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EFFECT OF EXTRUSION SPEED AND TEMPERATURE ON HOT EXTRUSION PROCESS OF 6061 ALUMINUM ALLOY CHIP

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ABSTRACT

In the present study, an attempt was made to predict the extrusion speed and temperature during the hot extrusion of 6061 aluminium alloy chips by using Deform 3D simulation. The influence of extrusion process parameters, namely ram speed (V_r), preheat temperature (T_{ph}), preheat time (t_{ph}) and extrusion die angle on the responses flow stress and heat distribution was investigated. One of the dies was a flat-face die, which represents a conventional extrusion die design for production of solid aluminium profiles. This study concentrated on improving the understanding of the behavior and the formation mechanism distribution with the aim of predicting the best on parameter process hot extrusion of 6061 aluminium alloy chip by using Deform 3D simulation without lubricant. Ram speed 2 mm/s at 500°C was affecting the amount of heat generated and also the amount of heat loss to the extrusion tooling and made insufficient on quality bonding. In the FEM code, the results of the simulations were compared and confirmed successfully by the experimental results.

Keywords: aluminum chip, hot extrusion, deform 3D simulation, sustainability.

INTRODUCTION

Aluminium alloy, AA6061 is one of the most used high-strength material for automotive structural components. The process of hot extrusion is a promising approach for the direct recycling of aluminium machining chips. The low productivity can however be improved through optimizing the metallurgical conditions of the alloy by applying a homogenization treatment prior to extrusion (Li *et al.* 2004). Understanding the state of stress, strain and the temperature of an aluminium alloy going through a die during extrusion is of great importance for running the aluminium extrusion process, because they are closely related to the surface quality of the extruded products, throughput and scrap rate. There are certain influences of the characteristic factors in the extrusion process. On the other hand, both the state of stress and the temperature are complicatedly related to the extrusion conditions, including initial billet temperature, ram speed, reduction ratio, friction at the interfaces, deformation resistance of the billet material, die geometry, as well as thermal characteristics of the billet material and the tooling (Chanda *et al.* 2000). In the present work, attempts were made to explore the possibilities of using the updated Deform 3D software by a Lagrangian approach to simulate the aluminium extrusion process in the steady state. The simulation model will be prepared and analyzed by FEM tool DEFORM-3D version 11. It was aimed at the prediction on parameter process hot extrusion of 6061 Aluminium Alloy chip by using Deform 3D simulation.

FEM SIMULATION

The one of the die was the flat-face die conventionally used in industry to produce aluminium solids section. The geometry of the machining chips is an important factor in the chip compaction strategy (Güley *et al.* 2013). The process parameters and frictional conditions are presented by billet temperature is 450°C & 500 °C, Extrusion ratio is 11.72, fraction factor at die-billet interface is 0.3 and friction factor at the billet-container interface is 0.9. The chips were compacted into a thick-walled steel tube forming billets of 30 mm diameter and 80 mm length. With a compaction force of 50KN a green density of approximately 2.55g/cm^3 was achieved, which corresponds to 94% of the theoretical density of aluminum. The billets were heated in a furnace to the extrusion temperature of 450 °C and 500°C followed held at this temperature for 1h and then extruded into solid profiles with a cross-section of 10 x 6 mm with a ram speed of 1 mm/s and 2 mm/s using 250T direct extrusion press. The die and container temperatures were both set at 400°C. The geometries of the die, container, stem and billet were generated in AutoCAD and the meshes within their space domains in DEFORM 3D version 11.0 which is a FEM based process simulation system designed to analyze various forming and heat treatment processes. It shows that the initial meshes of the tooling and the billet through the die at its bearing as shown in Figure-1. This die had a bearing length of 23 mm and was designed to produce a cross-shaped solid extruded.

