AIN SHAMS UNIVERSITY

Faculty of Engineering

Department of post graduate studies

An Investigation

in

The Production of Pistons by Backward

Extrusion

a thesis submitted for the degree of

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by

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gical as billet and die set temp., ram velocity and lubricant, or design as punch shape, or process as strain rates induced. Empirical and theoretical equations giving the relations between these parameters and the pressure after different investigators are given.

In chaper 2, some of the equations given in chapter 1 are modified to suite the piercing process under consideration. Also a solution using the slab method giving the pressure, and a proposed analytical procedure to attain the same aim is given. Opitmization of Avitzur's pressure equation given in the previous chapter is also contained in this one to obtain the optimum dead metal zone angle.

Chapter 3 is devoted for the description of the experimental rig, technique adopted and the plan of experiment. Method of measuring the different extrusion parameters is also given. Design of the sub-press and, pressure load cell and ram descend transducer is given in appendices I, II, III respecively.

In chapter 4, the experimental results and discussion are given. The pressure versus ram descend for different billet temperatures experimentally obtained are compared with the corresponding theoretical values found from equations given in chapters 1 and 2. The process optimum conditions, the microstructure and hardness across a meridional plane has also been investigated.

The last chapter of this thesis, chapter 5, is devoted for conclusions drawn out of the work.

In general, comparison between actual extrusion pressures and pressure calculated from theoretical approaches showed good agreement.

Using a kinematically admissible velocity field, it was possible to predict the instantaneous positions of any point

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CHAPTER I

LITERATURE REVIEW

Since the process-as mentioned in the introduction - is an inverted piercing process, the parameters affecting the production of pistons by this technique may be expected to be:

1- deformation ratio.
2- ram speed.
3- dead metal zone angle (α) (or punch geometry).
4- initial billet temperature.
5- hot shortness temperature.
6- type of lubricant.

Analysing this technique theoretically, the new procedure of visioplasticity introduced by Thomsen has imposed itself as a successfull means of studying the effect of different parameters of extrusion.

1.1- Deformation Ratio

Pearson [1], seems to have been the first to derive an expression relating the deformation ratio to the extrusion pressure. He remarked that, when plotting the extrusion pressure - in a conventional direct extrusion process - against the logarithm of the extrusion ratio (deformation ratio) a straight line relationship results.

Thus according to Pearson, the extrusion pressure is given by:

$$P = Y \cdot \log(A_o/A) \qquad (1.1)$$

where Y is the yield stree of the material
& (A_o/A) is the extrusion ratio .

Almost the same result was attained at by Ashcroft [2]. He found out that when the maximum extrusion pressure (direct extrusion) is plotted against the extrusion ratio on a logarithmic scale for extrusion ratios > 4, the results realised the linear relationship:

$$P = a \cdot \ln(A_o/A) + b \qquad (1.2)$$

where a, b are empirical constants.

A representation of the early stage of backward extrusion proposed by Yang [3], based on the concept of "unit rectangular deforming region" proposed by Kudo, is given in Fig.(1-1).

According to this model, Yang gives the minimum upper bound piercing pressure P at the initial point of ram displacement by the equation:

$$\frac{P}{2k} = 2\left(\left(\frac{1-r}{r}\right)^2 + \frac{7}{8}\left(\frac{r}{1-r}\right)\right)^{1/2} \qquad (1.3)$$

where $r = \frac{R_m}{R_1}$

& K = the shear yield stress of the material ($= \frac{\sigma_o}{2}$)

Yang stated that, the experimental results published in 1957 by Fukui, showed good agreement with results calculated from his equation (1.3).

Another upper-bound representation of the early stage of piercing proposed by Avitzur [4] on basis of a spherical velocity field which he proposed [4,5] - is given in Fig. 1-2. In his analysis, Avitzur (1972), assumes the equation of the ram pressure to be a function of process geometry; depth of ram penetration and friction (independent variables) and α (dependent variable). The equation he derived is:

