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European Journal of Advances in Engineering and Technology, 2017, 4 (5): 374-382

Research Article ISSN: 2394 - 658X

Parametric Effects on Backward Cup Extrusion Route for 6063-T6 Aluminum Alloy

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ABSTRACT

This paper is focused on examining the parametric effects on backward cup extrusion of aluminum billet. Four parameters including Temperature, Punch displacement, Billet radius and Time were considered in the course of the study. It was observed that the higher the percentage reduction in area, the higher the temperature increase during the extrusion process. The effect of an increasing billet length showed a corresponding increase in the extrusion pressure, whereas, the extrusion pressure increased as extrusion ratio increase. Extrusion speed varied directly with metal temperature and pressure developed within the container. However, the extrusion force depended on the flow stress of the billet material, extrusion ratio, friction condition between the billet and container, friction condition of the die material interface, initial billet temperature and the extrusion speed. Hence, this study becomes essential for the selection of the right parameters for optimal extrusion process of metals.

Keywords: Extrusion, Billet Temperature, Punch Displacement, Billet radius, Time

INTRODUCTION

Aluminium is one of the most widely extruded metals with a near perfect malleable property that makes it suitable for extrusion processes. Compared to other metals, aluminium's coefficient of linear expansivity is relatively large and can easily be worked in hot or cold conditions using most machining techniques such as cutting, punching, bending, etc [3, 11]. The term extrusion is applicable to a wide range of manufacturing route where material is confined in a container and external force is applied to compress the material through an orifice to obtain the shape required. Extrusion is oftentimes classified as direct or forward extrusion, indirect or backward extrusion, hot and cold extrusions, vertical and horizontal extrusion. Forward extrusion applies the principles of forcing a metal to flow in the direction of the same ram used in applying pressure.

In other words, the ram maintains a close fitting with the die cavity to prevent displacement of the extruding material, by so doing, the die head is held stationary and a moving ram forces the metal through it. However, backward extrusion which is the primary focus in this study is the opposite of forward extrusion in which the ram carries the die and exerts pressure on to the stationary billet which in turn causes it to flow in the opposite direction to the ram [6]. There may be variation to how the principles take place, but in every case the billet maintains a stationary position in relation to the container, thereby maintain the possible lowest friction loss. However, process parameters have may have negative effects on the extrudate if they are not determined accurately. For example, Saha [12] found out that die process parameters which may result in negative effects on the quality of extrudate includes extrusion ratio, capacity of the extrusion press, billet shape ratio etc. Hu *et al* [8] carried out a finite element simulation on extrusion improvement processes and found out that hyperbolic curved die can result in improved uniformity of metal flow, parabolic curve can equally result in continuous cracks on the surface of extruded materials [7]. According to Murai*et al* [9], forward and backward lengths can be determined from the height, flow stress as well as the billet dimeter. Moreover, the flow and displacement of punch as a result of deformation from the extrusion process depends upon the maximum pressure, die geometry, billet characteristics etc. [5, 10]. Extrusion process is commonly used to produce shapes like rod, bar, tube, pipe, hollow and solid profiles such as mullions, gutters, H and I beam, Tees etc. but the extrusion parameters such as the billet temperature, extrusion speed, container and die including the extrusion ratio and configuration of the die determines the material hardness or softness during the extrusion process [4, 13]. From the aforementioned points, influence of process parameter plays a major role in the outcome of the final extruded object, and that necessitated the investigation on some parameters (Temperature, Punch displacement, Billet radius and Time) and their effects on extrusion process and the final extruded shape in this study.

METHODOLOGY

During extrusion process, the punch is assumed to be approaching the work piece in the stationary bottom die with a steady velocity of unity. After contact with the work piece, material will be displaced backwards at the clearance between the punch cap and the outer die surface. This is the only option of flow for the deforming material since the tooling arrangement does not permit any forward extrusion of the material. Therefore, the material in the container remains rigid throughout the deformation process. Extrusion press of 500 KN capacity was used in the experimental set up. Ground nut oil lubricant was applied on the die orifice to ensure that the extrusion force is reduced and tooling was carried out. Sample of the billet was placed at the die orifice and the punch was fixed to the punch plate to support the punch in position. As shown (in Fig. 1) in the cross sectional view of the extrusion process, the ram exerts pressure on the dummy block which gradually pushes the billet until it enters the container. Under pressure the billet is crushed against the die, becoming shorter and wider until it has full contact with the container walls, thereby producing soft but solid metal through the die opening as shown in Fig 2. The die assembly is coupled using a set of fixtures to ensure that a good die position is maintained. The press ram was applied slowly on the punch plate and deformations where observed simultaneously on the billet within the die orifice, while taking note of the rate at which deformation load took place. The punch displacements were verified @ speed 3mm/s, 6mm/s and 9mm/s for zones 1, 2, 3 and 4 and @ speed 3.5mm/s, 7.5mm/s and 12.5mm/s for zones 1, 2, 3 and 4 respectively. An ejector punch was used to ensure easy removal of the product as soon as the punch is withdrawn from the billet.

In Fig. 2, D_C is the equivalent diameter of the billet (container bore diameter) filled in the container after upsetting, D_E is the equivalent diameter of extrudate, α is the semi dead-metal zone angle, σ is the flow stress of the material.

