Journal of
Mechanical
Science and
Technology

Journal of Mechanical Science and Technology 21 (2007) 1553~1559

The effect of selected parameters on temperature distribution in axi-symmetric extrusion process

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(Manuscript Received May 31, 2007; Revised August 30, 2007; Accepted September 30, 2007)

Abstract

A numerical method was developed to simulate the transient temperature distributions during forward extrusion process. The computer program simulates the extrusion process and takes into account some extrusion variables such as extrusion velocity, extrusion ratio, die preheat temperature, and percentage reduction in area. It can be seen that the higher the percentages reduction in areas, the higher the temperature rises during the extrusion process. Also, increasing speed of deformation shows an increasing dead zone temperature rise than a more gradual die land temperature rise. It is further seen that extrusion temperature increase is a function of the container temperature.

Keywords: Die land length; % reduction in area; Dead metal zone; Temperature distribution; Speed

1. Introduction

When a material is plastically deformed, a very large part of the work expended appears as heat energy. The temperature generated reduces the flow stress of the material, which consequently makes the energy required for deformation to be reduced. Altan and Kobayashi [1] found that, for large reductions and commercial speeds used in extrusion, temperature increases of several hundred degrees may be involved. They reported that about 95% of the mechanical work of deformation is converted into heat. Some of the heat is conducted away by the tools or lost to the atmosphere, but a portion remains to increase the temperature of the work-piece. Singer and Al-Samarrai [2] attempted to predict the emergent temperature of the product by assuming a simple model in which all deformation takes place, as the metal crosses the exit plane of the die. In their calculations of the heat generation, they considered only axial heat flow, neglecting the container friction. Johnson and Kudo [3] neglected the die material friction and assumed an ideal plastic material for their calculations of the adiabatic temperature increase in an axisymmetric extrusion based on an admissible velocity field.

In 1948 MacLellan [4] suggested the calculation of coefficient of friction in wire drawing directly from experiments by means of a split-die. He did not get good results by this method, Wistreich [5], in 1955, obtained reasonable data adopting MacLellan's experimental technique. Both MacLellan and Wistreich neglected the parallel portion or land of the die even though they thought it was important to include it. In the theoretical equation of drawing stresses derived by Sach's [6] and others, the land in the die was also neglected. In 1961 Yang [7], using Sach's approach, derived a theoretical equation which included the effect of the land and comparison of the values of coefficients from both calculations, including and neglecting land was made. The difference between the coefficients calculated with and without the land was found to be appreciable and hence concluded the inclusion of land of die in both the theoretical and experimental analysis. Avitzur [8]

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underscored the importance of land in the die for even if the land was not originally included in the die, L=0, a land will soon appear as a result of wear. Thus the die produced with an initial land has better dimensional stability. Avitzur [8] concluded, in his paper on analysis of wire drawing and extrusion through conical dies of small cone angles, that an increase in land will cause an increase in the required force. He stated further that increase in land decreases the maximum possible reductions. Ajiboye and Adeyemi [9] had shown in their previous work that significant contribution to overall extrusion load/ pressure is made at the die land due to ironing frictional effect. However, the effect of temperature rise, and its impact on the metallurgical structure of the product, due to frictional ironing at the die land length has not been investigated.

The present work gives generalized temperature distributions at any positions, arising from axisymmetric extrusion process by generalizing the shapes of the die profiles and analyzing deforming, undeforming and extruding zones. The temperature distributions arising from any configurations, complex or simple shapes sections can be tracked, using the present numerical simulations based on upper bound analysis, involving various zones during extrusion process.

2. Theoretical analyses

2.1 Kinematically admissible velocity

A mathematical model for simulating extrusion must represent the geometry of the die closely, particularly in the regions with the highest gradients in flow velocity and temperature.