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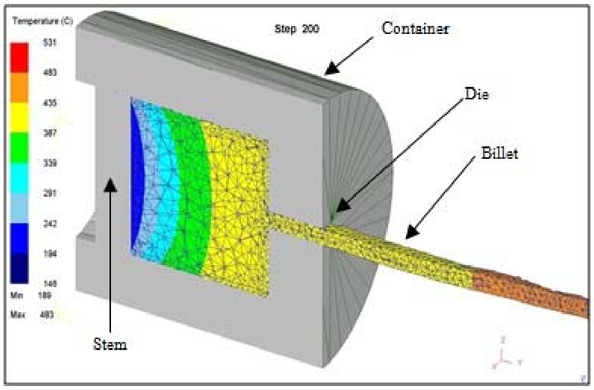

Figure-1. Initial meshes and wire-frame of the billet, container, die and stem.

The specimen was fed into the die for performing the simulation. The dimensions of the parts, the material used and the process parameters defined in the FEM were the same as those in the experiments (Mohammed Iqbal *et al.* 2013). The prismatic billet was characterized by a rectangular section (10 mm x 6 mm) and the initial height was 80 mm. It was meshed by means of more than 40,000 solid tetrahedral elements; however, specific mesh boxes were introduced in both the welding chamber and bearing areas due to severe material deformation occurring in such zones and the required accuracy in variable estimation (Gagliardi *et al.* 2012). The mesh generation is very important for the accuracy of the simulation. The mesh is reformulated at nearly every time step, in order to manage the material deformation. Finally, the tooling was modeled as rigid to reduce the simulation time. The physical properties of the tooling and workpiece process parameters used in the simulations were given in Table-1.

Table-1. Physical properties of the tooling and workpiece.

Properties	AA 6061chip	H-13 tool steel
Density (kg/m^3)	2550	7760
Young's modulus (N/mm^2)	68,950	210,000
Poisson's ratio	0.293	0.30
Coefficient of thermal expansion (mm/mm°C)	22.6 x 10^{-6} for 480°C	28.4 x 10^{-6} for 400°C
Heat capacity (N/mm^2 °C)	2.89	5.6
Thermal conductivity (N/s °C)	180	28.4 for 400°C
Heat transfer coefficient between workpiece and die/container/stem (N/s mm°C)	4.0	4.0
Heat transfer coefficient between die/container and air (N/s mm°C)	0.01	0.10
Emissivity	0.05	0.15

(Deform 3D Simulation Parameter Tools & Metal Handbook)

The initial billet temperature was 450 °C. Tooling temperature was set at 50 ◦C lower than that of the billet to allow part of the heat generated during extrusion to dissipate into the tooling. Extrusion ratio was 11.78:1. Ram speed varied from 1 to 15 mm/s, corresponding extrusion speed varying from 1 to 3 m/min, a range considerably wider than the recommended one of 1–3 m/min (Laue *et al.* 1981). The plastic material model was used for the billets as the billet is assumed to be void-free and the density of billet was taken as the theoretical density of aluminum (Güley *et al.* 2013). The common extrusion parameters for Aluminium Alloy 6000 series used by many researchers are shown in the column of average parameter summary as referring to Table-2. The common preheat temperature is used by previous researcher is 450 °C. Preheat temperature was commonly used at 2 hours by controlling the extrusion container area. Hence, many researchers used ram speed of 1 mm/s in their hot extrusion process (Rahim *et al.* 2015). The effect of process parameters on the final product properties in the hot extrusion process of aluminium chips was studied by several researchers.

Table-2. Summary of current research extrusion process parameter (Rahim *et al.* 2015).

Parameter / Material	AA6060	AA6060	AA6060	AA6060	AA6060	AA6061	AA6061
	V.Guley (2013)	M.Haase (2012)	Cunsheng Z. (2012)	Wojciech Z. (2012)	A.E. Tekkaya (2009)	J.B. Fogagnolo (2003)	Average Parameter
Preheat Temp. (°C)	500	550	-	450	500	-	450, 500
Preheat Time (hour)	2	6	-	-	-	-	2
Ram Speed (mm/s)	1	1	0.15	1	1	1	1, 2

RESULT AND DISCUSSION

Hot Extrusion Process by Deform 3D Simulation

This paper proposed an overview of the approach of FEM analysis of an extrusion process considering 3D modelling. Simulation of the extrusion process is continuously attracting researchers for better understanding the chip formation mechanisms and heat generation in deformation zone. Predictions of the physical parameters such as temperature, stress, strain distributions accurately play important role in producing process engineering of extrusion processes. The simulated results are in good agreement with experimental data, but some phenomena such as peripheral coarse grain and grain growth require a deeper investigation effort (Schikorra *et al.* 2008). The present study was limited to a flat-faced die, but the approach could extend to more type die designs. The extrusion process simulation shown as a Figure-2.