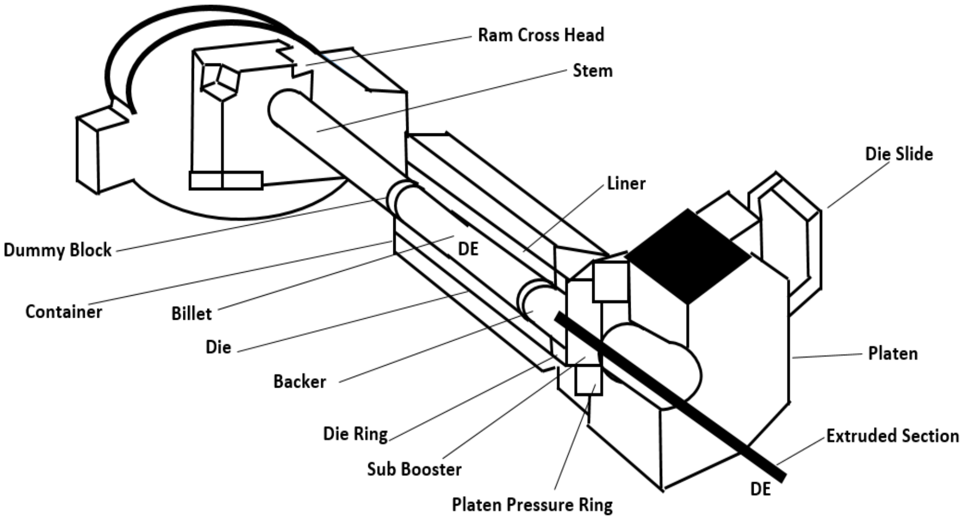


Fig. 1 Cross sectional view of the extrusion process

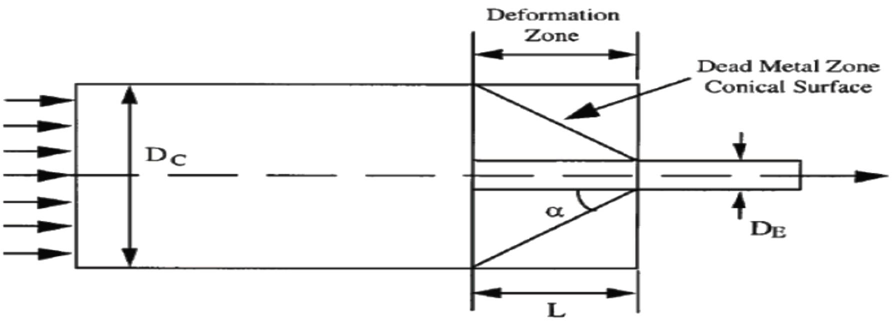


Fig. 2 Geometry of Billet to be crushed in the Container

THEORETICAL ANALYSIS

From the first law of thermodynamics, if an amount of heat energy (dQ) flows into a system then its energy must appear as increased internal energy (dU) for the system and the work done by the system on its surroundings. It is pertinent to state here that this internal energy change depends on the initial and final states and not upon the path taken that is

$$dQ = dU+dW \qquad \left[\text{ Where } dQ = \frac{kAdT}{L} \text{ and } W = fd\right] \tag{1}$$

If work is done on the billet by the force of the punch, and heat is generated and dissipated,

Then $\qquad dU = dQ – (-W) = dQ + dW$

Therefore, $\qquad dU = \frac{kAdT}{L} + fd \qquad (2)$

where,

k is constant = thermal conductivity of billet material (Aluminum),

dt = temperature increment of 5^oC from initial room temperature of 25^0c and

A = area of the billet, which can be varied with an increasing or decreasing radius of the billet

L= the height of the billet which decreases as the extrusion progresses,

dw = change in work done on the billet by the punch

d = distance travelled by the punch.

F = the force or load of the extrusion expressed from the deformation power

(force = power/velocity and the punch is assumed to descend with steady velocity of unity)

The relationship in equation (2) relates the deformation power in form of work to the heat transfer Q.

Considering the heat flow in radial (x- Ø) direction plane,

Heat in Flux $\qquad Q\text{'}r = -k(rd\,Ø.dz)\,\frac{dt}{dr}.dr \;\Xi > -KAdt \qquad (3)$

Heat efflux $\qquad Q\text{'}(r+dr) = Q\text{'}r + \frac{d}{dr}(Q\,r)dr \qquad (4)$

Condition Requirement

I = z, j=r, T_{ij}= Temperature at the various grid point or zone,

There, $T_{1,2}$ = Temperature at the zone 1 and 2 interface.

Boundary Conditions

$T_{12}= T_{13} = 0,\; T_{23} = T_{14}, T_{24} = T_{34} = 0, T_{25} = 0, T_{35} = 0,\; T_{45} = 0$

$0 \le z_j \le v_zt$ at $r= r_0$ at zone 1 & 2 interface, $0 \le r_j \le r_0$, $1 + 0 \le z_j \le 1 + 0 - v_2t$, t = 0, $T(z,r) = T_0 = T_\infty$ at zone 1 and 5 interface

At zone 4, $0 \le r_i \le r_0$, $0 \le z_j \le - v_zt$, t = 0 $T(r,z) = T_0 = T_\infty$, At zone 2: $0 \le z_i \le 1 + 0 – v_zt$ at r = R*, t = 0 , $T(r,z)\; T_\infty$

At zone 5: $0 \le r_i \le r0$, $x_1 \le z_j \le 1+0$, t = 0, $T(r,z) = T_\infty$

The net extrusion or deformation load dissipated within the material of the sleeve is the sum of the various plastic, frictional and shear power dissipated at appropriate volumes and surface areas of the material during deformation [15], and it is given as,

$$E = E_{p1} + E_{p2} + E_{d1} + E_{d2} + E_{d3} + E_{f1} + E_{f21} + E_{f3}\;\; E_{f32} + E_{f33} + E_{f4} \tag{5}$$