The kinematically admissible velocity fields' equations are derived[4] to be:

$$V_y(v) = \frac{V_0 \int_0^{\varphi(0)} r_s^2(\varphi,0)\, d\phi}{\int_0^{\varphi(v)} r_s^2\, (\varphi,y) d\varphi};$$

$$V_r(r,\varphi,y) = \frac{1}{r}\int_0^r r\left[\frac{\partial V_y(y)}{dy} + \frac{1}{r}\frac{\partial V_\varphi\, (r,\varphi,y)}{\partial\phi}\right]dr \tag{1}$$

$$V_\varphi(r,\varphi,y) = \frac{r}{r_s^2(\varphi,y)}\int_0^\varphi \frac{\partial}{\partial y}\left[V_y(y) r_s^2(\varphi,y)\right]d\varphi \tag{2}$$

2.2 Strain rates and powers of deformations

The strain rate components [10, 13] are defined based on kinematically admissible velocity fields' Eqs. (1) and (2) as follows:

$$\dot{\varepsilon}_{rr}(\varphi,y) = \frac{1}{2}\left[\frac{\partial\omega(\varphi,y)}{\partial\varphi} + \frac{\partial V_y\,(y)}{\partial y}\right],$$

$$\dot{\varepsilon}_{\varphi\varphi}(\varphi,y) = \frac{1}{2}\left[\frac{\partial\omega(\varphi,y)}{\partial\varphi} - \frac{\partial V_y\,(y)}{\partial y}\right] \tag{3}$$

$$\dot{\varepsilon}_{yy}(y) = \frac{\partial V_y\,(y)}{\partial y},\quad \dot{\varepsilon}_{r\varphi}\,(\varphi,y) = -\frac{1}{4}\frac{\partial\omega(\varphi,y)}{\partial^2\varphi},$$

$$\dot{\varepsilon}_{\varphi y}\,(r,\varphi,y) = \frac{r}{2}\frac{\partial\omega(\varphi,y)}{\partial y} \tag{4}$$

$$\dot{\varepsilon}_{yr}(r,\varphi,y) = \frac{r}{4}\left[\frac{\partial^2\omega(\varphi,y)}{\partial y\partial\varphi} + \frac{\partial^2 Vy}{\partial y^2}\right] \tag{5}$$

2.3 Upper bound solution

The rate of total energy generally consists of three terms such that:

$$\dot{E}_T = \frac{2}{\sqrt{3}}\sigma_o \int_v \sqrt{\frac{1}{2}\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij}}dV + \tau\int_{\Gamma_s}|\Delta V|\Gamma_s\, dS + m\tau\int_s|\Delta V|dS \tag{6}$$

The first term of equation (6) represents the internal powers dissipated for the deformed zone, second term represents shear losses and the third term, frictional losses, $|\Delta V|$ is the velocity discontinuity over the shear surfaces and m is the constant friction coefficient.

3. Heat equations and finite difference representations

During extrusion, heat is generated by deformation of the material, shearing at the deformation-zone boundaries and friction at the tool-material interfaces. Some of the heat generated is transported with the deformed material, some is transmitted to the punch, container and die, and some increases the temperature of the billet. This complex problem, involving simultaneous heat generation, transportation and conduction was numerically simulated and presented in the present work.

3.1 Heat transfer zones and analyses

The typical heat equation which, with appropriate boundaries conditions, is applicable to different zones within extrusion chamber and is expressed as:

$$\rho_n C_n\left[\frac{\partial T_n}{\partial t}+V_z\frac{\partial T_n}{\partial z}\right]=K_\eta\left[\frac{\partial^2 T_\eta}{\partial r^2}+\frac{1}{r}\frac{\partial T_\eta}{\partial r}+\frac{\partial^2 T_\eta}{\partial z^2}\right]+q^\vartheta \tag{7}$$

$0\le z_j\le V_z t,\ 0\le r_i\le r_o,\ t=0,\ T(r,z)=T_o$

where $n=1,2,3;\ \eta=1,2,3\ \&\ \vartheta=1,3,4\ \&\ 5$

$$\frac{K_i\partial T}{\partial r}=0 \quad at \quad r=0 \tag{8}$$

3.2 Energy balance at the interfaces with zones

The typical energy balance equation which, with appropriate boundaries conditions, is applicable at the boundaries separating the billet (undeformed, deforming and extrude) from container, punch, die and ambient can be expressed as:

$$K_n\frac{\partial T_n}{\partial r}+\rho_n C_n\frac{\Delta l}{2}\frac{\partial T_n}{\partial t}+q^\vartheta=K_\eta\frac{\partial T_\eta}{\partial r}+\rho_\eta C_\eta\frac{\Delta l}{2}\frac{\partial T_\eta}{\partial t} \tag{9}$$

