels in order to break the mold angle Φ. In fact to break angle format can via interface channels, can be divided angle format Φ into two smaller angles. So that the sum of these two angles is equal to Φ. For example, one can form an angle Φ=90° can be divided to two angles $\Phi_1=\Phi_2=45°$ .Based on this idea and with using finite element simulation, how effective two-level reduction in force, shaping and smoothing angle format equivalent plastic strain in the ingot output, in comparison with single-mode angular form is checked. The effectiveness of this idea requires that in the case of the shaping force reduction and uniform increase of plastic strain, the value of this strain in comparison with the single angle is not greatly reduced.

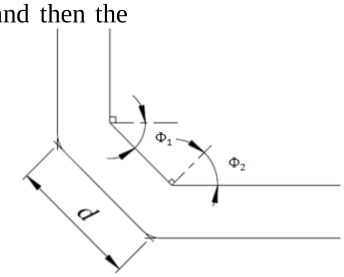


Figure 2. Structure of two-stage ECAE process

Table 1. Material constants of equation (1) and mechanical properties of steel (IF Steel) in simulations

Zhang's modulus (GPa)	Poisson's ratio	Density (kg/m^3)	n	K (MPa)	ε_0
195	0.29	7800	0.235	544.96	0.004852

In the simulations, first for a sample process, Simulation results are compared with the upper limit of the analytical theory and credibility of simulation results is shown. Then in order to the two-stage simulation framework ECAE process to form the desired angles, effect of two-stage in the format angle on process force and equivalent plastic strain of output ingot is evaluated. It should be noted that the amount of plastic shear strain, has a direct effect on the formation of desired microstructure. Proposal and reviewing form an angle two-stage channel has novelty.

2. FINITE ELEMENT MODELING

In order to finite element simulations, sample process from the reference [6] has been selected. In this reference, crossing IF Steel with steel brand dimensions a=10(mm), height 80(mm) and angle channel with Φ=90° and minimal friction is reviewed. Characteristics of this process have been selected as the basis of the simulations. Relationship stress - plastic strain for the steel is expressed by using equation (1).

$$\bar{\sigma} = K(\varepsilon_0 + \bar{\varepsilon}^{\mathrm{p}})^n \qquad 1)$$

In equation (2) $\bar{\sigma}$ Yield stress, $\bar{\varepsilon}^{p}$ Plastic strain, ε_0 Strain compensation and the constants *K* and *n* are respectively the coefficient and the hard material.

Constants of equation (1) and mechanical properties of this steel are given in Table 1 [6]. Figure 3 also shows charts the stress - plastic strain for the steel.

In this paper simulations for single and two-stage molds angles 90°, 75° and 60° replicates and their results are compared. In the simulations, the punch and format were modeled as analytical rigid. Template angle Φ=90°, the radius of the outer edge of the mold R=5 (mm) inside corner radius mold r= 0.5 (mm) is intended.

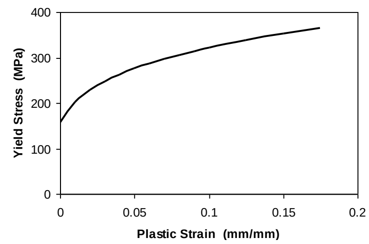


Figure 3. Diagram of stress - plastic strain for Steel IF Steel

The angle Ψ is based on geometry in Figure 1, using equation (2) equals Ψ=36.86° is achieved [5].

$$\Psi = 2\tan^{-1}\left(\frac{R}{2a-R}\right) \quad (2)$$

Radius R=5(mm) is chosen because in the allowed range, R is become much larger, shaping force is reduced and ingot leads to better format. Allowable range in any process is equal to the value of b in the form of ingot cross-section [9].In the other hand, form the inside corner radius of r, has a little effect on the cross-channel angular extrusion process. But how much inside corner radius mold is closer to zero, Causes a uniform distribution of plastic strain in the ingot and the punch force is reduced [1]. But exist of a sharp corner in the form and ingot hit with this spot can cause errors in the simulations. For this reason a small amount to the inside corner radius of format is chosen. Within a radius corner instead of two-level inside and outside mold, there are both internal and external corner radius forms. Used value for the similar radius corners, the same is considered.