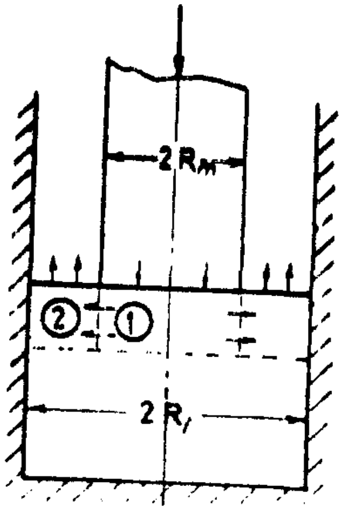

Fig. 1.1 Schematic Drawing of Piercing

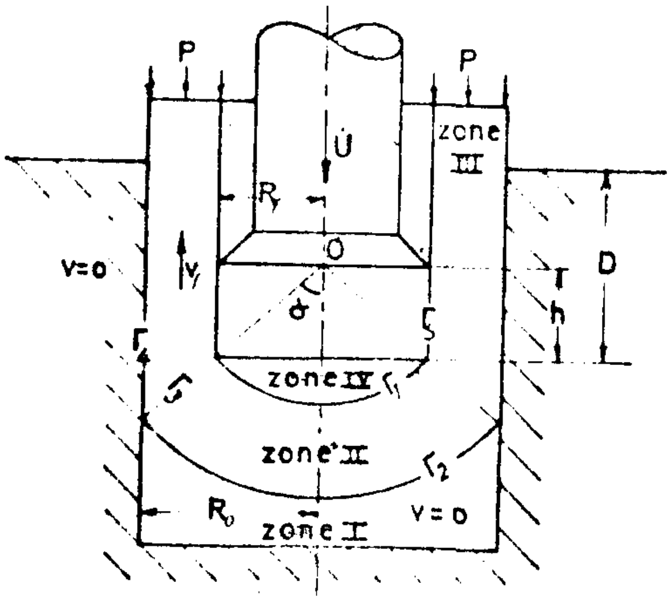

Fig. 1-2. Representation of the Early Stage Piercing

$$\frac{P_{av}}{\sigma_o} = \frac{2}{\sqrt{3}}\left(\frac{1}{1-(R_f/R_o)^2}\right)\times\Big[\sqrt{3}\cdot f(\alpha)\cdot \ln\frac{R_o}{R_f} + \frac{\alpha}{\sin^2\alpha} - \cot\alpha + \cot\alpha\cdot\ln\frac{R_o}{R_f}$$
$$+\frac{\sqrt{3}}{2}\left(1-\left(\frac{R_f}{R_o}\right)^2\right)\frac{P}{\sigma_o} - \frac{\sqrt{3}}{4}\,\frac{\rho \dot{U}^2}{g\,\sigma_o}\,\frac{(R_f/R_o)^2}{1-(R_o/R_f)^2} + m\left(\frac{h}{R_f} + \frac{R_f}{R_o}\left(\frac{D}{R_f} + \left(\frac{R_o}{R_f} - 1\right)\right.\right.$$
$$\left.\left.\times\ \cot\alpha\right)\right)\Big]$$

where m is a friction factor ranging from zero - in case of perfect lubrication - to 1 - in case of sticking full friction. and $f(\alpha)$ is a correction factor.

$$= \frac{1}{\sin^2\alpha}\left(1-\cos\alpha\sqrt{1-\frac{11}{12}\sin^2\alpha} + \frac{1}{\sqrt{11\times12}}\ln\frac{1+\sqrt{11/12}}{\sqrt{\frac{11}{12}}\cos\alpha + \sqrt{1-\frac{11}{12}\sin^2\alpha}}\right) \qquad (1.5)$$

The value of (α) which gives the lowest ram pressure for the chosen independent variables both - according to Avitzur - are assumed to the the actual ones prevailing under this given set of conditions. This equation (Eq. 1.4) is solved using a computer, to find this optimum value of α (i.e. α_{opt}).

In explanation to his equation (Eq.1.4) Avitzur states that the R.H.S. of the equation demonstrates the contribution of the different process variables in extrusion;

1- $\sqrt{3}\, f(\alpha)\cdot\ln\frac{R_o}{R_f}$ is the power required for internal deformation.

2- $\frac{\alpha}{\sin^2\alpha} - \cot\alpha + \cot\alpha\cdot\ln\frac{R_o}{R_f}$ is the power dessipated in overcoming friction over surfaces Γ_1, Γ_2 & Γ_3

3- $\frac{\sqrt{3}}{2}\left(1-\left(\frac{R_f}{R_o}\right)^2\right)\frac{P}{\sigma_o}$ is the power to overcome the external pressure p (see Fig.1.2) the importance of which is to suppress void formation during metal forming .

4- $\frac{\sqrt{3}\ \rho U^2 (R_1/R_o)^2}{4\ g\sigma_o\ [1-(R_o/R_1)^2]}$ is the power to overcome inertia, when the velocity of deformation is a domenating factor, i.e. in high speed metal forming (e.g. impact extrusion). If inertia is considered, increased density of the material and faster ram velocities both add to the ram pressure requirements.

