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Simulation study on the material stress distribution respect to different angle of ECAP

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Abstract: This research study was centred on the influence of channel angle towards stress distribution of material aluminium alloy 5083. The size of the grain is related to the mechanical properties of material. Equal channel angular pressing (ECAP) is a process to produce ultrafine-grained, a method for deforming materials in such a way that a strong mechanical properties material is generated while the dimensions of the work piece remained unchanged. Die channel angle is one of the parameter in ECAP. To design a die channel angle, it is important to understand the effect of it with material stress distribution. A simulation using ABAQUS CAE has been carried out at channel angle 90°, 110°, and 130° to understand the effect die channel angle toward stress distribution. The die channel angle are designed differently to see the effect of stress distribution when the work piece passed through the channel angle. The grain structure was assessed at the point where the die's channels angle intersected. The analysis obtained in this study shows the result of the influence of die channel angle towards stress distribution. It is understood that the channel angle affect the mechanical behaviour as the angle decrease from 110° to 90°, the higher the stress occur at the channel angle.

Keywords: ECAP, Aluminum, ABAQUS CAE, Die Channel Angle

1. Introduction

The process of SPD have been widely used according to (Gzyl et al., 2016) for the specialist toward characterization modification, and development due to its unique physical and mechanical properties inherent to ultra-fine grained materials. In the 1980s at Minsk in the former USSR, Segal and colleagues introduced this equal channel angular pressing (ECAP) process with their main purpose was to develop a metal forming process with a high strain rate.

The idea of SPD comes from deforming a material in a tight space while it lets the work piece to accumulate plastic strain up to the enormous magnitudes without material fracture/failure. For the past few decades, from previous study (Sanusi et al., 2012) severe plastic deformation (SPD) has been a centre of research for the fabrication of bulk nanostructured and ultrafine-grained (UFG) materials. ECAP is which the process of pure shear deformation can be repeatedly imposed on materials so that

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an intense plastic strain is produced with the materials and remained cross-sectional dimensions of the work piece unchanged. (Azushima et al., 2008)

Through grain refinement using ECAP, an intensive plastic strain has been introduced into materials after repetitive pressing, it is a clear method to develop the strength of metallic alloys. (Mazurina et al., 2008) ECAP simulation indicated that the effect of corner angle on the strain rate is much sizeable than that of the channel angle due to the enlarged main deformation zone and the decreased deforming time (Ebrahimi et al., 2019). The materials for UFG is prepared by ECAP exhibit in comparison with the conventional grain (CG) size metals and alloys which are substantially higher tensile properties and has sufficient ductility. The effect of grain refinement by ECAP on the improvement of the mechanical properties of Al and its alloys from different previous works have been explained. (Abd El Aal & Sadawy, 2015)

The main advantages of UFG metals are high strength, improved fatigue resistance and has good formability. UFG materials processed by ECAP differ qualitatively and quantitatively from their CG counterparts in terms of their characteristic structural parameters without change of shape, producing materials with ultrafine grains and considerably different properties in comparison with CG materials. (Sklenicka et al., 2012) The grain size can affect the mode of deformation and determines the mechanism of grain refinement. The deformation along the die is inhomogeneous during pressing for various channel angles under different hydrostatic pressure conditions (Samsudin et al., 2015). It has been shown that by changing the microstructure from coarse grain to ultrafine or nanostructure, the possibility of deformation becomes more effective. (Bagherpour et al., 2019) With no doubt, these factors influence the microstructure and finally the properties of ultra-fine grain material. (Parshikov et al., 2013)

2. Materials and Methods

2.1 Materials

The process of producing ultra-fine grained materials using ECAP have attracted industrial interests as a result of the attractive properties of the materials. These materials have mechanical properties that include high hardness, high yield strength, improved toughness and ductility with increasing strain rate. Many types of materials such as aluminium and its alloys have been successfully processed through ECAP. Under some testing conditions of stress and temperature the measured minimum in the pressed materials with ultrafine grain sizes are slower than in the same material in a coarse-grained steady condition appear anomalous for high-purity aluminium.