This heat exchange rate is done between the deforming billet, the container peripheries and the ambient. If correct forces of deformation are ascertained at every instant of the punch displacement in whole, it therefore means we can mathematically and thermodynamically relate the temperature variations and deformation forces with respect to the change in the internal energy of the system during the extrusion process. The heat transfers during the extrusion in relation with the extrusion or deformation load or force as a form of work done on the billet can be expressed through the descretization of the temperature distribution in the subsystems (the zones). In other words, one could graphically interpret or predict the response of one extrusion quantity to be the changing effect of the other. Replacing the partial differential form of equations (1, 2, 3 4). Therefore, the energy balances between the billet/pad, billet/container and rigid metal interfaces, i.e zones 1, 2, 3, and 4 respectively, with the equivalent finite difference form, the temperature distributions at respective interfaces may be expressed in four zones as follows,

Zone 1 and Energy Balance Interfaces

$$T_{i,j}^{n+1} = F_0\left(1+\frac{1}{2i}\right)T_{i+1,j}^{n} + F_0\left(1-\frac{1}{2i}\right)T_{i-1,j}^{n} + \left(1-4F_0\right)T_{i,j}^{n} + \left(F_0 - \frac{V_0\beta}{2\Delta l}\right)T_{i,j+1}^{n} + \left(F_0 + \frac{V_0\beta}{2\Delta l}\right)T_{i,j-1}^{n} + \Delta T_2 \tag{6}$$

The coordinates of the $(i,\; j)$ are simply $h = r = i.\Delta r$and $z = j.\Delta z$and the temperature at the node $(i,\; j)$ is denoted by $Ti_{,j.}$

$$T_{i,j}^{n+1} = \left\{ \left(\frac{k_2 - k_1}{k_1} \right) \left\langle \frac{2k_1 F_{01} F_{02}}{\left(k_1 F_{02} - k_2 F_{01}\right)} \right\rangle \right\} T_{i+1,j}^{n} + \left\{ 1 + \left(\frac{k_1 - k_2}{k_1} \right) \left\langle \frac{2k_1 F_{01} F_{02}}{\left(k_1 F_{02} - k_2 F_{01}\right)} \right\rangle \right\} \times T_{i,j}^{n} + \Delta T_{1-2} \qquad (7)$$

$$T_{i,j}^{n+1} = \left\{ \left(\frac{k_5 - k_1}{k_1} \right) \left\langle \frac{2k_1 F_{01} F_{05}}{\left(k_1 F_{05} - k_5 F_{01}\right)} \right\rangle \right\} T_{i+1,j}^{n} + \left\{ 1 + \left(\frac{k_1 - k_5}{k_1} \right) \left\langle \frac{2k_1 F_{01} F_{56}}{\left(k_1 F_{05} - k_5 F_{01}\right)} \right\rangle \right\} \times T_{i,j}^{n} + \Delta T_{1-5} \qquad (8)$$

$$T_{i,j}^{n+1} = \left\{ \left(\frac{k_4 - k_1}{k_1} \right) \left\langle \frac{2k_1 F_{01} F_{04}}{\left(k_1 F_{04} - k_4 F_{01}\right)} \right\rangle \right\} T_{i+1,j}^{n} + \left\{ 1 + \left(\frac{k_1 - k_4}{k_1} \right) \left\langle \frac{2k_1 F_{01} F_{04}}{\left(k_1 F_{04} - k_4 F_{01}\right)} \right\rangle \right\} \times T_{i,j}^{n} + \Delta T_{1-4}$$

(9)ΔT_{1-2} = The temperature increase due to boundary friction in a time increment β given by

$$\Delta T_{1-2} = \frac{W_{fc}\beta}{JVol\,(C_1\rho_1 + C_2\rho_2)/2} \qquad (10)$$

J is a mechanical equivalent of heat= 4185j/kcal, Wf = friction power generated at billet/container, vol. = volume of billet in contact with container, C =heat capacity, p=density and β =time increment

Zone2

Substituting the partial differential form of zone 2 with the equivalent finite difference form, the temperature distribution at any point within the deforming billet is

$$T_{i,j}^{n+1} = F_0\left(1 + \frac{1}{2i}\right) T_{i+1,j}^{n} + F_0\left(1 - \frac{1}{2i}\right) T_{i-1,j}^{n} + \left(1 - 4F_0\right) T_{i,j}^{n} + \left(F_0 - \frac{V_0\beta}{2\Delta l}\right) T_{i,j+1}^{n} + \left(F_0 + \frac{V_0\beta}{2\Delta l}\right) T_{i,j-1}^{n} + \Delta T_2 \qquad (11)$$

ΔT_2= temperature change due to heat generated due to plastic deformation. At each point in the deformation zone, ξ per cent of the deformation energy is transformed into heat, where ξ has a value between 85% and 95%. The change in temperature, ΔT_2, which is induced by plastic deformation in the interval β is given by,

$$\Delta T_2 = \frac{W_i}{JC\rho} \frac{\xi}{100}, \qquad (12)$$

Where J is the mechanical equivalent of heat 4185J/kcal and $W_i$the power of plastic deformation/unit volume evaluated by upper bound method of analysis using volume integral. The energy change between zone 2, zone 3 and zone 4 interfaces are,

$$T_{i,j}^{n+1} = \frac{2\beta}{\left(\rho_2 C_2 - \rho_n C_n\right)\ \Delta l} \times \left\{ k_3 \frac{\left(T_{i,j+1}^{n} - T_{i,j}^{n}\right)}{\Delta l} - k_2 \frac{\left(T_{i,j+1}^{n} - T_{i,j}^{n}\right)}{\Delta l} \right\} + T_{i,j}^{n} + \Delta T_j \qquad (13)$$