$0\le z_j\le V_z t,\ at\ r=r_o$; where n = 1,2,3;

$\eta=4,5,6,a_m\ \&\ \vartheta=1,2,3;\ a_m=$ *ambient temp.*

$$K_n\frac{\partial T_n}{\partial z}+\rho_n C_n\frac{\Delta l}{2}\frac{\partial T_n}{\partial t}=K_\eta\frac{\partial T_\eta}{\partial z}+\rho_\eta C_\eta\frac{\Delta l}{2}\frac{\partial T_\eta}{\partial t}$$

$0\le r_i\le r_o,\quad at\quad z=0;\ t=0,\ T(r,z)=T_o;$

here $n=1,2,3\ \&\ \eta=1,2,3.$ (10)

3.3 Method of numerical solutions

The solutions to the above governing Eq. (7) and energy balance (9) at their boundaries conditions are expressed in the finite difference forms as follows [9, 10]

3.3.1 Temperature Increase Due to Plastic Deformation

Substituting the partial differential form of equation (7) with the equivalent finite difference form, the typical temperature distributions at any point within the extrusion chamber, assuming a square grid points i.e. $\Delta r=\Delta z=\Delta l$, is expressed as

$$\begin{aligned}T_{i,j}^{t+1}&=F_o(1+\frac{1}{2i})T_{i+1,j}^{t}+F_o(1-\frac{1}{2i})T_{i-1,j}^{t}\\&+(1-4F_o)T_{i,j}^{t}+(F_o-\frac{V_o\beta}{2\Delta l})T_{i,j+1}^{t}\\&+(F_o+\frac{V_o\beta}{2\Delta l})T_{i,j-1}^{t}+\Delta T'\end{aligned} \tag{11}$$

The typical energy balance equation which, with appropriate boundaries conditions, is applicable at the

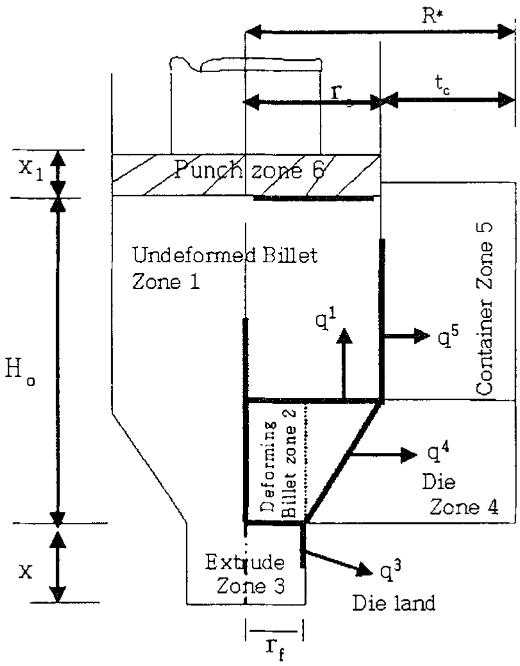

Fig. 1. Idealized extrusion chamber with arrows showing the position and direction of heat generation and flow during extrusion process.

boundaries separating the undeformed billet from deforming billet and deforming billet from extrude is expressed as:

At each point in the deformation zone, ζ percent of the deformation energy is transformed into heat, where this ζ has a value between 85-95 percent [1]. The change in temperature, $\Delta T'$, which is induced by plastic deformation in the time interval β, is given by

$$\Delta T'=\frac{\dot{W}_i}{JC\rho}\frac{\zeta}{100} \tag{12}$$

where J=the mechanical equivalent of heat 4185J/Kcal $\dot{W}_i$ = the power of plastic deformation /unit volume evaluated by upper bound method of analysis using volume integral