After simulating and comparing different interface channel length (d) for the model in this paper, the intermediate channel length d=25(mm) is selected. In two-step molding angle, interface channel length should be given so that the ingot tolerate fracture due to the angle Φ_1 in interface channel, and after cutting imposed by the angle Φ_2 directed to the output channel. If the channel interface is a much smaller, causes the ingot cannot completely intolerant fracture caused by the angle of Φ_1 & Φ_2. Also the excessive length of the channel interface cause of excessive force in shaping and strain concentration zone of the friction force. Other simulations are also concluded, equal divisions for angles Φ_1 & Φ_2 at a fixed angle template is the best choice. In simulations for networking element stress analysis of two-dimensional square-shaped ingot is used. Because the ingot size is constant, in all simulations from 1800 billet element is used.

Ingot contact mold is defined with friction coefficient μ=0.05, if the amount of friction between the ingot and the mold is more, somewhat can help uniform ingot output format. On the other hand, increases the shaping force several times the maximum friction mode is almost zero [8]. In simulations have been used explicit salver dynamics. Speed of processing in the laboratory work are 0.5(mm/s) to 1(mm/s). Due to the number of two-dimensional simulations in this study, much time would be needed to simulate the real-time. Hence the proposed software based on ABAQUS, is used to solve the stark dynamic cursor fix. But to reduce the simulation time, But to reduce the simulation, time Analysis time than the actual amount of time the device is brought down in large quantities. According to proposed criteria ABAQUS, it is necessary in the case of reduce the time to analyze the problem of quasi-static, should not the amount of kinetic energy in the piece more than 5% of the energy is transformed section. After performing simulations at each stage of the two values is extracted and compared. These values are fully met criteria has ABAQUS. The amount of kinetic energy in all simulations in this study, is also less than 0.001 of the internal energy ingot.

3. DISCUSS ABOUT THE RESULTS OF SIMULATIONS

3-1. ASSESSMENT OF SIMULATION RESULTS

Before using the results of simulations to check the parameter, it is necessary to show the validity of the simulation. To do this, a process that was described in the previous section, in case of the frictionless case and ingot with square cross, a=b=10(mm) is simulated. Then put shaping force in relation to an analysis of previous research to compare.

Alkorta and Sevillano [8], have suggested equation (3) for calculating the forces shaping the steady-state process.

$$P_{\mathrm{EACE}} = \frac{P_{\mathrm{EACE}}}{S} = \left(\frac{K}{n+1}\right) \times \left\{ \left[\left(\frac{\sigma_0}{K}\right)^{\left(\frac{1}{n}\right)} + \left(\frac{2\cot\left(\frac{\Phi+\Psi}{2}\right)+\Psi}{\sqrt{3}} \right) \right]^{(n+1)} - \left[\right. \right. \quad (3)$$

The equation (3) FECAE and PECAE, force and force forming respectively, S is cross-sectional area of ingot and σ_0 is the initial yield stress. K and n are the property of ingot material that described in pervious Section.

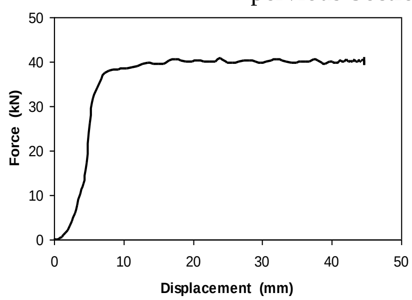


Figure 4. Chart of Energy - punch displacement obtained from finite element simulations for conditions (μ=0, Φ=90°, R=5(mm), Ψ=36.86°)

Table 2. Comparison of forming force analysis and finite element for the process conditions

Finite element force	Analytical force	Percent error
40764 (N)	41500 (N)	1.8 %

Figure 4 shows graphs shaping force that in terms of displacement pines that obtained from finite element simulation. The comparison result of the finite element with analytical equation (3) in Table 2 is shown. Negligible error of these two forces in Table 2 is made clear validation of the simulation results.

3-2. EVALUATING EFFECT OF TWO ANGLE-STEP FORM

3-2-1. FORM WITH AN ANGLE 90°

After simulation finite element of the process, for single and two-stage molding angle 90° values for displacement of the punch force and value and distribution of plastic strain in elements after simulation from the ABAQUS software has been extracted. In figure (5) plot of force versus punch displacement is observed. According to figure (5), a two-level form of angle-changing force in shaping the ECAE process. The changes are as follows.

1. Reduce the maximum force required to form.

2. Delayed time to reach shaping force in their maximum, which may lead to reduce the impact of mold and mandrel.

Reduction of maximum force in the case of two-stage of this process that is the result of dividing the given format, could be reduce cost-cutting shaping. This means that, by reducing the shaping force of a punch can be used with lower compression force. Also increases reaching its maximum power to shape and mold punch is also reduced damage to the device. So here's a two-stage angle form of power aspect was effective.

