Further analysis and extrusion defects

1.1 Strain rate in hot extrusion:

Strain effects on flow stress and hence on extrusion pressure are predominant for hot extrusion (due to strain rate sensitivity). Therefore, it is rather difficult to predict extrusion force in hot extrusion. We can estimate the strain rate at any location x in the billet from the geometrical considerations.

Let a cylindrical billet has initial radius of Ro and extruded radius of Rf. α be semi-cone angle of the die.

We can write the strain rate at any location x from entry of die as:

$$\dot{\varepsilon} = \frac{d\varepsilon}{dt} = -2\frac{V_o R_o^2}{(R_o - x\tan\alpha)^3}\tan\alpha \text{ ------------3.1}$$

The average strain rate undergone by a billet is given by:

$$\bar{\dot{\varepsilon}} = \frac{6V_o D_o^2 \tan\alpha}{(D_0^3 - D_f^3)} \ln R \text{ -------3.2}$$

V_o is velocity of ram

We can say that for hot extrusion, the extrusion pressure,

p is directly proportional to stain rate. As strain rate increases, the extrusion pressure also increases, almost linearly. As ram speed increases, the extrusion pressure also increases, due to increasing strain rate. However, the extrusion pressure is reduced with increased working temperature in hot extrusion.

Further, with higher ram speeds, adiabatic conditions prevail, the billet does not cool fast enough, causing increase in temperatures rapid enough to cause localized melting. Cracks may initiate due to this. Hot shortness also can cause cracking. Such cracks are called speed cracks, as they are caused by high ram speeds.

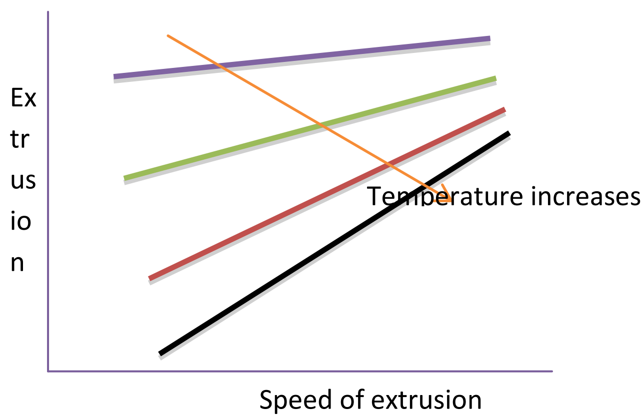


Fig. 1.1.1: Effects of temperature and velocity on extrusion force

A general expression for extrusion pressure in hot extrusion is usually given in the form:

P = klnR, where k is a factor depends on other factors during hot extrusion.

Optimum extrusion die angle:

We have seen in previous lecture that for ideal, frictionless extrusion, the extrusion pressure is given by:

p = Y lnR, which indicates that the extrusion pressure is independent of the die angle.

However, during extrusion, there is friction, which in turn increases the extrusion pressure.

There is redundant deformation which also demands some work or energy. We have seen that the extrusion force with friction depends on length of contact between die and billet. See equation 20.

Variation of extrusion pressure or force with die angle is shown.