The materials of the studied are aluminium alloy 5083, the commonly used aluminium are one the materials that succeeded in ECAP process at the time when ECAP was introduced. the properties can indicate how the strain will be when the aluminium alloy passes through ECAP die with the features as mentioned Table 1.

Table 1 : Material properties of Aluminium alloy 5083

Material	**Aluminum 5083**					
Density (kg/m^3)	2650					
Poisson ratio	0.33					
Young's modulus	72e9					
Yield stress	0.01792	15.61876	55.75999	101.3856	199.8434	231.334
Plastic strain	0.00003	0.00009	0.00073	0.00134	0.00344	0.0043

2.2 Methods

The deformation behaviour of a square cross-sectioned sample with dimension 2cm x 2cm x 15cm in an ECAP die with a designated channel angle was simulated using ABAQUS CAE under isothermal plane strain conditions. The material properties assigned were in general and plastic applied on the work-piece. The process tools, including the ECAP die were assumed as discrete rigid parts also a deformable sample was used for the billet. The ECAP die is designed of two channels with identical rectangular cross sections connected through the intersection at a specific channel angle of 90°, 110° and 130°. This study are to produce an ultra-fine grained material using the ECAP technique with all the parameter measured for the dimension of the dies and work-piece in Table 2.

Table 2 : Parameter for die geometry and sample geometry of angle 90°, 110°, and 130°

Part	Length(mm)	Height(mm)	Fillet	Angle(°)
Die internal 1	18	18	0.4	
Die external 1	20	20	0.5	90°
Sample	2	15	-	
Die internal 2	18	18	0.4	
Die external 2	20	20	0.5	110°
Sample	2	15	-	
Die internal 3	18	18	0.4	
Die external 3	20	20	0.5	130°
Sample	2	15	-	

This study we focused on 2D discrete rigid, wire and 200 for the approximate sizes which needs two part internal and external. Each part have its own dimension shown in *Table 2*. The design of the sample must be deformable and shell. The work-piece was assumed as solid, deformable material. Element type of this analysis are CPS4R. The size of mesh are 0.3mm. The number of elements was increased during the first remeshing operation and was maintained constant throughout the simulation. Both internal and external die are assumed rigid and the mesh size is 1mm. The element type of this part are R2D2, a 2-node 2-D linear rigid that used in plane stress.

The assembly are done by create instance using 3 part which includes both internal and external part and the work piece. By creating interaction for the internal and external we use surface to surface contact (explicit) for both die. There is always a non-uniform strain distribution from the top surface to bottom surface of the die and from one end to other end of the deforming work piece. Different loading conditions were simulated, and the difference was the condition at the entry end with respect to that at the exit end, while the geometry, boundary conditions, and meshes were kept the same. Both the inner and outer channel surfaces were assumed to be rigid and stationary by imposing zero displacement boundary condition along the X and Y directions. The reference point are selected as the first boundary conditions with the type of symmetry/antisymmetry/encastre and encastre was selected to observe each direction. For second boundary condition, top edges of the sample was selected and use displacement/rotation step procedure. The value of the displacement at angle 90°, 110° and 130° for Y direction are -30, -40 and -25 respectively. The 500 load maximum are applied at top of the work-piece to extrude the material through ECAP process. The flow method of the simulation shown in the flow chart below in Figure 1.