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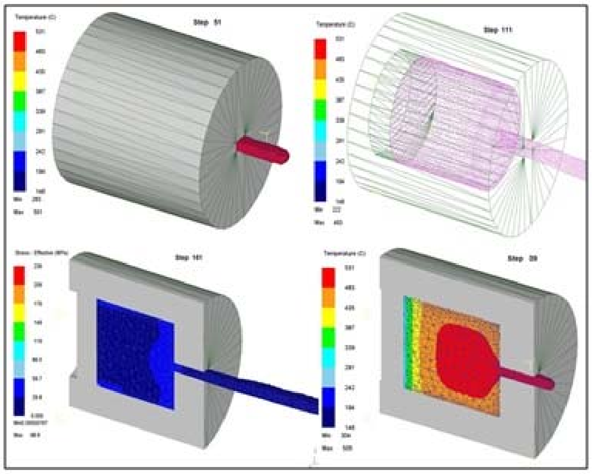
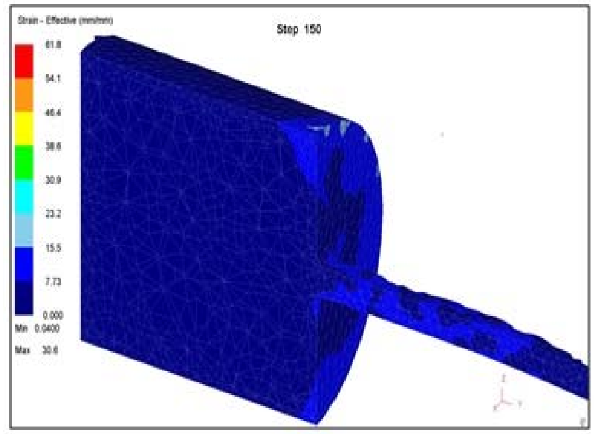


Figure-2. Pattern movement location of hot extrusion simulation.

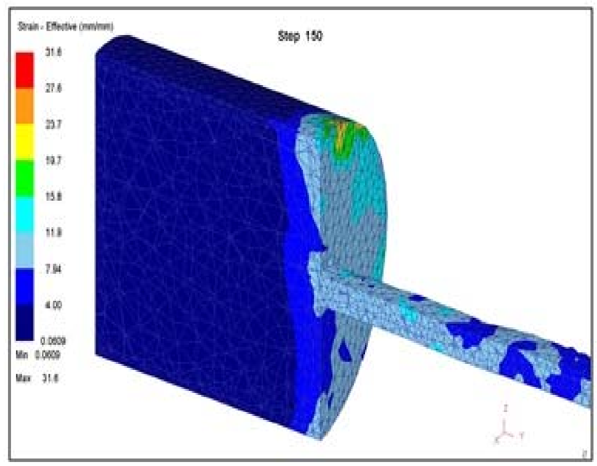
The predicted extrusion pressure/ram displacement diagram and the patterns of the maximum temperature developments can well be utilized to improve the process so that the die pressure will remain invariable and the continuous extrudate temperature increase be suppressed. As extrusion proceeds, deformation spreads toward the rear end and the periphery of the billet and radial flow becomes more significant, leading to the expansion of deformation zone and shrinkage of the dead metal zone (Zhou *et al*. 2003). The most important data obtained from the FEM simulation are tool movements and deformed mesh at each saved step; geometry of tool and workpiece after the simulation process; velocity and displacement; distribution of state variable; chip formation; predicted of extrusion torque and extrusion force; and stress, strain, temperature also damage.