The deforming billet/zone 3 and the deforming billet/zone 4 has the same material, it can be assumed that the density ρ, heat capacity C, and thermal conductivity K, remain constant for the material under consideration in this analysis. The typical finite difference representation of temperature distribution at any of these interfaces is given by,

$$T_{i,j}^{n+1} = 2F_o T_{i,j+1}^{n} + (1 - 4F_O)T_{i,j}^{n} + 2F_o T_{i,j}^{n} + \Delta T_j \qquad (14)$$

Zone 3-Extrusion Section

Substituting the partial differential form of zone 3 with the equivalent finite difference form, the temperature distribution at any point within the un deformed billet assuming a square mesh points, i.e. $\Delta r = \Delta z = \Delta l$, gives

$$T_{i,j}^{n+1} = F_0\left(1 + \frac{1}{2i}\right) T_{i+1,j}^{n} + F_0\left(1 - \frac{1}{2i}\right) T_{i-1,j}^{n} + \left(1 - 4F_0\right) T_{i,j}^{n} + \left(F_0 - \frac{V_0\beta}{2\Delta l}\right) T_{i,j+1}^{n} + \left(F_0 + \frac{V_0\beta}{2\Delta l}\right) T_{i,j-1}^{n} + \Delta T_3 \qquad (15)$$

ΔT_3 = temperature change due to heat generated by frictional ironing at die land $= \dfrac{W_{fl}\beta}{J(C_3\rho_3 V_3 + C_c\rho_c V_c)/2}$ (16)

Where W_{fl} is the friction power generated over the die land length evaluated by upper bound using surface integral and V_3, V_c the volume of the billet and container (die land housing), respectively. The energy balance between the extruded portion and the surrounding in the finite difference is given as

$$T_{i,j}^{n+1} = (1 + 2F_0 + 2BiF_0)\, T_{i,j}^{n} - 2F_0\left(T_{i+1,j}^{n} + BiT_\infty\right) \qquad (17)$$

Zone 4

Substituting the partial differentia form of zone 4 with the equivalent finite difference form, the temperature distributions at any point within the rigid material, assuming a square grid or mesh point, i.e. $\Delta r = \Delta z = \Delta l$, gives,

$$T_{i,j}^{n+1} = F_0\left(1+\frac{1}{2i}\right)T_{i+1,j}^{n} + F_0\left(1-\frac{1}{2i}\right)T_{i-1,j}^{n} + (1-4F_0)T_{i,j}^{n} + \left(F_0 - \frac{V_0\beta}{2\Delta l}\right)T_{i,j+1}^{n} + \left(F_0 + \frac{V_0\beta}{2\Delta l}\right)T_{i,j-1}^{n} \quad (18)$$

The finite difference of the equation representing the energy balance the die and the ambient is given as

$$T_{i,j}^{n+1} = (1 + 2F_o + 2BiF_O)T_{i,j}^{n} - 2F_o\left(T_{i+1,j}^{n}\right) + BiT_\infty \quad (19)$$

RESULTS AND DISCUSSION

The resultant pressure exerted on the billet, produced a soft but solid metal that squeezed through the die opening as shown in Fig. 3. As a result of contact between the ram and the billet, the buildup stresses can be computed as shown in equation (20).

$$\sigma = \frac{E_l}{P_a} \qquad \text{[Where - } E_l \text{ is the extrusion load and } P_a \text{ is the punch area]} \quad (20)$$

Effect of Punch Displacement on the Extrusion Temperature

Figure 4 reveals that an increase in the displacement of the punch results in temperature increase, and this could be as a result of the friction and deformation encountered within the interval of initial displacement to final displacement and this further gives an insight into the temperature distribution in the zones as seen from the graph, observing the peak temperatures, it could be inferred that zone 1 peaked at a higher temperature accompanied by lesser temperatures at other zones. This can be explained by the fact that in the steady state extrusion process, there is limited time for the heat generated due to compression and friction to be distributed to the peripheral zones and also considering the effect of the lubricant (shear butter) with low diffusivity, which forms a barrier between billet and container. When extrusion commences and progresses, there is a squeezing out and distribution of the lubricant along the periphery of the billet/container wall and as it flows, it tends to distribute its heat gained to the other zones by convection and from there to the ambient. This will have accounted for these low temperatures in these zones.

Effect of Extrusion Temperature with Time

As shown in Fig. 5, it can be observed that zones 3 and 2 show sharp increase in temperatures at the initial stage of the compression due to high compressive forces between the billet and container wall, however as the deformations progresses, the billet experiences high frictional forces with the tool material leading to higher temperatures at zone 1. At the near end of the process, zone 4 has higher surface contact with the tool .It also receives and emits temperatures from the tool and deforming billet at this stage resulting in higher temperatures, thus generally, temperatures peaks at zone 1 further which as time progresses and the process is gradually leaving the steady state to the unsteady state, there is high heat dissipation to the ambient resulting in the lower temperatures in zones 2 and 3 and in other zones beyond the peak temperature at zone 1. It can then be inferred that temperatures increases during the extrusion process provided it is within the steady state heat transfer, beyond which there is bound to be a decrease in temperature.

Effect of Billet Radius on Temperature

It is inferred from the graph of temperature against billet radius, that as billet radius increased so does the temperature and so for various regions of the extrusion tool/material. Considering the fact that the radius r is a function of Area, a larger area will require a larger force to extrude, and this consequently increases the extrusion temperature. Ajiboye and Adeyemi [1], noted that the effect of increasing punch size lead to increasing deforming load due to increasing frictional energy. Increasing punch size is seen here as also increasing billets size. Udomphol [14], also noted that for a given extrusion load, extrusion ratio increased with increasing temperature. Extrusion ratio = (initial billet area or size to its final area or size) has area, radius and diameter as functions, so higher extrusion ratios means higher initial radius and consequently areas, which meant load required for deformation will increase and subsequently the extrusion temperatures.