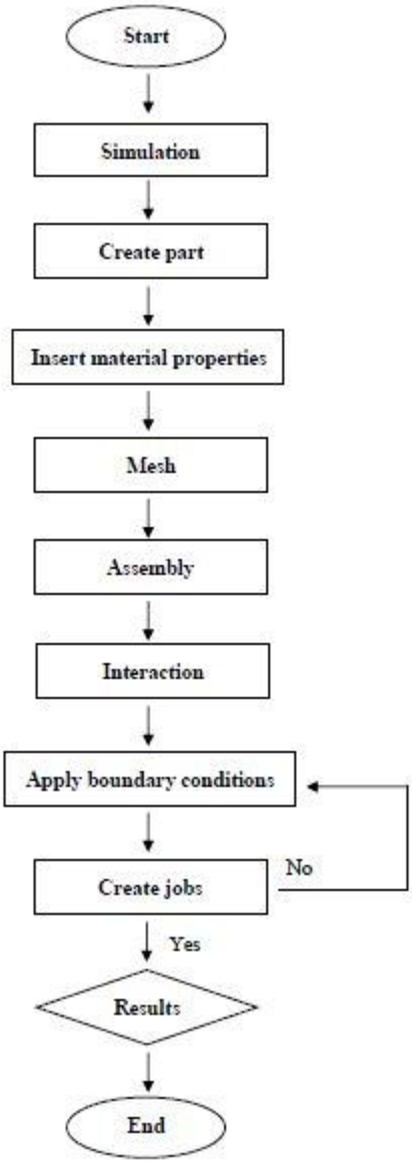

Figure 1 : Flow chart for Simulation using ABAQUS CAE

3. Results and Discussion

3.1 Stress Analysis

Figure 2 shows the result of stress distribution at angle 90°. The result shows that the highest stress distribution occur at the corner angle. The red colour indicate the highest stress area with value of $1.594 \times 10^8\ N/m^2$ stress occurs when the work piece passed through the corner angle where the corner angle has a tight space which compressed the work piece and produce a higher stress area.

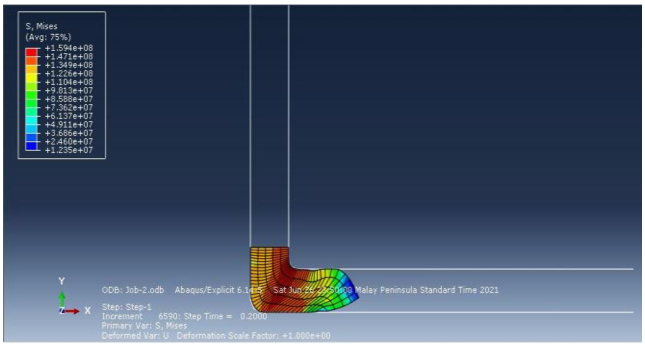

Figure 2 : Analysis for stress distribution at angle 90°

In Figure 3 shows the result analysis of stress distribution at angle 110° and 130°. It is shown in the result that the stress distribution value is less for higher corner angle. It is caused when at a higher value of corner angle, it allows the material to pass through without much resistance. The highest stress value recorded is $5.802 \times 10^7\ N/m^2$ and $1.226 \times 10^8\ N/m^2$ at angle 110° and 130° respectively.