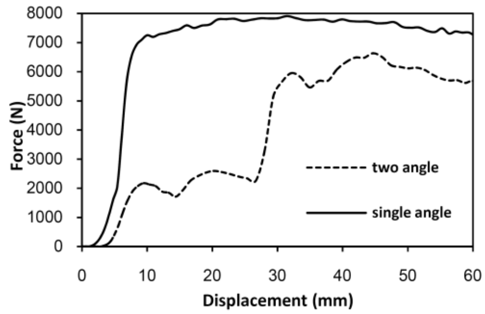
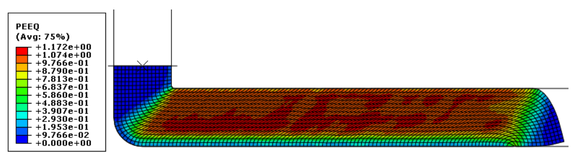
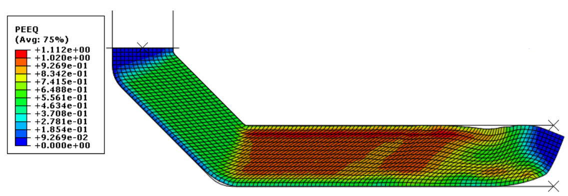


Figure 5. Diagram of force - displacement format and single-step process
ECAE die angle 90°



(A)



(B)

Figure 6. Distribution of equivalent plastic strain (PEEQ) ECAE process for molding
Single-stage and two-stage molding angle 90°
(A) is a single frame, and (B) is a two-stage framework

But as mentioned to the judge about using of this type of form should view the amount and distribution of plastic strain in the ingot make decision. In figure (6) we can observed distribution of plastic strain in the form of single and two-stage molding angle 90°. As it is observed in Figure (6) plastic strain distribution in the ingot for the two-stage format when the channel length is d=25(mm), there is a good distribution in ingot. Also the single step form has the appropriate uniform in strain distribution.

But for a final conclusion about the plastic strain in the ingot is to discuss the amount of plastic strain. To compare the value of the plastic strain is used average of plastic strain equivalent to elements passed out in output channels in both position (Figure 6). This value of average equivalent plastic strain (PEEQ) of each element at the end of each simulation process from the ABAQUS software has been extracted. In Table (3) these values are observed.

By comparing the results of two format position, single and two-stage in Table 3 can get that for example the case study, Average equivalent plastic strain in the ingot output of Single template is about 0.1 more than two-level formatting. Thus, two-stage angle to angle template format $\Phi_1+\Phi_2=90°$ can leads to a slight decrease in the average equivalent plastic strain.

Table 3 - Comparison of plastic strain and maximum forming force between two single and two-stage template templates angle 90°

Uniform distribution of plastic strain	Comparing the The peak shape		Comparison of Average Equivalent plastic strain		States Given format
Good	17.5% Difference	7907 (N)	14% Difference	0.859	$\Phi=90°$
Good		6633 (N)		0.746	$\Phi_1+\Phi_2=90°$

But should not in the section of shaping force reduction also be ignored in the two-stage formats. Also in Table (3) a comparison between single-stage and two-stage framework 90° of the force has been conducted. As can be seen, in this prototype simulation framework for angle 90°, a two-level form angle of about 17.5% percent is cussed Shaping force reduction.

3-2-2. TEMPLATE WITH ACUTE ANGLES 75° AND 60°

First Shaping force in the angle format Φ=60° and Φ=75° in Single-stage and two-stage framework is compared. Figure 7 shows Graph of force - displacement ECAE process to form acute angles. Fig (7) in acute angle in extrusion process with the cross-channel angular, two step of angle format has also strong influence in shaping.

For better comparison shaping force in the form acute angles, the results in Table 4 are compared. By comparison tables (3) and (4) we can conclude that percent reduction in force, forming acute angles form in the two-stage molding angle is more that angle format Φ=90°. According to table (3) Shaping force in the form of two-level reduction in angle, for example for an angle form Φ=90°. Is about 14%. This value for the angle format Φ=75° is about 20.5% and for angle format *Φ*=60° is about 26%. So it can be concluded that if the angle format is smaller, the effect of two steps angle of format in reduction of shaping force is further.