5- $m\left(\frac{h}{R_1} + \frac{R_1}{R_o}\left(\frac{D}{R_1} + \left(\frac{R_o}{R_1} - 1\right)\cot\alpha\right)\right)$ is the power to overcome friction over surfaces Γ_4 & Γ_5

Avitzur plotted the relationship between P_R and α according to his equation, with the result of emphasizing the statment he previously mentioned, namely; α has an optimum value below and above which the piercing pressure increases. And when plotted against R_o/R_1 he demonstrated that P_R shows progressive increase, the effect of m being shifting the curve higher or lower* as m increases or decreases.

A general look on equations 1.1, 1.2 & 1.4 shows that an accurate estimate of the flow stress σ_o will affect their results.

With this respect Kang [3] states that for materials sensitive to strain rate (e.g. lead) the yield stress should be obtained from the $\dot{\epsilon} - \bar{\sigma}$ curve, which when plotted on a log-log scale demonstrates a progressively increasing linear relationship.**

According to Kang [3], the average effective strain rate is given by:

$$\dot{\Phi} = \frac{\text{ram speed}}{\text{billet length}} \cdot \ln\left(\frac{A_o}{A}\right) \qquad (1.6)$$

where A_o/A = extrusion ratio.

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* Ref. 5 page 1041, Fig. 3 & 4.

** Ref. 3 page 399, Fig. 2-b.

In Ref.[5*] , Avitzur states that, for a first approximation for the extrusion stress, equation (1.4) can be used where the flow stress σ_o is taken from tensile test data, that is, when the effective strain in uniaxial tension is

$$\Phi_o = 2 \ln\left(\frac{R_o}{R_f}\right)$$

For more accurate results, the average effective strain of the product is computed using equation (1.7).

$$\bar{\Phi} = f(\alpha) + \frac{(1/\sqrt{3})\left[(\alpha/\sin^2\alpha) - \cot\alpha\right]}{\ln(R_o/R_f)} \qquad (1.7)$$

Further on, Avitzur [5] states that for a material deformed above its recrystallization temperature, where no strain hardening can take place, the material is very sensitive to strain rates, and the flow stress can be expressed as:

$$\sigma_o = S\,\dot{\Phi}^n \qquad (1.8)$$

where S and n are constants of the material that are determined experimentally. S is the flow stress of the material for unit strain rate (in/in/unit time) and n is the strain rate sensitivity of the flow stress. Increased values of n indicates an increase in the strain rate sensitivity of the material.

For an average value of the flow stress, let $\dot{\Phi}$ in equation (1.8) be replace by $\dot{\bar{\Phi}}$ of equation (1.9).

$$\dot{\bar{\Phi}} = 2\,\frac{\dot{V}}{V}\cdot f(\alpha)\cdot \ln\frac{R_o}{R_f} \qquad (1.9)$$

where $\dot{V} = \pi \cdot v_f \cdot R_f^2$ (for v_f , R_f, R_o & α see Fig.1.2)

$$V = \frac{2}{3}\pi\,\frac{R_o^3 - R_f^3}{(1+\cos\alpha)\sin\alpha}$$

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* Page 201, 202.

$f(\alpha)$ being defined by equation (1.5).

Chandra [6], perhaps is the one that has first demonstrated -quantitatively- the dependence of $\bar{\sigma}_o$ on the strain rate sensitivity. He developed an expression for the mean strain rate, when the strain rate sensitivity of the material is considered, given by the equation

$$\bar{\dot{\Phi}} = 4\, V_o D_o^2 \tan\alpha \left[\frac{2}{3n \ln R} \left\{ \left(\frac{1}{D_L}\right)^{3n} - \left(\frac{1}{D_o}\right)^{3n} \right\} \right]^{1/n} \qquad (1.10)$$

where V_o, D_o, α & D_L are shown in Fig. 1.3 and n is the strain rate sensitivity of the flow stress.

NOTE: it is to be noted that equations 1.6, 1.9 & 1.10 are for direct extrusion processes. Application to piercing, though looks promissing, yet needs verification.