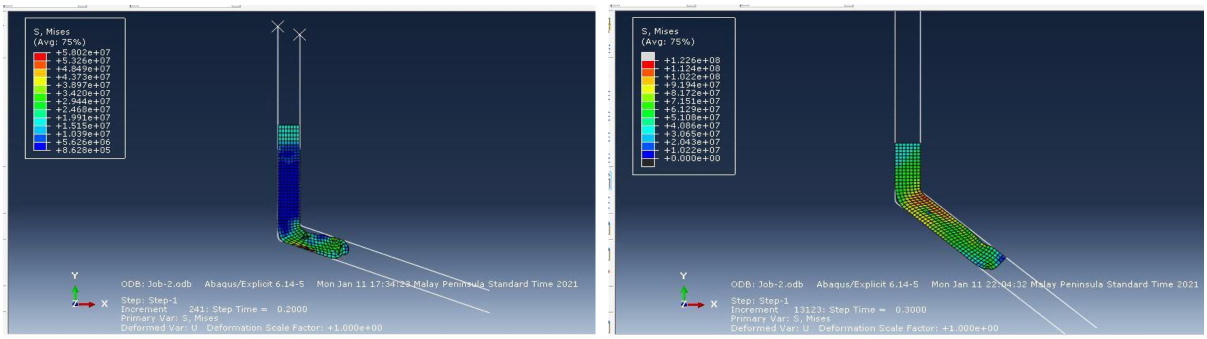

Figure 3 : Analysis for stress distribution at angle 110° and 130°

3.2 Strain Analysis

The pattern of strain as it passes through the die, it will changes along the work piece at its bottom, middle, and top portions. The work piece passed through a die with its specified corner angle, the smaller the angle of the die the higher the value of strain. In **Figure *4*** shows the result analysis for strain at angle 90°. The results proves that the highest strain distribution occurs at the corner angle with value of 1.997.

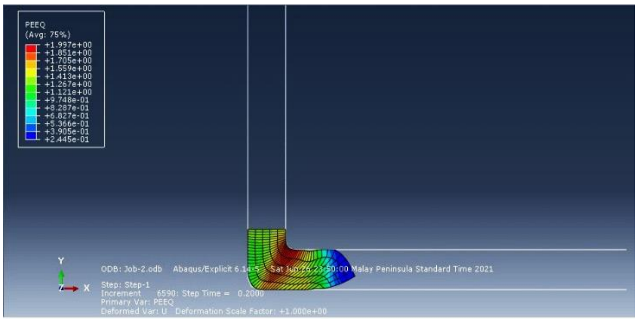

Figure 4 : Analysis for strain distribution at angle 90°

As the work piece passed through the die at 110°, there is a lower strain from top of the work piece until the bottom of the work piece than when the work piece passed through a die at 130° as shown in Figure 5. The strain value are minimal at top and bottom of the work piece as shown in the results, this is because a part of the material remain undeformed at the end of the process.

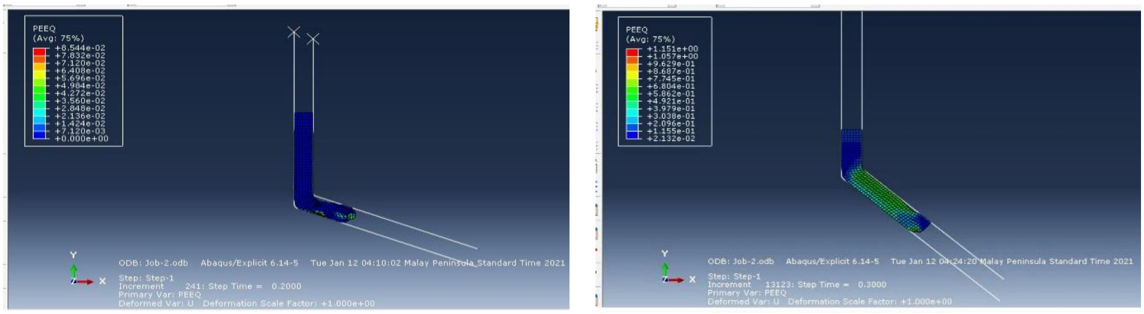

Figure 5 : Analysis for strain distribution at angle 110° and 130°

3.3 Magnitude Analysis

As shown in Figure 6, the magnitude for angle 90° are highest at top of the work piece and it lower at bottom of the work piece. It shows that the angle does not affect that much to magnitude since it does not occur the highest at the corner angle. It can be seen that the highest magnitude occur with value of 1.600 at top of the work piece.

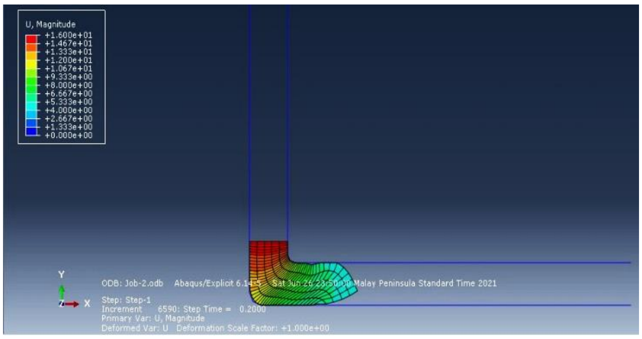

Figure 6 : Analysis for magnitude at angle 90°

Though, for angle 110° and 130° as shown in Figure 7 shows almost all the work piece from top to bottom has highest magnitude. The effect of die channel angle on the magnitude influence the homogeneity of the work piece. As can be observed, the increasing of die channel angle cause a higher magnitude in the whole work piece with value of 8.767 and 1.200 at 110° and 130° respectively.