Effect of Ram Speed on the Welding Quality of Extrusion

In the square extruded, the temperature distribution is inhomogeneous and the corners tend to have a high temperature, especially when the reduction ratio is low. Ram speed has a significant influence on the temperature distribution in the billet as a result of complex heat loss and heat generation. The initial temperatures of the billet and extrusion tooling were 450°C and 500°C, respectively. Bonding quality of chips recycled with the flat face die, according to Schikorra *et al.* (2008), extrusion temperature, extrusion ratio and the die shape are significant process parameters controlling the quality of the chip bonding. For all die sets used in the performed experiments, the bonding quality increased with increasing temperature. In the experiment of Ceretti *et al.* (2009), higher temperatures led to a better solid state bonding, measured by optical investigation and micro-hardness tests in the normal direction to the bonding line.



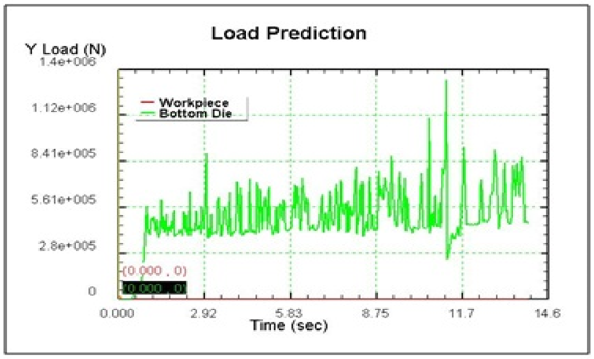
(a)



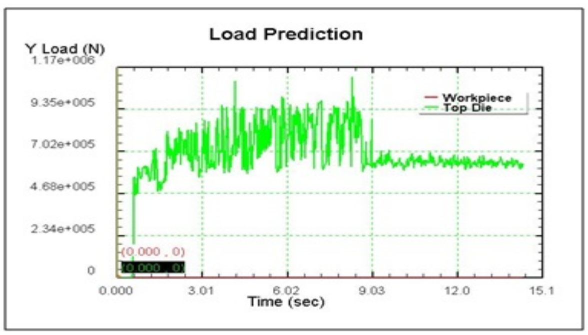
(b)

Figure-3. Strain effective contour profile (a) ram speed of 1 mm/s and (b) ram speed of 2 mm/s.

At the entrance of the square die, strain is more confined and strain gradient larger. The heat flow is basically in the axial direction except that at the front end of the billet (Figure-3). A high extrusion load is needed for breakthrough in a square die and severe shearing in the deformation zone in front of the square die causes a high temperature rise at the initial stage of the extrusion process. The strain effective shown in Figure-3(a) and Figure-3(b) by the ram speed of 1 mm/s is 7.3 mm/mm and ram speed of 2 mm/s is 11.9 mm/mm. By the way, there is a large strain gradient at the die entrance. At this high reduction ratio (11.72:1), the maximum strain is also higher. Chiba *et al.* (2015) shown the contour plot is displayed in the transverse section of the steady deformation region. The predicted extrusion speed shows that the process is in a transient state at the beginning, moves into the steady state and finally change the non-steady state again.



(a)



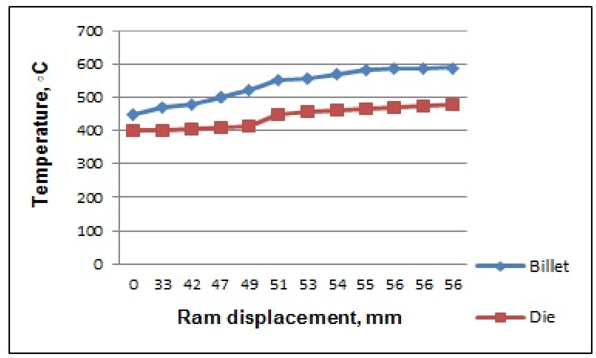
(b)

Figure-4. Predicted extrusion force in [N] on Y direction; ram speed (a) for 1 mm/s and (b) for 2 mm/s.