Fig. 3 View of Extrudate Passing through the Die Opening

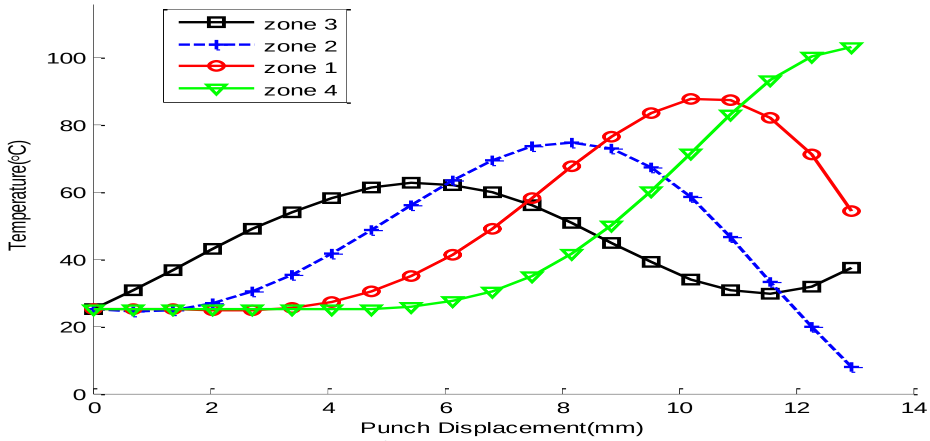


Fig. 4 Graph of temperature Vs punch displacement

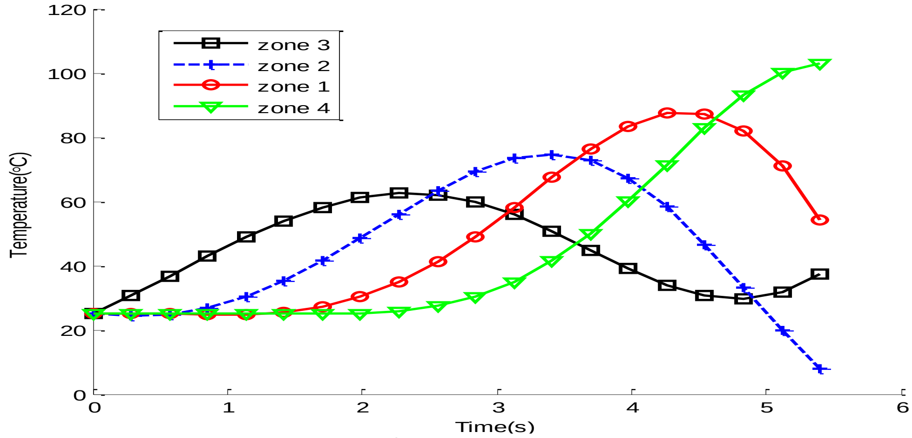


Fig. 5 Graph of Extrusion Temperature Vs Time

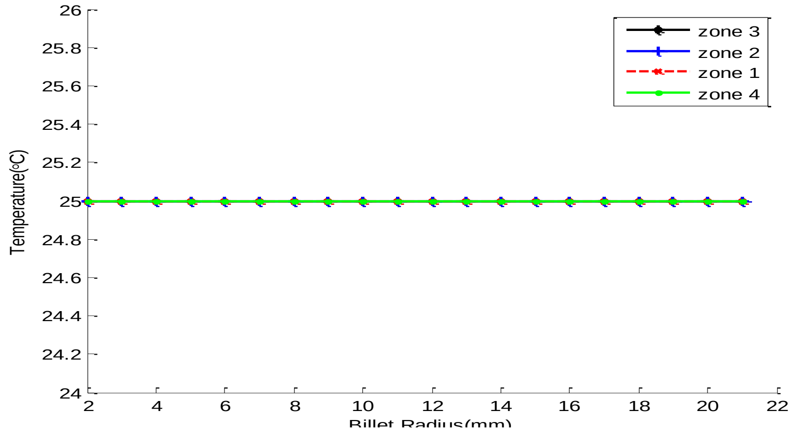


Fig. 6 Graph Temperature Vs Billet radius @ Z= 0

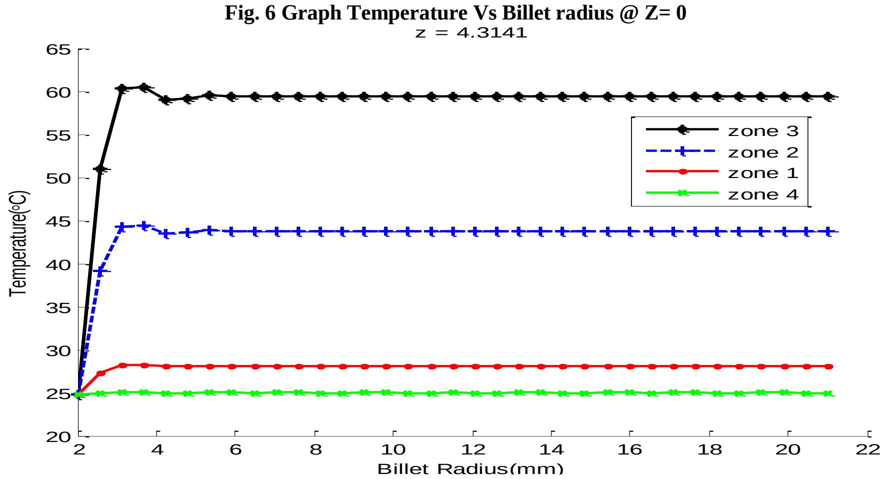


Fig. 7 Graph of Temperature Vs Billet radius vs temperature @ z=4.3141

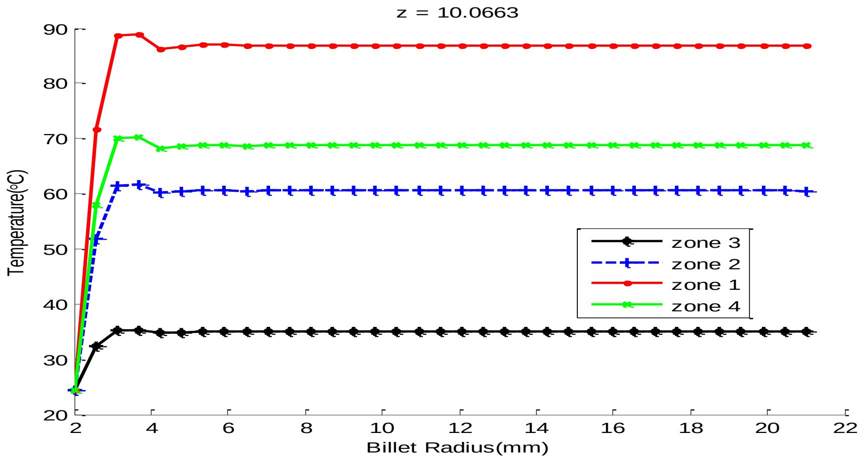


Fig. 8 Graph of Temperature Vs Billet radius @ z=10.0663

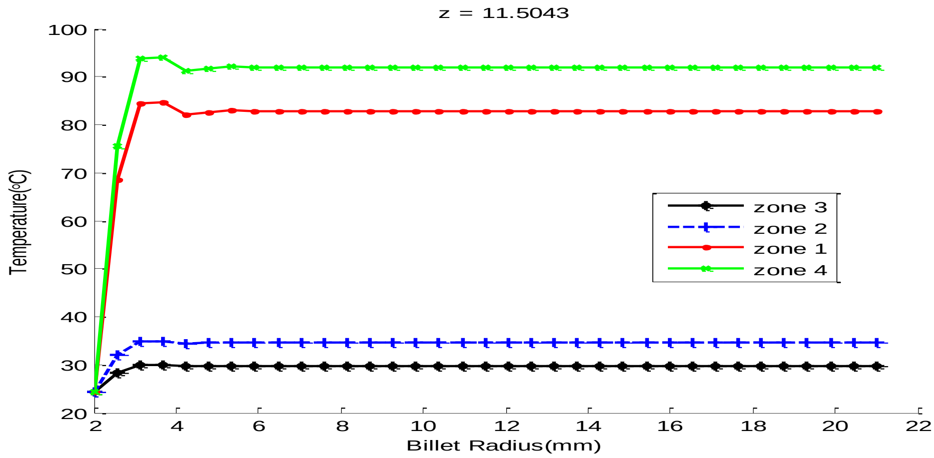


Fig. 9 Graph of Temperature VsBillet radius @ z=11.5043

The graphs for billet radius show that the temperatures are peaking at various points of the deformation process with respect to the axial punch movement and the extrusion regions. Prior to deformation the system is observed to be at room temperature within all the zones as shown in Fig. 6. It is observed Fig. 7 that at barely less than 30% reduction in height for zone 1 and 4 are still within low temperature ranges compared to zone 2 and 3, this might be due to compressive forces which tends to push the billet against the container walls prior to deformation. However as shown in Fig. 8 and 9, as the process progresses beyond 60% and 70% (i.e. @ z = 10.0663 and z = 11.5043) there is reduction in billet height as zone 1 and 4 are observed to rise to the peak at higher temperatures due to increasing billet/tool surface meshing, thus, increasing friction with the possibility of the lubricant with low thermal diffusivity acting against high rate of heat dissipation outwards from these zones to the peripheries which have direct heat exchange with the ambient.