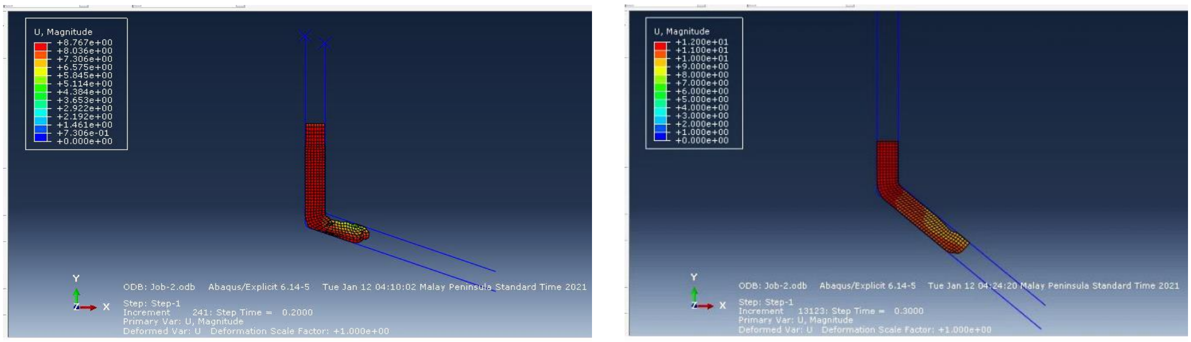

Figure 7 : Analysis for magnitude at angle 110° and 130°

3.4 Reaction Force Analysis

The reaction force during ECAP process are shown Figure 8. As can be observe the reaction force for angle 90° are 0 value. The reaction force occur on the whole of the sample and obtained the same value when entered the die and after passed through the corner angle.

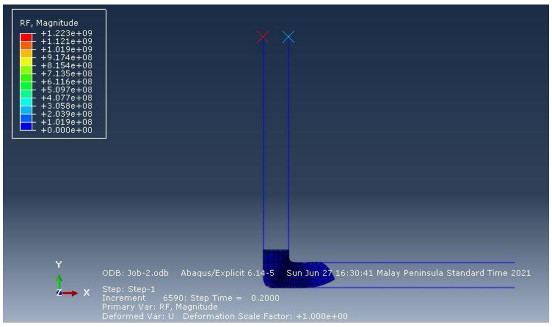

Figure 8 : Reaction force at angle 90°

In Figure 9 shows the result analysis of reaction force for angle 110° and 130°. The reaction force from the sample resulting in the formation of the increasing channel angle. As shown in the analysis. Increasing the channel angle gives the reaction force value at 0 for both analysis. The result is the same with reaction force at 90°.