Chandra* compared results obtained from his equation and those obtained from another equation (Eq. 1.11) given by Wilcox - in some previous paper - where no account is made for strain rate sensitivity. The comparison showed that, for an extrusion ratio (R) ranging from 4 to 169,

$$\bar{\dot{\Phi}} = \frac{6\, V_o D_o^2 \ln R \tan\alpha}{D_o^3 - (D_o - 2L\tan\alpha)^3} \qquad (1.11)$$

the ratio $\dot{\Phi}_{10}/\dot{\Phi}_{11}$ increased from 1.24 to 9.00 with consequent increase in the ratio $\bar{\sigma}_{10}/\bar{\sigma}_{11}$ from 1.04 to 1.58*, where $\bar{\sigma}_{10}$ and $\bar{\sigma}_{11}$ are obtained by substitution of the corresponding value of $\dot{\Phi}$ from equation (1.10) and (1.11) into (1.8).

However, Avitzur** has shown that, for sound flow through conical converging dies, the upper bound solution with and

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* Ref. 6 page 2061, table 1.

** Ref. 4 page 1000 (first column, last paragraph).

without taking strain hardening into account differed only by 1-2%.

1.2 Ram Speed

The extrusion process is significantly affected in several ways by the speed at which it is conducted.

In experiments made by Pearson [1] on lead, he found that to bring about a tenfold increase in speed, the pressure has to be increased as follows:
at 17°C by 36 percent : at 100°C by 44 percent:
at 166°C by 50 percent: and at 325°C by 55 percent.
Yet, when extruding brass under technical conditions, at different rates, Pearson found that the matter is complicated by a factor, namely the cooling of the billet, the extent of which is greater the lower the rate of extrusion and the hotter the billet in relation to the pressure container.
At low rates the extrusion pressure was found to rise as a result of the increasing stiffness of the cooling metal.

An empirical relationship deduced from experimental data by Pearson [1] , relates the speed and pressure of extrusion as follows:

$$V = b.P^{a} \qquad (1.12)$$

in which a and b are constants for the given temperature.

According to Yang*, up to recently, and apart from some empirical relationships as equation (1.12), non of the researchers has been able to deduce a theoretical relationship between ram speed and extrusion pressure, it was yet possible according to Yang to introduce the effect of the ram speed on the pressure through equation (1.10) and consequently σ_o equation (1.8).

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* Ref. 3 Page 403 (first column, first paragraph).

The only difference between this equation and equation (1.4), being that; what were shear losses along Γ_1 in (1.4) are friction losses in (1.13).

Avitzur compared the ram pressure versus R_0/R_f for flat and nosed rams. This result is given in Fig. 1-6.

Although it is not possible to write an explicit equation for the optimum value of α as a function of the other process variables, its value can be determined according to Avitzur by optimization of equation (1.13).

1.4- Initial Billet Temperature

As in the ram speed, the billet temperature has much emplications on the extrusion process.

Perhaps, the first empirical relationship between the maximum extrusion pressure P (direct extrusion) and initial billet temperature, is that developed by Shishokin* (1929), equation (1.14), who studied the extrusion of lead, tin, cadmium, bismuth and gallium:

$$P = x \cdot e^{-\gamma T} \qquad (1.14)$$

where x and γ are empirical constants.

Pearson [1] (1960), has confirmed that the data obtained in the extrusion of some aluminium alloys over the rang 300-600°C, at a ram speed of 0.2 in/min., also satisfy this relationship.

However, the work of Ashcroft [2] , (1961) showed that the extrusion pressure is related to the initial billet temperature not by an equation of the form given in (1.14), but by the relationship :

* Ref. 2 page 12.

$$P = d - CT \quad (1.15)$$

where C and d are empirical constants.
For the Al-Zn-Mg-Cu alloy which he extruded from slugs with initial temperature ranging from 20 to 400°C, at an extrusion ratio of 10, the relationship was

$$P = 79 - 0.137\ T \quad (1.16)$$

Further experimentations made by Ashcroft investigating the reliability of his equation to other materials and different extrusion conditions revealed that the C/d ratio was approximately constant.*

To investigate the dependence of the temperature rise during extrusion on the initial billet temperature, Ashcroft extruded billets of the Al-Zn-Mg-Cu alloy with thermocouples embeded in. The temperature rise characteristic, thus observed, is shown in Fig. 1-7. Ashcroft devided the temperature rise obtained into three stages; a sudden initial rise of the order of 10°C due to slug deformation to fill the extrusion chamber, followed by a lower rate increase as a result of heat being conducted back (direct extrusion) through the slug from the deformation zone. Finally is a more rapid rise in temperature as the thermocouple moves into the deformation zone.