Ajiboye and Adeyemi [1] asserts that the dead zone temperature generally rises sharply more than the die zone temperature essentially beyond 90% reduction in area, which is due to direct and wider contact area of this zone with the main deformation zone as well as of great amount of heat flowing into it and emitted in this zone during conversion of the deformation work into heat. Generally, increasing billet radius led to increasing temperature in all the regions of the extrusion process. This can further corroborate with studies carried out by Atesman [2], where it was noted that in hot drawing of a bar the temperature increased as radius increased**.**

Effect of Ram Speed on Temperature

From the graph (Fig. 10 and 11) of temperature against punch displacement at some selected incremental speeds, it is observed that there is an increase in temperature as ram speed increased in all the zones. This can be explained by the fact that in the steady state extrusion process, at higher speeds the heat generated barely has little time to flow, unlike at slower speeds where there is available time to dissipate the generated heat. However, an increase in ram speed led to an increase in temperature, this correlates with the studies carried out by Ajiboye and Adeyemi [1]. Udomphol [14] also corroborates this by noting that an increase in ram speed can result in increased extrusion load which consequently results in extrusion temperature. Figure 10 shows the graph of temperature vs. punch displacement @ speeds 3mm/s, 6mm/s and 9mm/s for zones 1, 2, 3 and 4 and Fig. 11 shows the graph of temperature vs. punch displacement @ speeds 3.5mm/s, 7.5mm/s and 12.5mm/s for zones 1, 2, 3 and 4.