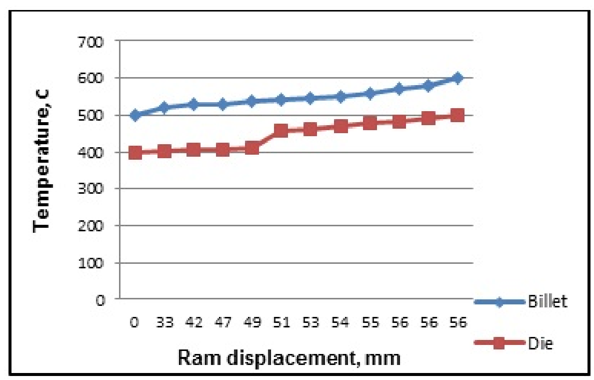
The load prediction showed in Figure-4 (a) and (b) was the predicted extrusion force in Y direction using ram speed 1 mm/s and 2 mm/s. The result showed the effect of ram speed change in temperature distribution. On the other hand the effective strain rate distribution after the ram speed changed from 1 mm/s to 2 mm/s. That at the beginning of the process at a higher ram speed, heat generation is much more and heat loss to the extrusion tooling is much less, with the temperature in the billet core remaining largely unchanged. The simulated remaining billet and extruded profile showing the principle stress distribution. The principle stress value changes with increasing ram displacement and decreasing ram speed, it is increased from the rear side to the die exit side. The temperature in the deforming billet is redistributed throughout the extrusion process from the transient state of the steady-state. Ram speed affects the amount of heat generated and also the amount of heat loss to the extrusion tooling. Moreover, Li *et al.* (2004) showed that a major influence on the temperature values in the remaining billet and temperature distributions. Furthermore, these phenomena demonstrate that with increasing ram speed the temperature of the billet material increases as it enters the deformation zone.

The Temperature Distribution of the Extrudate

The maximum temperature of the extrudate does not coincide with the maximum temperature of the die, and the difference in these two temperatures becomes larger when ram speed is higher. A comparison of the relative variation in the optimal temperature with different process condition is shown as a Figure-5. The temperature evolution of the extrudate after a ram displacement of 0 mm where the measurement of extruded temperature became stable. Variations in temperature during extrusion seem to influence flow behavior in a number of ways. Computer simulation can provide accurate temperature predictions in a complex environment and avoid the difficulties associated with real temperature measurements whose accuracy is influenced by the measuring tool (Chanda *et al.* 2001).



(a)



(b)

Figure-5. Evolution of the maximum temperatures of the extruded and die during the extrusion; (a) at a ram speed of 1 mm/s; (b) at a ram speed of 2 mm/s.

In Figure-5(a) reported an evolution of the maximum temperatures of the extruded and die during the extrusion at a ram speed of 1 mm/s. Based on these observation the initial temperature is slightly more sensitive to the geometry that the ram speed, although the overall variation from the optimum value is small. Normally the temperature of workpiece rises markedly at the beginning. Therefore, full homogenization and fast cooling are a must for economic production of AA6061 extrusions. The maximum temperature is located near the corner of the die entry where strain and strain-rate are concentrated (Li *et al.* 2004).

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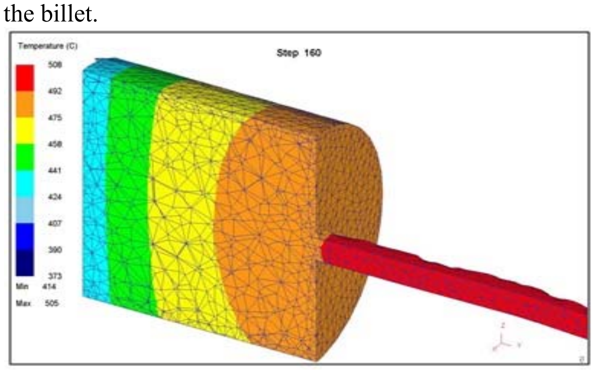
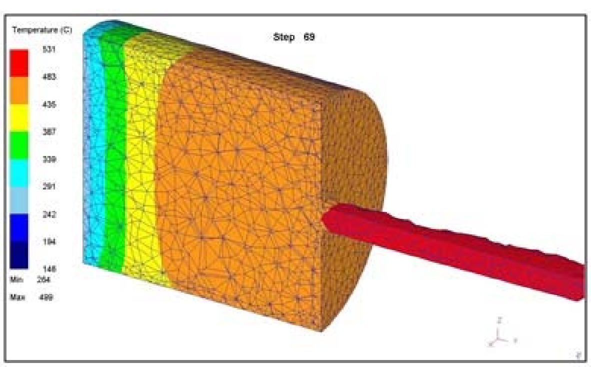
Ram speed affects the amount of heat generated and also the amount of heat loss to the extrusion tooling. Thus the major influence on the temperature values in the remaining billet and temperature distributions. Figure-5(b) shows evolutions of the maximum temperatures of the extruded and die during the extrusion at a ram speed of 2 mm/s. At ram speed of 2 mm/s, a half of the billet has a temperature higher than the initial billet temperature, while another half has temperatures lower than the initial billet temperature. The maximum temperatures become a one of factors that should be considered in determining the optimum extrusion parameter condition.