3.3.2 Temperature Increase at Undeformed/ container Interface

Similarly, replacing the partial differential form of Eq. (9) with the equivalent finite difference form to give, a typical expression representing the temperature distribution between undeformed billet and container interface is

$$T_{i,j}^{t+1} = \left\{ \left(\frac{K_5 - K_1}{K_1} \right) \left\langle \frac{2K_1 F_{o_1} F_{o_5}}{(K_1 F_{o_5} - K_5 F_{o_1})} \right\rangle \right\} T_{i+1,j}^{t} + \left\{ 1 + \left(\frac{K_1 - K_5}{K_1} \right) \left\langle \frac{2K_1 F_{o_1} F_{o_5}}{(K_1 F_{o_5} - K_5 F_{o_1})} \right\rangle \right\} T_{i,j}^{t} + \Delta T'' \tag{13}$$

The temperature increase $\Delta T''$ due to boundary friction in a time increment β over the cylindrical part of the surface unextruded/container interface

$$\Delta T'' = \frac{\dot{W}_{fc} \beta}{J Vol (C_b \rho_b + C_c \rho_c)/2}. \tag{14}$$

where

$\dot{W}_{fc}$ = friction power generated over the container surface evaluated by upper bound using surface integral.

Vol = volume of billet in contact with container

Similar expressions representing the temperature distributions between undeform billet and punch, deforming billet and die are similarly obtained.

Since deforming billet/undeformed billet and the deforming billet /extruded billet is still the same material, it can be assumed that the density, ρ, heat capacity, C, and even thermal conductivity, K, remain constant. The finite difference representation of temperature distribution at any of these interfaces is given by

$$T_{i,j}^{t+1} = 2F_o T_{i,j+1}^{t} + (1 - 4F_o) T_{i,j}^{t} + 2F_o T_{i,j-1}^{t} \tag{15}$$

3.3.3 Temperature increase during extrusion through conical dies

The typical finite difference equivalent of the temperature distribution within the irregular nodes along the irregular boundary is

$$T_{i,j}^{t+1} = \left(\frac{2F_o}{F(1+F)} + \frac{F_o}{2i}\right) T_{i+F\Delta r,j}^{t} + \left(\frac{2F_o}{(1+F)} - \frac{F_o . F^2}{2i}\right) T_{i-1,j}^{t} + \left(1 - \frac{2F_o}{F} - \frac{2F_o}{G}\right) T_{i,j}^{t} + \Delta T + \left(\frac{2F_o}{G(1+G)} - \frac{V_o \beta}{2G(1+G)\Delta l}\right) T_{i,j-G\Delta l}^{t} + \left(\frac{2F_o}{G(1+G)} - \frac{V_o \beta}{2G(1+G)\Delta l}\right) T_{i,j+1}^{t} \tag{16}$$

where ΔT = temperature change due to internally generated heat due to frictional effect, internal power of deformation and heat resulting from velocity discontinuities; this is obtained using upper bound as $\Delta T = \Delta T' + \Delta T^*$, where $\Delta T'$ is the change in temperature resulting from plastic deformation and ΔT^* is the change in temperature due to frictional power at the die zone

The expression for the heat transfer governing equation across the boundary of the deforming billet and the die is given, assuming a square grid network, as

$$T_{i,j}^{t+1} = \left\{ \frac{2K_4 F_{o2} F_{o_4}}{(K_2 F_{o_4} - K_4 F_{o2})} \right\} T_{i+1,,j}^{t} \left\langle \frac{2K_2 F_{o2} F_{o_4}}{(1+F)(K_2 F_{o_4} - K_4 F_{o2})} \right\rangle T_{i+F\Delta l,j}^{t} + \left\{ 1 + \frac{2F^2 K_2 F_{o2} F_{o_4}}{(1+F)(K_2 F_{o_4} - K_4 F_{o2})} - \frac{2K_4 F_{o2} F_{o_4}}{(K_2 F_{o_4} - K_4 F_{o2})} \right\} T_{i,j}^{t}. + \Delta T \tag{17}$$

where $\Delta T = \frac{\dot{W}_i}{JC\rho} \frac{\zeta}{100} + \frac{\dot{W}_{f_d} \beta}{J(C_b \rho_b V_b + C_d \rho_d V_d)/2}$ (18)

where J=the mechanical equivalent of heat 4185J/Kcal

V_b, V_d =Volume of the billet and die region respectively.