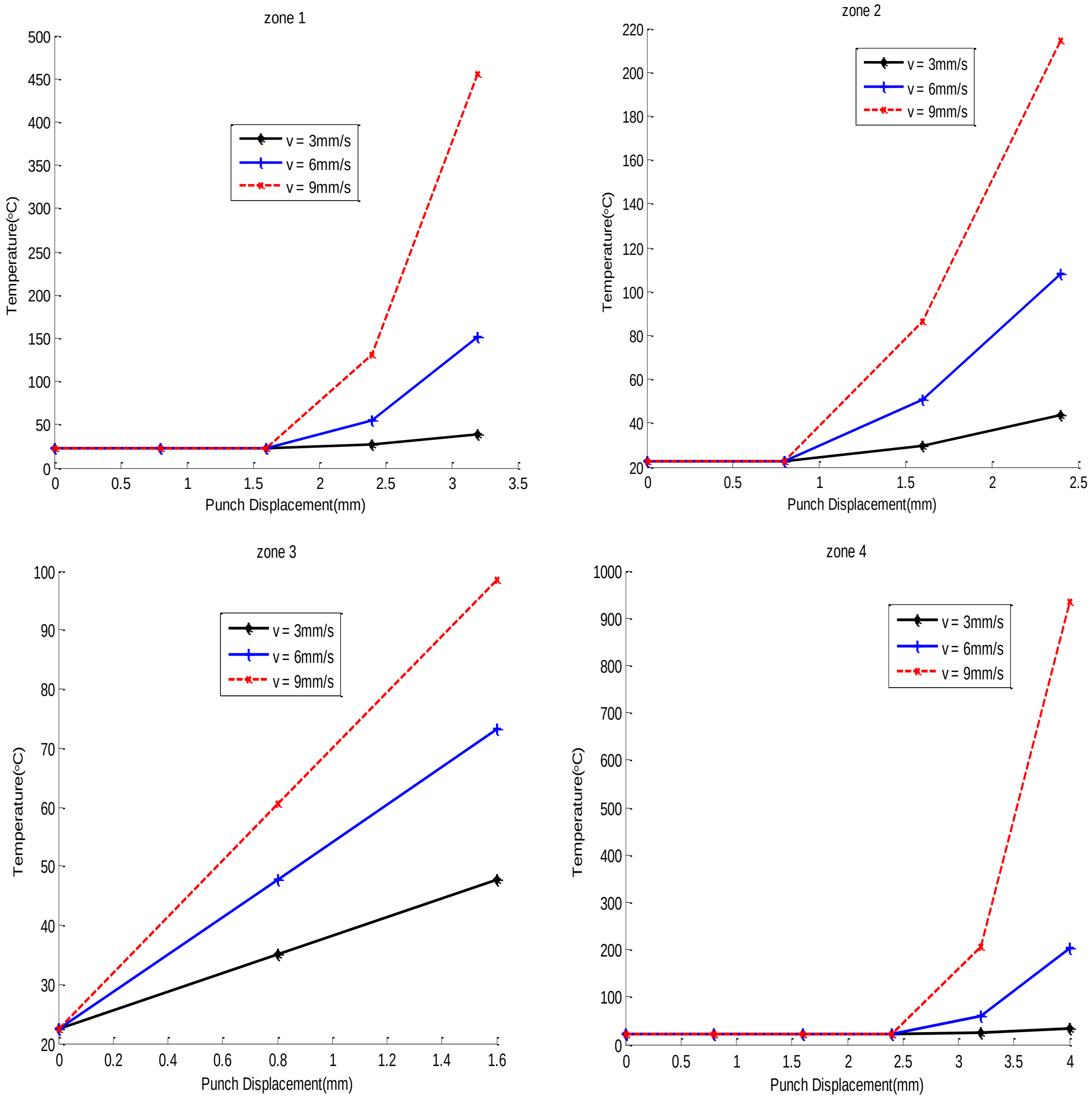
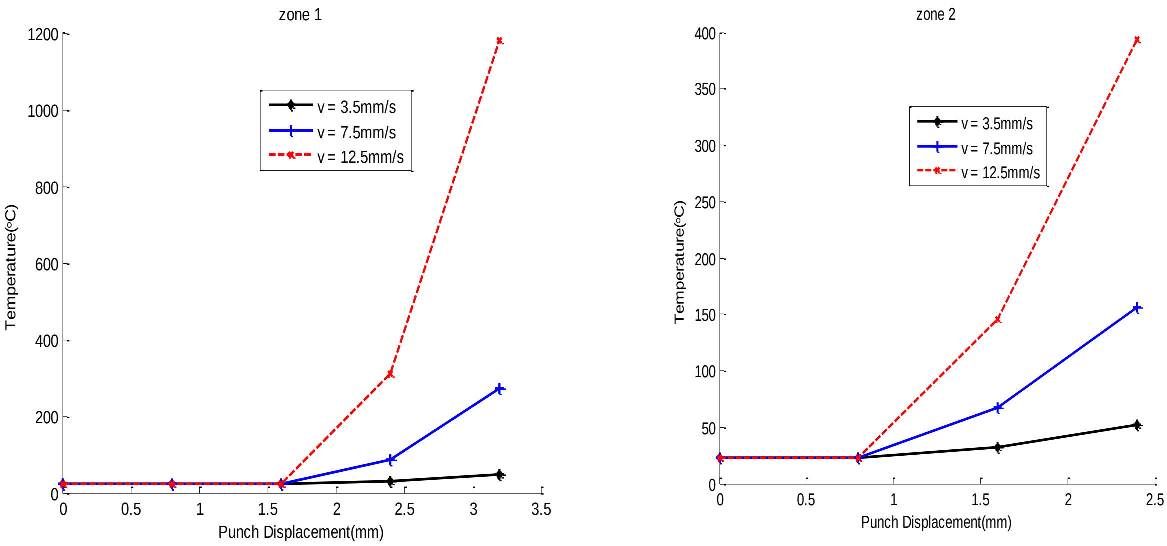