Therefore, the temperature increase caused by friction factors between the workpiece and the tooling. Also the temperature, contour profile in the extrudate is very sharp, meaning that if taken a section at any point of the square extruded along its length, there will be a temperature variation in the range of 5-10°C. This is because at the higher reduction ratio the section area is smaller and hence temperature can equalize more quickly during the process. As a result, the heat generated is mostly carried out with the extrudate. At a lower ram speed, less heat is generated but the extrusion pressure and flow stress are higher. Chanda *et al.* (2000), reported on the observed difference in the maximum temperature may be because of the same reduction ratio, the square die has a larger contact area for heat conduction from the extrude to the die that has a lower initial temperature than that of the billet.



(a)



(b)

Figure-6. Temperature contour profile; (a) ram speed of 1 mm/s; (b) ram speed of 2 mm/s.

The temperature contour profiles of billet going through the rectangular shape die at an extrusion ratio of 11.72:1, respectively. The developments of the maximum temperatures of the container die and workpiece are given in Figure-6(a), it also shows the temperature distribution along the extrusion process on ram speed for 1 mm/s. For that step the temperature achieved to 505°C. The sudden change of the slope of temperature rise is to be a result of the following factors. The less heat is generated from mechanical work due to the sudden decrease of the extrusion pressure. The results revealed on Figure-6(b), it also shows the temperature distribution along the extrusion process on ram speed for 2 mm/s. These figures show that the velocity distribution at the die exit is approximately constant and temperature variation along the die length is very small.

Furthermore, by decreasing billet length leads to frictional heat. Zhou *et al.* (2003) found that after leaving the die bearing the extrudate carries away with part of the heat generated. The plunger and the other assembly features have been removed for better clarification. It is apparent that the maximum stress occurs in corners, because these regions are in contact with the die interior surfaces. Since the heat transfer was higher at the die edges, the specimen was hot extruded. According to Mohammed Iqbal *et al.* (2013), when the heated billet is inserted into the die, the temperature of the billet will be transferred to the die interior surfaces. It is concluded from the simulation results that the mode of deformation is also the important factor in reducing the grain size. In this way, better welding performance and reduced tooling stress can be reached, looking contemporary at the process performance and at the environmental impact. On the other hand, the results of the work can be used for optimizing the parameters of hot extrusion process of AA6061 aluminium alloy.

CONCLUSIONS

Among the multiple process parameters in aluminium extrusion, the extrudate temperature is the most important because it determines the quality of the product and indicates the possibility of increasing extrusion speed. The most important process variables affecting both the quality of the extruded and the productivity of the extrusion process by giving pressure power capacity and given sizes and shapes of container and die, billet temperature and ram speed. Ram speed 2 mm/s affects the amount of heat generated and also the amount of the heat loss to the extrusion tooling. Result shown the temperature 500°C on the cross-section of extrudate becomes more inhomogeneous at a higher ram speed. The temperature always rises occurred at the beginning stage and the temperature tends to be stable as the ram travels further. Simulation models can be used as a tool in the prediction of extrusion forces and surface quality. The simulated results are in good agreement with summarizes data, but some phenomena such as peripheral coarse grain and grain growth require a deeper investigation effort.

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