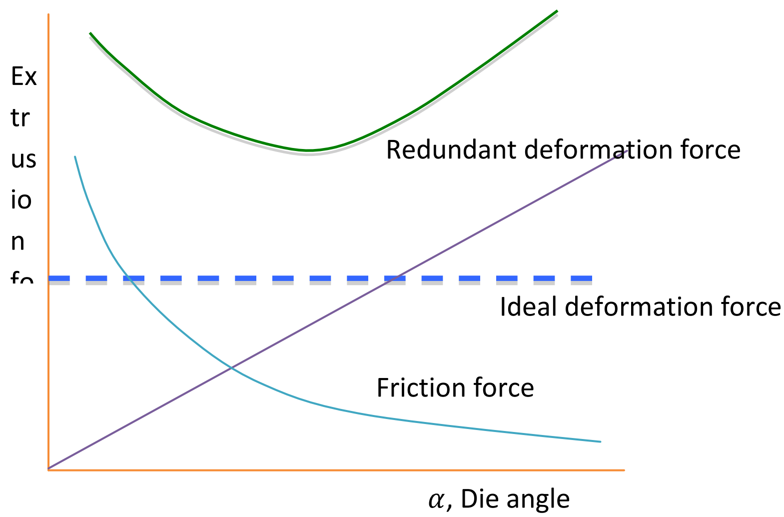


Fig. 1.1.2: Variation of various forces during extrusion with die angle

As seen from the graph, the force required to overcome friction increases with decrease in die angle. This is because, with reduced die angle, length of contact increases. Thus extrusion force increases. See eqn. 20.

On the other hand we observe that the force needed for redundant shear deformation increases with increase in die angle. This is because as the die angle is increased, there is more shear of the material, hence more redundant deformation.

The total extrusion force is a minimum at a particular die angle. This angle is called optimum die angle.

The area reduction r is defined as:

$r = (Ao-Af)/Ao = 1-Af/Ao \rightarrow \quad R = 1/(1-r)$

In extrusion, the extrusion ratio and also reduction r increase with increase in die angle. Reductions of 8 are commonly used in extrusion. That is, R = 8 and hence r = 0.875.

Example: Low carbon steel billet of initial diameter of 60 mm and length of 150 mm is extruded at 1400 K using a square die at a speed of 130 mm/s. Estimate the extrusion force for extruding the billet to a final diameter of 40 mm. Assume suitable data and assume poor lubrication.

Solution:

We can employ the expression: p = $\bar{Y}$(a+blnR) for estimating extrusion pressure.

The constants a and b are: a=0.8, b=1.5

In hot working the flow stress is strain rate dependent.

We can assume the flow stress as: $\sigma = C\dot{\varepsilon}^m = \bar{Y}$

For low carbon steel, C = 100 MPa and m = 0.1 (Average values)

R = Ao/Af = $(Do/Df)^2$ = 3600/1600 = 2.25

Strain rate is calculated using equation 23: $\dot{\bar{\varepsilon}} = \frac{6V_o D_0^2 tan\alpha}{(D_0^3 - D_f^3)}$lnR= 14.99 s^{-1}

Assume square die, that is, α=45 degrees

$\bar{Y}$ = 131.09 MPa

p = 264.33 MPa

Extrusion force = p X Area = 0.75 MN

1.2 Extrusion die:

Die and punch for extrusion are subjected to severe conditions of stress. Extrusion die are made from die steel or high carbon high chromium steels. The die is supported in a die holder and bolster. All these constitute the die head. The container has a liner shrunk into a thick shell in order to withstand high pressures. The extrusion ram has a follower pad in front so as to protect it from the hot billet. Usually, extrusion dies are conical in shape. Too small a die angle will increase friction and too large an angle will increase the friction force. The optimum semi-die angle for extrusion is usually in the range 45 to 60^o. Square dies, with 90o angle can be used for aluminium, as it has low flow stress. Special wear resistant coatings can be applied on die surface for enhancing the life of the die.

3.3 Defects in extrusion products:

Defects in extruded products occur predominantly due to friction and non-homogeneous material flow. Further, temperature variations across the billet during hot extrusion can also lead to inhomogeneous deformation. Three types of defects are prominent in extrusion. They are: extrusion defect, surface cracks and internal cracks.

Extrusion defect is basically due to inhomogeneous deformation. Material at the centre of the billet comes across least resistance compared to the material near the die wall. As a result, rapid flow happens at center. After one third of the billet is extruded, the material from periphery gets entrained towards the center and flows rapidly . Oxides present in peripheral layers are also entrained. Oxides form internal stringers near the center. This defect is known as pipe or tail pipe or extrusion defect. Die wall chilling of the outer layers of material also leads to inhomogeneous deformation. Outer layers of material cools rapidly and hence resistance to flow is higher. By reducing the friction and temperature variation between centre and periphery, this defect can be reduced. Using a dummy block smaller in diameter than the billet may form a thin film of metal and protect the billet against oxidation.