Fig. 10 Graphs of Temperature Vs punch displacement @ speeds 3mm/s, 6mm/s and 9mm/s for zones 1, 2, 3 and 4



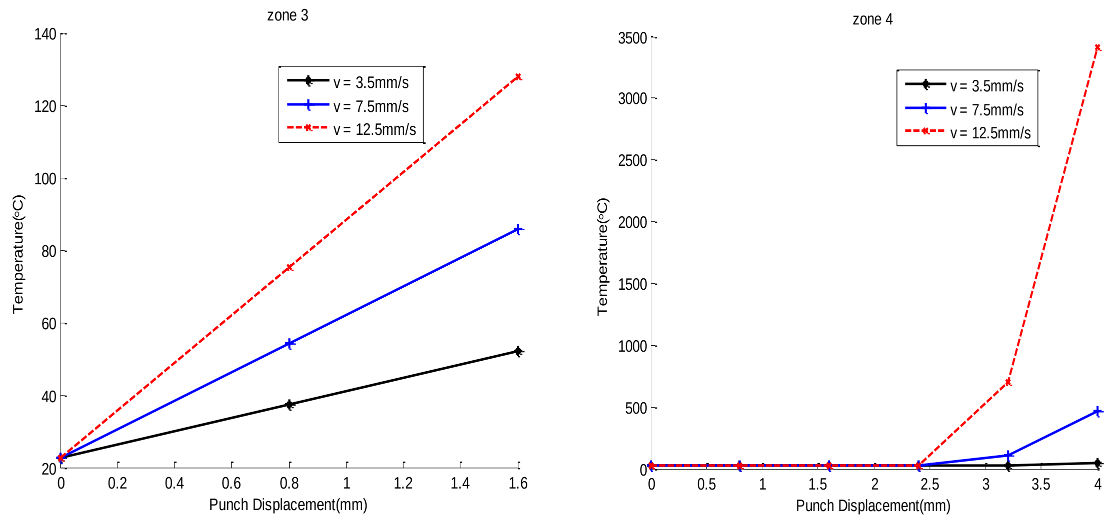


Fig. 11 Graphs of Temperature vs punch displacement @ speeds 3.5, 7.5 and 12.5mm/s for zones 1, 2, 3 and 4

CONCLUSION

From the analysis carried out in this study, it is possible to predict the crucial variables and as well select the right process parameters necessary to carry out an effective extrusion process by understanding and good prediction of their interrelationship. In that case, engineers and industries should be able to predict the optimal temperatures, extrusion load, ram speed and extrusion press capacity required for optimal process, further to say that lubrication becomes essential to reduce friction and temperature efficiently in other to preserve tools, save on material and process execution cost.

REFERENCES

[1] JS Ajiboye and MB Adeyemi, Effects of Extrusion Variables on Temperature Distribution in Axis Symmetric Extrusion Process, *International Journal of Mechanical Sciences*, **2007**, 50(3),522-537.
[2] MK Atesman, *Everyday Heat Transfer Problems: Sensitivities to Governing Equations*, ASME Press, Three Park Avenue, New York, **2009**, 51-64.
[3] M Bauser, G Sauerand K Siegert, *Extrusion*, ASM International, 2006, 270.
[4] J Danckert, A New Punch Design in Backward Can Extrusion, Department of Production, *ICFG International Cold Forging Group 37th Plenary Meeting*, **2004**.
[5] OP Gbenebor, OSI Fayomi, API Popoola, AO Inegbenebor and F Oyawale Extrusion Die Geometry Effects on the Energy Absorbing Properties and Deformation Response of 6063-Type Al–Mg–Si Aluminum Alloy, *Results in Physics*,**2013**, 3, 1-6.
[6] Hubpages Manufacturing Process-Forward and Backward Extrusion, *http//hubpages.com/technology/extrusion-process*,**2017**.
[7] HJ Hu, YY Li, ZY Zhai, XB Gong and H Wang, Comparisons of Extruded Magnesium Rods by Hyperbolic Curve Die and Parabolic Curve Die, *Russian Journal of Non-Ferrous Metals*,**2015**, 56, 212-216.
[8] HJ Hu, JZ Fan, ZY Zhai, H Wang and YY Li, Physical Fields Evolution and Microstructures for Compound Extrusion of AZ31 Magnesium Alloy, *Russian Journal of Non-Ferrous Metals*,**2014**, 55, 254-262.
[9] E Murai, M Ono, Y Tozawa, Y Sawai, T Kojima and S Hamaya, Effect of Shape Ratio of Billet on Extruded Length and Extrusion Load in Forward and Backward Can Combined Extrusion Forging, *Japan Society for Technology of Plasticity*, **2009**, 50, 847-851.
[10] SO Ojo, M Erinosho and JSAjiboye, Experimental Analysis for Lubricant and Punch Selection in Shear Extrusion of AA-6063, *Journal of Material Science and Engineering*,**2015**, 4 (4), 1-5.
[11] P Sapa, *Properties of Aluminium*, http//www.aluminiumdesign.net/why-aluminium/properties-of-aluminium,**2017**.
[12] P Saha, Aluminium *Extrusion Technology*, ASM International,**2002**, 1-22.
[13] M Bauser and K Siegert, *Extrusion*: Second Edition, ASM International, ISBN: 9781615032631, **2006.**
[14] T Udomphol, Extrusion, *Journal of Suranaree University of Technology*, Thailand, **2007**, Chapter 4.
[15] IT Yong, SH Kang and JS Cheon, Finite Element Investigation of Friction Condition in a Backward Extrusion of Aluminium Alloy, *Journal of Manufacturing Science and Engineering*,**2003**, 125 (2), 378-383.