Chadwick [8] , (1962) whose work was done on direct extrusion of non-ferrous metals, demonstrated that the work done in extrusion is not employed entirely in deforming the metal at the die mouth (direct deformation work). A considerable proportion of the applied pressure is used up -according to Chadwick - in forcing the billet through the container (redundant work).
In the extrusion of copper, Chadwick puts the ratio between direct deformation to redundant work at about 1.3, and also he gave the following two equations to calculate the temperature rise in both cases;

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* Ref. 2 page 12.

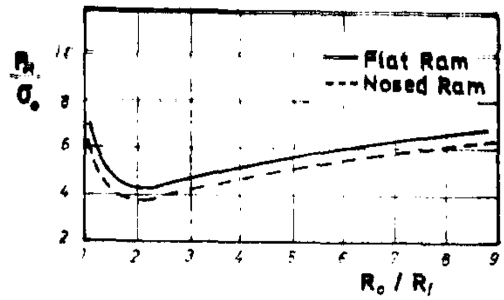


Fig.1-6. Comparison of Ram Pressure Versus Wall Thickness for Piercing with a Flat and Nosed Ram. (After Avitzur [5])

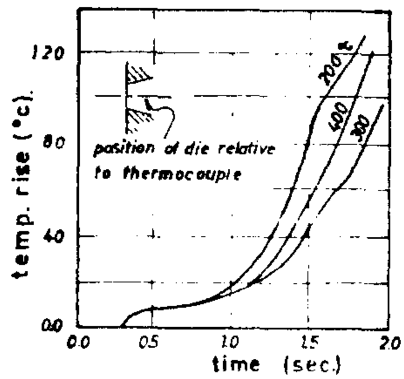


Fig.1-7. Temperature Rise in Al-Zn-Mg-Cu Alloy Extruded from Various Initial Temperatures. Extrusion Ratio 25, v= 29 Ipm. (After Ashcroft [7])

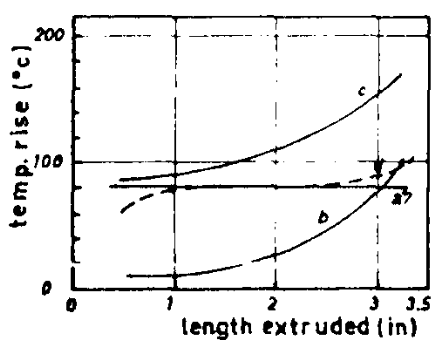
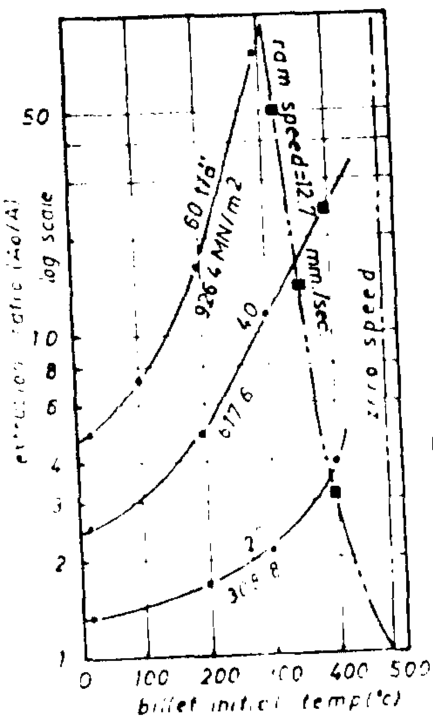


Fig.1-8. Theoretical Temperature Rise in Lead Extrusion, specific pressure 11 t/d', v = 0.5 in/sec. (After Chadwick [1])

a-temp.rise due to def. at die (T_2), b-temp. rise due to redundant work (T_1). c- total calculated temp. rise ($T_1 + T_2$), d- experimental temp. rise.



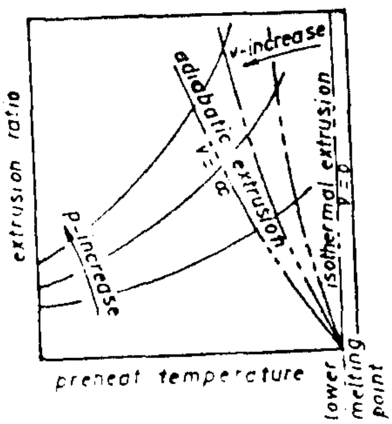


Fig. 1-9. Limiting Factors in Extrusion.

Fig. 1-10. Limiting Curves for the Extrusion of Al-Zn-Mg-Cu alloy at a Ram Speed = 12.7 mm/sec and Various Pressures.

■ [illegible] due to hot [illegible]