$\dot{W}_{f_i}$ = the power of plastic deformation /unit volume evaluated by upper bound method of analysis using volume integral

$\dot{W}_{f_d}$ = friction power generated over the die surface evaluated by upper bound using surface integral

Also, the heat conducted into the die region will eventually be dissipated into the surrounding this is made up of heat conducted to grid point added to the change in the internal energy of the die at the grid point bordering with the ambient,

$$T_{i,j}^{t+1} = (1 + 2F_o + 2BiF_o) T_{i,j}^{t} - 2F_o (T_{i+1,j}^{t} + BiT_\infty) \tag{19}$$

$F_o = \frac{\alpha\beta}{(\Delta l)^2}$ is the finite difference representation of Fourier number and $Bi = \frac{h^* \Delta l}{K}$ is the finite difference representation of Biot number, where h^* is the convective heat transfer coefficient

3.3.4 Temperature Increase at Extruded/Die Land Interface

The typical finite difference equivalent of the temperature distribution at any point within the undeformed billet assuming a square grid points i.e. Δ r = Δ z = Δ l, gives

$$T_{i,j}^{t+1} = F_o(1+\frac{1}{2i})T_{i+1,j}^{t} + F_o(1-\frac{1}{2i})T_{i-1,j}^{t} + (1-4F_o)T_{i,j}^{t} + (F_o - \frac{V_o\beta}{2\Delta l})T_{i,j+1}^{t} + (F_o + \frac{V_o\beta}{2\Delta l})T_{i,j-1}^{t} + \Delta T^{////} \quad (20)$$

$\Delta T^{////}$ = temperature change due heat generated due to ironing at die land and is expressed as

$$\Delta T^{////} = \frac{\dot{W}_{fl}\beta}{J(C_b\rho_b V_b + C_c\rho_c V_c)/2}. \quad (21)$$

where

$\dot{W}_{fl}$ = friction power generated over the die land length evaluated by upper bound using surface integral.

V_b, V_c = Volume of the billet and container respectively

3.3.5 Computational details

The method used in the present work for determining the transient temperatures in extrusion requires a kinematically admissible velocity field. A computer program written in C++ language, which essentially simulates the extrusion process and takes into account the motion of the billet-punch interface, was used to evaluate the volume and area integrals to give the powers of plastic deformation, $\dot{W}_i$, the frictional power, $\dot{W}_f$, and the power due to velocity discontinuities at the boundaries, $\dot{W}_s$, from where temperatures increases, ΔT, at different zones or position may be estimated.

Using the values of ΔT-values, which include the increase due to plastic deformation and friction, the heat flow, is analyzed, and the temperature rise which exists after conduction takes place in the time interval β is determined. The other properties used in the calculations are: work material; thermal conductivity = 35.3Wm^{-1}.k^{-1}, specific heat = 129Jkg^{-1}k^{-1}, density = 11340kg.m^{-3}; die material; thermal conductivity = 48.2 Wm^{-1}.k^{-1}.

4. Results and discussion

4.1 Extrusion speed on temperature increase

Using a lead alloy of 39.4mm diameter and die opening of 4.4mm diameter, the initial temperature rise at dead metal zone is found to be lower than that at the die land, because at the die land region more heat has been generated due to frictional ironing work being converted to heat leading to a gradual rise above the dead metal zone temperature rise (see Fig. 2). However, as the extrusion speed increases, the rate of temperature rises is faster at the dead metal zone than at extrude or die land position. This is the result of the direct and wider contact area of the dead metal zone with the main deformation zone as well as the great amount of heat flowing into it and emitted in this zone during conversion of the deformation work into heat. This is in agreement with Singer and Al-Samarrai [2] that changes in speeds are followed by more gradual changes in emergent temperatures. Also, Sheppard and Raybould [11] asserted that the dead metal zone temperature rise is always higher than any other position considered during extrusion. In the present investigation, the extrusion speeds below 4.23mm/s have the die land zone temperature rise, show a higher temperature rises than that of the dead zone. However, beyond this extrusion speed, dead metal zone shows speedy rises in temperature than that of the die land zone with increasing extrusion speeds. This should be because of the higher intensity of heat generated at the main deformation zone flowing to this dead metal zone portion.