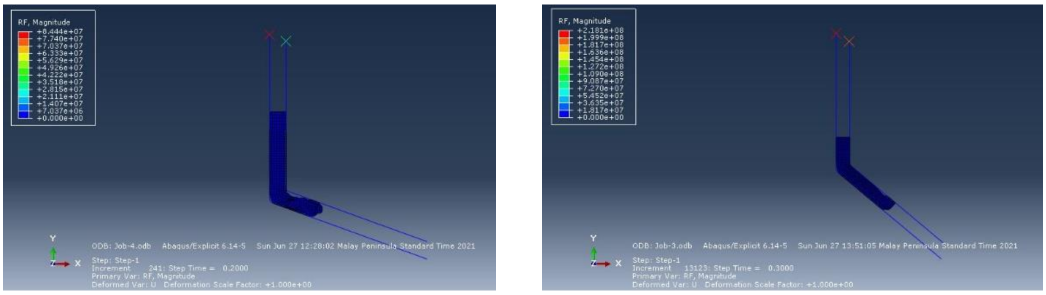

Figure 9 : Reaction force at angle 110° and 130°

3.5 Force Analysis

Figure 10 shows the result analysis of punch force for angle 90°. As can be seen at top of the sample obtain higher value, this happens because of the load applied at top of the sample to punch the sample downwards. The load applied for this angle are 500, if the value exceed 500, the result appeared as error. The highest area of the force are $1.458 \times 10^7 N/m^2$ at the start of the process where the punch push the work piece until before it passed through the corner angle. The result when it passed through the corner angle, the work piece obtain a lower force.

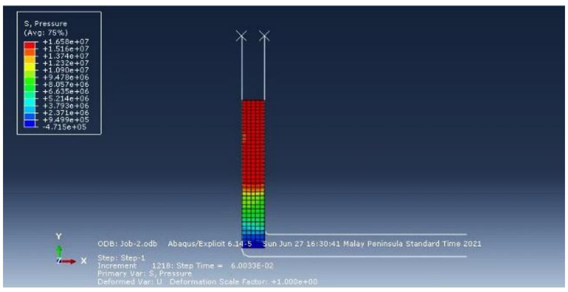

Figure 10 : Force analysis at angle 90°

In Figure 11 shows the result analysis of force at angle 110° and 130° of $2.836 \times 10^7 N/m^2$ and $3.441 \times 10^7 N/m^2$ respectively. The force applied on top of the work piece has proven the results of highest force area start when the work piece forced downwards and has the least force at the bottom of the work piece. Increasing the channel angle influence the sample with a maximum force as the force applied for both of this angle are 500 at maximum.

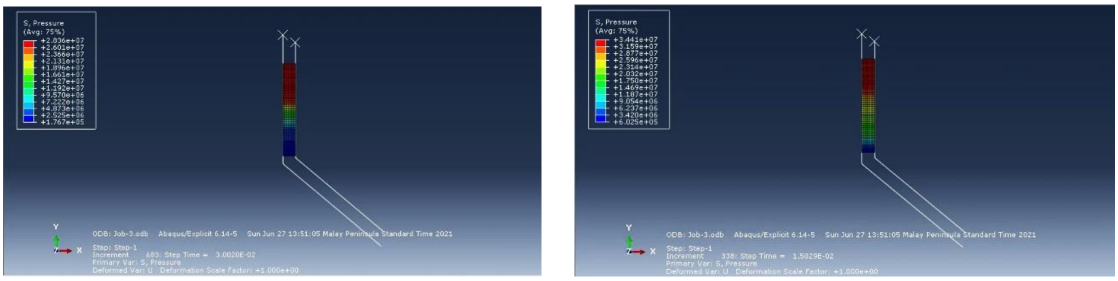

Figure 11 : Force analysis at angle 110° and 130°

4. Conclusion

In conclusion, the objective to determine the influence degree of ECAP parameters on aluminium 5083 is achieved. It has been proven in the result analysis that the angle does affect the deformed sample. It was discovered through simulations that the dies channel angle has a greater impact on the increase in effective plastic strain and maximum punch force. The dies channel angle increment are about 20 increment is influential from the punch force to the effect of stress and strain behavior. The pressing force are required to extrude the sample. The applied force gives the highest area on almost half of the sample since the sample received a 500 load being pushed downwards. The pressing force produce a high strain in the sample at 90° channel angle. By contrasting the simulation results, the increasing die channel angle at 110° and 130° obtained a low strain distribution at value 0 and 4.921×10^1 respectively, so it can be assumed that the applied force do not have any effect on the strain behavior at an increasing channel angle. From the study, it is understood that ECAP dies channel angle can be designed to produce many engineering material with a small grain size and strong mechanical properties.

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