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Numerical Simulation of INCONNEL 625 Alloy Deformation Behaviors Using Equal Channel Angular Extrusion Process With Different Die Angles

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Abstract: *Extrusion is a process in which the work piece is forced to flow through a die opening by applying compressive force to produce a desired cross-sectional shape. In this process a few significant drawbacks are presented like only single pass process; surface cracking occurs due to the extrusion temperature, friction and high speed of ram. Sometimes with lower temperatures the extruded product will temporarily sticks to the die. To overcome these drawbacks, the equal channel angular extrusion (ECAE) is introduced. ECAE is a special deformation technique. This ECAE process is significant for cold and hot work; it can perform without changing the cross-sectional area of the deformed part. The area of cross section of the channel is equal in entry and exit. High plastic strains were introduced into the bulk material without changing the cross-sectional area. ECAE process is to control the material structure, texture and physical, mechanical properties are briefed in detail. Inconnel 625 material is processed by ECAE method at 900^0 c temperature. The die profile uses inner corner angles of (φ) =115°, 135°and 160° outer corner angle (ψ) of 6°, punch profile with a radii of R=4.75mm and height of 50mm are simulated using DEFORM software. In this paper we have to find out which die channel angle is optimal from load-stroke curve and energy – stroke curve.*
Keywords: *ECAE, DEFORM, Die channel angles, Load, Stroke, process parameters; Deformation behavior;*

I. Introduction

Equal channel angular extrusion (ECAE) is a metal deforming technique. It is a technique for producing ultra fine grain structures in submicron level by introducing a large amount of shear strain into the materials without changing the Billet shape or dimensions. A grain refinement is one of the important methods to improve the mechanical properties of Inconnel 625 alloys; especially their strength and ductile properties can be changed by equal channel angular extrusion (ECAE). Inconnel 625 material is used in jet engines and chemical processing equipment. The ECAE process is most widely used in industry; however, still it is followed on experimental methods which are cost effective.

Equal channel angular extrusion is being used in the field of in automotive industry, in military and aerospace industries. Many research studies have been carried out on the numerical simulations of equal channel angular extrusion process. The FE study is conducted to analyze the plastic deformation zone and evolution of working load with ram displacement during single pass of ECAE. They simulated the ECAE of two key characteristics of the morphology and strain distribution observed.

In ECAE process different tool angles was used to analyze the effect of strain homogeneity and deformation behavior of extruded material. The result found that the optimal strain homogeneity in the sample with lower dead zone formation can be achieved with channel angle of 90° and outer corner angle of 10° [1]. The effect of stress- strain and punch force can be calculated using different die angles. The result found that the peak punch force was decreased gradually with increase in channel angle. The effective strains were achieved with channel angle of 90° [2]. The effect of fracture toughness was investigated using AZ31 magnesium alloy processed by ECAE. The result found that the fracture toughness was improved by the ECAE process. This was possible by large elongation-to-failure and high strain hardening exponent due to the modified distribution of basal texture [3].

The effect of indentation behavior was processed by ECAE using different bending angles. Using dislocation dynamics, the result found that the initial dislocation density increases with the decrease in the bending angle at the macroscopic yielding during the indentation. For the same indentation load, the plastic energy dissipated in the indentation increases with increasing bending angle [4]. The effect of friction can be investigated between work piece and die during ECAE process. The result found that forming loads varied very sensitively depending on the friction conditions [5]. Pure aluminum billets were ECAPed up to four passes, the results indicated that there is a great improvement at the hardness measurement, yield strength and ultimate tensile strength after ECAP process. The elongation to failure and impact energy has been reduced by 23% and 50% [6]. The 6063-T835 aluminum alloy was processed by ECAP up to six passes. The materials were tested by uniaxial tensile test. The result found that the ECAP process increases the mechanical properties [7]. The Al was process by forward-extrusion and ECAP. This method was superior to conventional extrusion. The result found that Al particles with full density and excellent mechanical properties [8].