Tool temp =30°C, Billet temp. = 70°C, r = 90%.

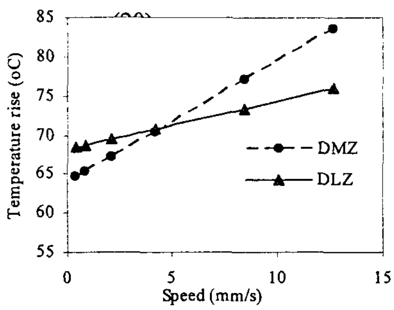

Fig. 2. The effect of extrusion speed on temperature rise at the dead metal zone (DMZ) and die land zone (DLZ) during the extrusion of lead alloy.

4.2 Percentage reduction in area on Temperature rise

Fig. 3 shows the relationship between temperature rises at dead metal zone with percentages reductions in areas. We can see that below percentage reduction in area of 90%, temperature rise at the dead metal zone is lower than that at the die land zone. This can

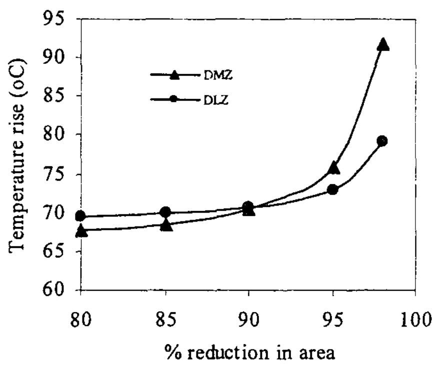

Fig. 3. Relationship between temperature rise at dead metal zone (DMZ) and die land zone (DLZ) with increasing percentage reductions during extrusion of lead alloy.

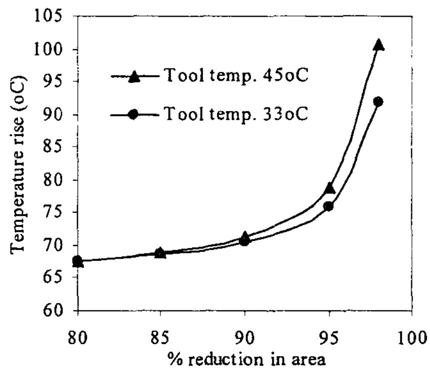

Fig. 4. Relationship between temperature rise at dead metal zone (DMZ) with increasing percentage reduction at different tool temperature.

be explained that; at lower percentage reduction not much deformation work is converted into heat at the main deformation zone and consequently not much heat is emitted into the dead metal zone, unlike the direct contact and conversion of frictional work into heat at die land zone, leading to direct but gradual rise in temperature. But as percentage reduction in area increases, especially beyond 90, it leads to increase in extrusion temperature. This can be further explained by the fact that the power needed to deform the material increases, so does the deformation work which converts into heat in the main deformation zone.

Fig. 4 shows the effect of tool temperature on the temperature rises during extrusion process. A steady rise in temperature is noticed with increasing percentage reduction in area till a critical percentage reduction of 90 when a sudden temperature rise is noticed for the two tool temperatures considered. It can be seen that the higher the tool temperature the higher the extrusion temperature at the dead metal zone (see Fig. 4).

4.3 Initial billet temperature on temperature rise

The steady rise in the extrusion temperature in Fig. 5 continues till percentage reduction in area of 95 before a sudden rise in temperature is observed. Notice that the sudden rise in temperature does not occur at usual percentage of 90 because at higher billet temperature the flow stress of the material is reduced. Also, it can be seen that the higher the billet temperature the higher will be the extrusion temperature rise.

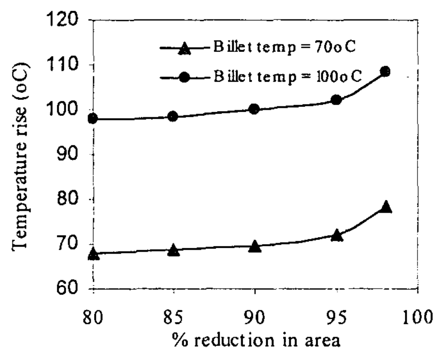

Fig. 5. Relationship between temperature rise at die land zone (DLZ) with increasing percentage reduction at different billet temperature.