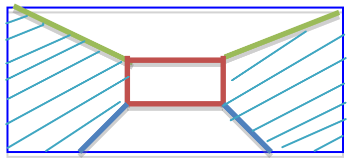
Towards the end of the process, rapid flow of material at the centre will result in pipe formation.

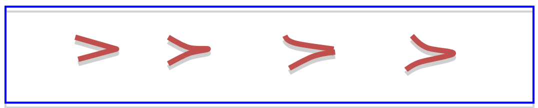
Surface cracks:

Too high extrusion speed, too large a friction too high a temperature may result in formation of surface cracks. Fir-tree cracks are transverse cracks which often occur in aluminium or magnesium due to hot shortness. Longitudinal tensile stresses may be induced on the outer layer, causing the cracks. At lower temperatures, stick-slip phenomenon may cause cracks especially in hydrostatic extrusion where pressures are very high. Sticking may happen due to thick viscous oil film.

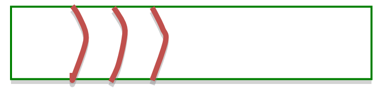
Internal cracks:

Secondary tensile stress at the centre can cause centre cracks called chevron crack or centre burst. Such defects are known to occur under low friction conditions and low extrusion ratio. Additionally, die angle and contact length play major role in centre burst. Larger the die angle, more the inhomogeneous deformation, thereby causes chevron cracks. The ratio of height of deformation zone to length of deformation zone, h/L is very important parameter controlling this defect. Large h/L values cause secondary tensile stress at centre, because the material at centre has not reached plastic stage – due to non-homogeneous deformation. As a result, centre burst occurs. Large die angle causes larger h/L.





Chevron cracks



Fir tree cracks

Fig. 3.3.1: Extrusion defects

Temperature of extrusion plays a very vital role on soundness of the extrudes. Multiple factors are involved in selection of working temperature. Strain rate, temperature of working and deformation force are inter-related factors affecting the quality of extruded parts. The following graph illustrates this.

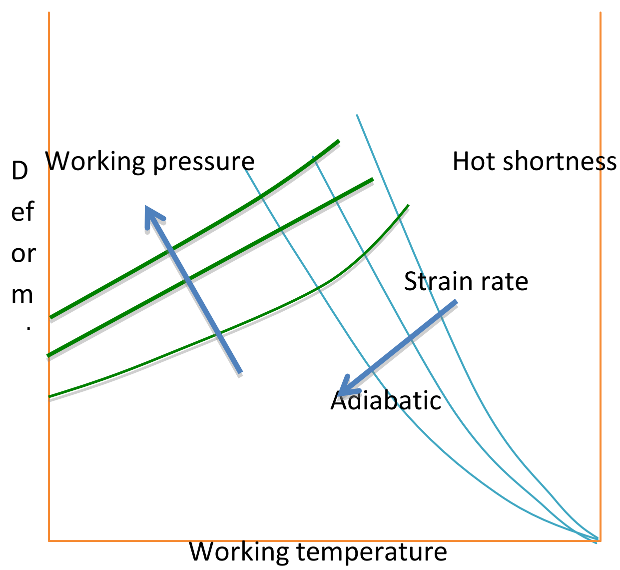


Fig. 3.3.2: Temperature and strain rate effects on deformation of material during extrusion

When working temperatures are higher, corresponding working pressures are lower. Limiting temperature is decided by hot shortness. Similarly, strain rates are limited by adiabatic conditions and retention of more heat in the billet. Excess strain rates at a particular temperature restricts the extent of deformation due to the possibility of crack formation. Or if excess strain rates are involved in the process, the working temperature has to be reduced for avoiding hot shortness. Higher deformation temperatures reduce the pressure required for a given deformation or for a given pressure, larger deformations can be achieved.

Source:
http://nptel.ac.in/courses/112106153/25