II. Literature Review:

Li *et al* analyzed the formation of the plastic deformation zone (PDZ) and evolution of the working load along with the ram displacement in a single pass of equal channel angular extrusion (ECAE) with an intersection angle of 90◦. This study explored systematically coupled with the effects of material response, outer corner angle ($\Psi = 0^{\circ}, 45^{\circ}$, or 90°), and friction on ECAE deformation. Effective strain calculations are compared with various analytical models and it is directly an account for the PDZ tends to perform better [9].

Nagasekhar *et al* investigated about the stress and strain histories in equal channel angular extrusion/pressing. In this study to produce sound ultrafine grain billets and to design an optimized ECAE die, the knowledge of stress-strain histories, and punch force requirements are very important. This analysis can be carried out by the finite element analysis code was Abaqus/Explicit for a range of different channel angles. The result of this analysis the peak punch force decreased gradually with the increase in channel angle [10].

Luri *et al* (2006) studied about the new configuration for equal channel angular extrusion dies. This process was used to impart severe plastic deformations to processed the material and improving the properties of the materials and reducing the grain size. This new configuration of die has more advantage compared to conventional die. The new die was obtaining higher plastic strain in each passage than conventional die. This analysis was to determine how the variations are effected on die geometry. The result of this analysis was both finite element method and analytical method will allow us to affirm that by using this new die configuration, it is possible to achieve higher deformation values per ECAE passage [11].

HU Hong-jun *et al* studied about the die structure optimization of equal channel angular extrusion for AZ31 magnesium alloy based on finite element method. In this analysis DEFORM-3D finite element code was used. The die was designed in three dimensional geometric models with different angles and with or without inner round fillets in the bottom. The process parameters, stress-strain data, temperature of die and billet, and friction coefficient on deformation process were discussed. The result of this analysis the equalent strains are increased by comparing the 3D FEM results with theoretical calculations because of thermal and friction conditions. The lubrication condition was important to plastic deformation. The deformation homogeneity caused by fillets of the outer corner is larger [12].

Basavaraj v patil et al studied about the influence of friction in equal channel angular pressing. The friction between die and work piece has most influence on the on the extrusion pressure and flow in the process. This analysis was carried out using the ABAQUS software. The three dimensional finite element analysis was using for different values of coefficient of friction to understand the influence on material flow, pressure and strain homogeneity in equal channel pressing. The result of this analysis was if the friction was increased the corner gap decreased due to back pressure. The inhomogeneity in strain distribution decreases with increase in friction until the backpressure is just sufficient to fill the corner gap [13].

Hao Li *et al* studied about the selection of outlet channel length and billet length in equal channel angular extrusion process. In this work, the finite element analysis was used. Deformation behavior of the material during the equal channel angular extrusion of a typical strain hardening with different combinations of outlet channel length and billet length were simulated. The result of this work was evaluated in terms of strain heterogeneity along the longitudinal direction, punch load-displacement curves, shape of the deformed billet. The shorter outlet channel leads to a longer steady state region and lower working load. The effect of outlet channel length was attributed to the friction forces in the outlet channel. The steady-state region in the billet increases with the billet length-to-width ratio until the ratio reaches a critical value [14].

III. Methodology:

3.1 Base material and process parameters:

The Inconnel 625 material is used in FE simulations. The considered parameters for the simulations like coefficient of friction, punch speed, die angles and die inner corner radii are shown in Table 1.