5. Conclusion

The dead metal zone temperature generally rises sharply more than the die zone temperature essentially beyond 90% reduction in area. This 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. However, increasing speed of deformation shows a greater dead metal zone temperature rise than a more gradual die land length temperature rise beyond an extrusion speed of 4.23mm/s. Generally, increasing speed leads to increasing temperature rise.

Acknowledgement

One of the authors, Ajiboye, JS is grateful to the University of Lagos, Lagos, Nigeria for their financial support during the research work.

Nomenclature

W_i,	: internal power of deformation,
W_f	: frictional power losses
W_s	: shear power loss
σ_o	: flow stress
V_o	: steady punch velocity
V_r, V_y, V_φ	: velocity components,
$r_s(\varphi, y)$	: shape of die geometry
$\varepsilon_{ii}, \varepsilon_{ij}$	: Strain rate components
Δv	: resultant velocity,
H_o	: original height of billet
x	: die land length
ΔT	: temperature rise
ρ	: the density of workpiece
C	: the specific heat
E_T	: total upper bound on power
K_i	: thermal conductivity
α	: $k/\rho c$
T_∞	: ambient temperature
$\Delta T'$	: temperature increase in a time interval Δt due to plastic deformation.
$\Delta T''$	: temperature increase due to boundary friction between the billet and container
F, G	: factor multiplying grid size at irregular nodes ($0 < F, G \leq 1$)
β	: spatial time step;
x	: die land lengths
F_{oi} (Fourier number)	: $(\alpha\beta)/(\Delta l)^2$
T_o	: initial temperature
C_b, ρ_b	: heat capacity and density of billet material respectively
$C_d\ \rho_d$	: heat capacity and density of die material respectively
$C_c\ \rho_c$	: heat capacity and density of container material respectively

References

[1] T. Altan and S. Kobayashi, A numerical method for estimating the temperature distributions in extrusion through conical dies, *Journal of Engineering for Industry, Transactions of the ASME.* 80 (1968) 107-118.

[2] A. R. S. Singer and S. H. K. Al-Samarrai, Temperature changes associated with speed variation during extrusion *Journal of the Institute of Metals.* 89 (1961) 225-231.

[3] W. Johnson, and H. Kudo, The use of upper-bound solutions for the determination of temperature distributions in fast hot rolling and axisymmetric extrusion processes, *Journal of Mechanical Sciences.* 1 (1960) 175-191.

[4] G. D. S. MacLellan, A critical survey of wire-drawing theory, *Journal of the British Iron and Steel Institute.* 158 (1948) 347-356.

[5] J. G. Wistreich, Investigation of the mechanics of wire drawing, *Proceedings of the Institution of Mechanical Engineers.* 169 (1955) 654-665.

[6] O. Hoffman and G. Sachs, Theory of Plasticity, McGraw-Hill Book Company, Inc., NY, NY. (1953) 176-180.

[7] C. T. Yang, On the mechanics of wire drawing, *Transactions of the ASME; Journal of Engineering for Industry.* 73 (1961) 523-530.

[8] B. Avitzur, Analysis of wire drawing and extrusion through conical dies of small cone angle, *Transactions of the ASME: Journal of Engineering for Industry.* 75 (1963) 89-96.

[9] J. S. Ajiboye, M. B. Adeyemi, Effects of die land on the cold extrusion of lead alloy, *Journal of Materials Processing Technology.* 171 (2006) 428-436.

[10] J. S. Ajiboye, Extrusion pressure and Temperature changes during forward extrusion process PhD Thesis, Department of Mechanical Engineering, University of Ilorin, Nigeria (2006).

[11] T. Sheppard and D. Raybould, On load and temperature rise during the extrusion of superpure Al, Al-Zn, and Al-Zn mg alloys, *Journal of the Institute of Metals.* 101 (1973) 33-44.

[12] M. Kiuchi, H. Kish and M. Ishikawa, Study on Non symmetric extrusion and drawing, *Int. Journal Mach. Tool Design and Res.* 21 (1981) 523-532.