Figure 7. Force versus displacement in two-stage ECAE process and in the acute form of single angles 75° and 60°

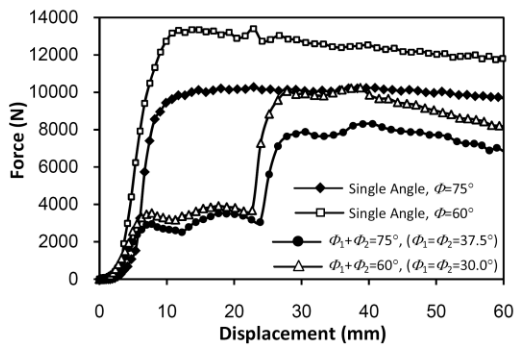
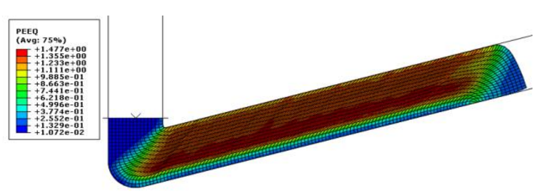


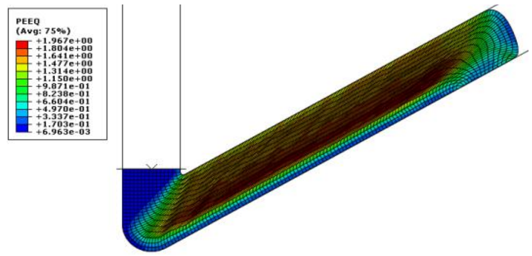
Table 4. Comparison between the shaping force in the form of single and two-stage template form acute angles 75° and 60°

Comparing the peak shape		Angle Form
20.5% difference	10236 (N)	Φ=75°
	8312 (N)	$\Phi_1+\Phi_2=75°$
26% difference	13355 (N)	Φ=60°
	10249 (N)	$\Phi_1+\Phi_2=60°$

After reviewing the shaping force in the form of a two-stage acute angles, the effect of two- stage of angle format in distribution and amount of plastic strain for the angle format Φ=60° and Φ=75° is checked. In Figure (8) plastic Distribution of strain equivalent (PEEQ) in single and two-stage molds and for angles format Φ=60° and Φ=75° can be seen. By observing the form (8) and the results (Table 5) We found that in two-level form than the single the average equivalent plastic strain elements of cross-channel output was reduced. Also the plastic strain distribution in two-stage is more uniform than the single template.



(A)



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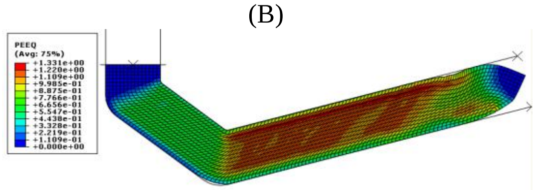

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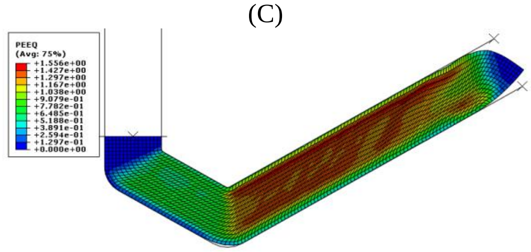

(D)

Figure 8. Distribution of equivalent plastic strain (PEEQ) ECAE process template single-step and template for the form acute angles

A. $\Phi=75°$, B. $\Phi_1+\Phi_2=75°$, C. $\Phi=60°$, D. $\Phi_1+\Phi_2=60°$

Table 5. Comparison between the amount of plastic strain in the form of single and two-stage template form acute angles 75° and 60°

Average equivalent plastic strain		Angular form
About 12.5% difference	1.01	$\Phi=75°$
	0.893	$\Phi_1+\Phi_2=75°$
About 13.5% difference	1.2	$\Phi=60°$
	1.03	$\Phi_1+\Phi_2=60°$

4. CONCLUSIONS

1. The two step of angular format reduces the maximum force in shaping the ECAE process that this is due to breaking the angle format into two stages. Also with two step angular format increases the time to reach maximum shaping force in the process.

2. With two step of angular format has significant role in the uniform plastic strain distribution ingot ECAE process.

3. For acute angular form the ECAE process, two step of angular format has more effective than non-acute angular in reduction necessary force for shaping.

4. In general for two step of angular format is concluded that with the importance of reducing power in the process of shaping the form of two-stage ECAE can also be used as a new solution. But it should also be noted that if there are no constraints shaping force and also maximum shear strain created in a single step of the process is the main target, using this method is not recommended.

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