Table1: Process parameters for simulation

Process Parameter	Value
Coefficient of friction (μ)	0.25
Punch speed (mm/sec)	15
Die channel angles	$115^{\circ}, 135^{\circ}, 160^{0}$
Die outer Radii	6

Mesh elements	32000
Temperature	900^0c

3.2 Modeling and Simulation of ECAE process:

For the simulations, the tools required for the test punch and die were generated as shown in Figure 1 using CAD modeling. Simulations of ECAE were performed using a finite element code. The 3D models of the tools are shown in the figure 2. A base material of diameter 9.5mm was used with a height of 50mm. The tools used were die with angles of 115°, 135° and 160°. A uniform meshing elements of 32000 was used throughout the simulations. The yield strength and frictional coefficient were kept constant. The punch speed was considered to be 15mm/sec. The downward stroke to the punch was given with a velocity of 15mm/sec and die-punch corner radii used 6 mm was considered. From the simulation results the deformation behavior of billet was evaluated.

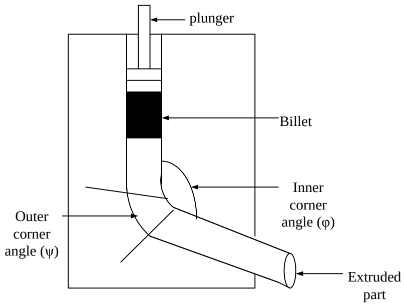


Figure1. 2D modeled tools

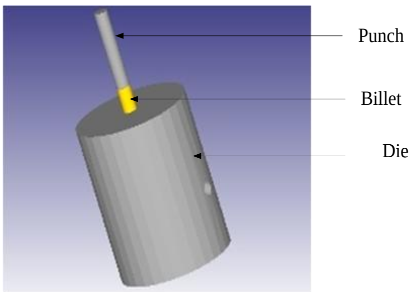


Figure2. 3D modeled tools

IV. Results And Discussions

In order to give an overall view of the Energy rate and stroke as well as the load required for the extrusion for deformed sample at the end of a single pass was examined. The ECAE process simulation was then carried out at 900^0 c temperature for different die angles by taking into consideration realistic behavior of the material.

4.1 Deformation behavior of the sample

4.1.1 Effect of load-stroke curve

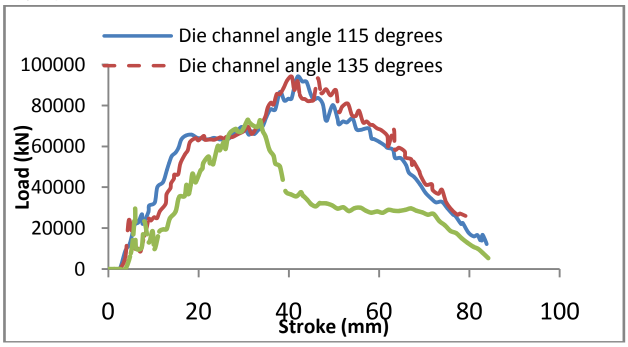
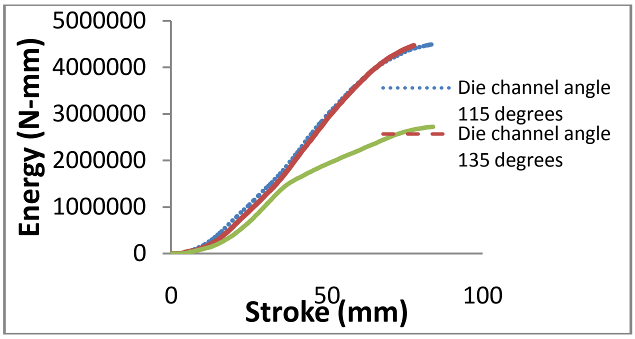


Fig.3. Load-stroke comparison at different die angles during ECAE

The load-stroke curve is investigated and is shown in the following figure 3; the load required for die channel angle 115 & 135 degrees is very close compared to other die channel angle. Whereas the load required for die channel angle of 160 degrees is less.

4.2 Effect of energy-stroke curve

The energy-stroke curve is investigated and is shown in figure 4; the energy required for die channel angle 115 & 135 degrees is very close compared to other channel angle. Whereas the energy required for die channel angle of 160 is less.



V. Conclusion

The following conclusion has been made from the above investigation:

The deformation behavior was studied for different tool angles by considering the influence of material parameters of an Inconnel 625. The results indicate the importance of taking into consideration the rate sensitivity since the mechanical variables (load, energy and stroke required) are rate dependent.

- The load as well as stroke required for die channel angle of 135 degrees is more.
- The load as well as stroke required for die channel angle of 160 degrees is less.
- The energy as well as stroke required for die channel angle of 115 degrees is more.
- The energy as well as stroke required for die channel angle of 160 degrees is less.

Further it is now essential to combine the modeling analysis of the deformation behavior of samples during ECAE with multiple pass and experimental approaches.

References

[1]. A.V. Nagasekhar, Yip Tick-Hon (2004) optimal tool angles for equal channel angular extrusion of strain hardening materials by finite element analysis, *Computational Materials Science* 30 489–495.

[2]. A.V. Nagasekhar, Yip Tick-Hon, S. Li, H.P. Seow (2006) Stress and strain histories in equal channel angular extrusion/pressing *Materials Science and Engineering,* A 423 (2006) 143-147.

[3]. Hdetoshi somekawa, Toshiji Mukai (2006) Fracture toughness in Mg–Al–Zn alloy processed by equal-channel-angular extrusion *Scripta Materialia,* 54 633–638.

[4]. Fuqian yang and Kenji Okazaki (2007) Indentation behavior of aluminum processed by equal channel angular extrusion: Effect of bending angle*, Scripta Materialia,* 56 185–188.

[5]. Basavaraj V Patil, Uday chakkingal and T S Prasanna kumar (2008) Influence of friction in equal channel angular pressing – a study with simulation *Metal* 13-15.

[6]. F. Al-Mufadi, F. Djavanroodi (2014) Finite Element Modeling and Mechanical Properties of Aluminum Proceed by Equal Channel Angular Pressing Process, *International Scholarly and Scientific Research & Innovation* 1411-1416.

[7]. Vasile Dănuţ cojocaru, Doina răducanu, Nicolae şerban, Ion cinca, Rami ŞABAN (2010) Mechanical behavior comparison between un-processed and ECAP (equal channel angular pressing) processed 6063-T835 Aluminum alloy *U.P.B. Sci. Bull., Series B, Vol. 72*, 193-202.

[8]. M.H. Paydar, M. Reihanian, E. Bagherpour, M. Sharifzadeh, M. Zarinejad, T.A. Dean (2008) Consolidation of Al particles through forward extrusion-equal channel angular pressing (FE-ECAP), *Materials Letters*, 3266–3268.

[9]. S. Li, M.A.M. Bourke, I.J. Beyerlein, D.J. Alexander, B.Clausen (2004) Finite element analysis of the plastic deformation zone and working load in equal channel angular extrusion, *Materials Science and Engineering* 217–236.

[10]. A.V. Nagasekhar, Yip Tick-Hon, S. Li, H.P. Seow (2006) Stress and strain histories in equal channel angular extrusion/pressing *Materials Science and Engineering* 143–147.

[11]. R. Luri, C. J. Luis, M. A. Sebastian (2006) a new configuration for equal channel angular extrusion dies, *manufacturing engineering* 860-865.

[12]. HU Hong-jun, ZHANG Ding-fei, PAN Fu-sheng Die structure optimization of equal channel angular extrusion for AZ31 magnesium alloy based on finite element method (2010) *Transaction of nonferrous metals society of china*, 20.259-266.

[13]. Basavaraj V Patil, Uday Chakkingal, T S Prasanna Kumar (2008) Influence of friction in equal channel angular pressing – a study with simulation, *Metal* 13-15.

[14]. Z.Q. Fan, T. Hao, S.X. Zhao, G.N. Luo, C.S. Liu, Q.F. Fang (2013) The microstructure and mechanical properties of T91 steel processed by ECAP at room temperature Journal of Nuclear Materials 434 417–421.