Metal Forming Lecture 4: Extrusion

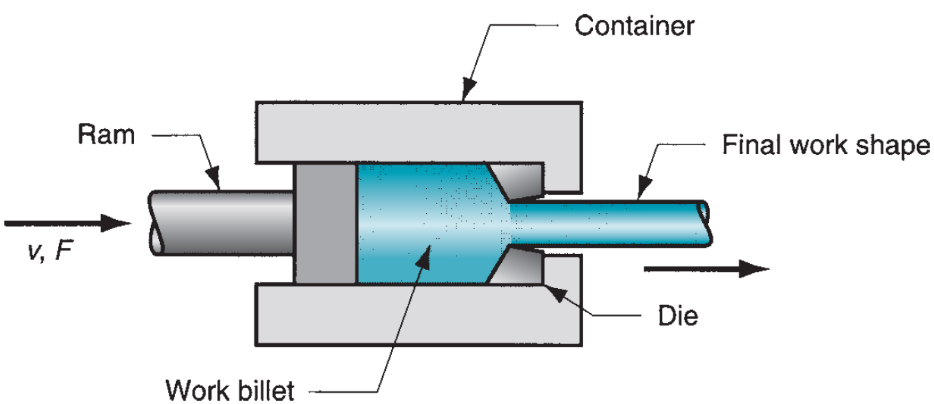
- Hosford, William F., and Robert M. Caddell. Metal forming: mechanics and metallurgy. Cambridge university press, 2011.
- Groover, Mikell P. Fundamentals of modern manufacturing: materials, processes, and systems. John Wiley & Sons, 2010.

Extrusion

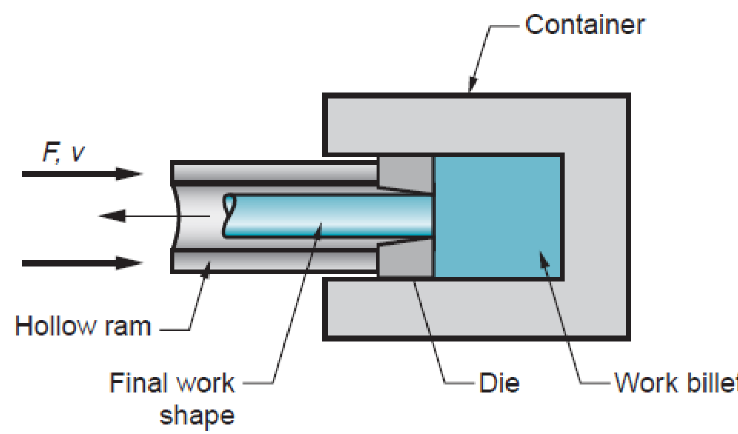
Extrusion is a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape.

Extrusion is carried out in various ways. One important distinction is between direct extrusion and indirect extrusion. Another classification is by working temperature: cold, warm, or hot extrusion. Finally, extrusion is performed as either a continuous process or a discrete process

Direct extrusion/ forward extrusion



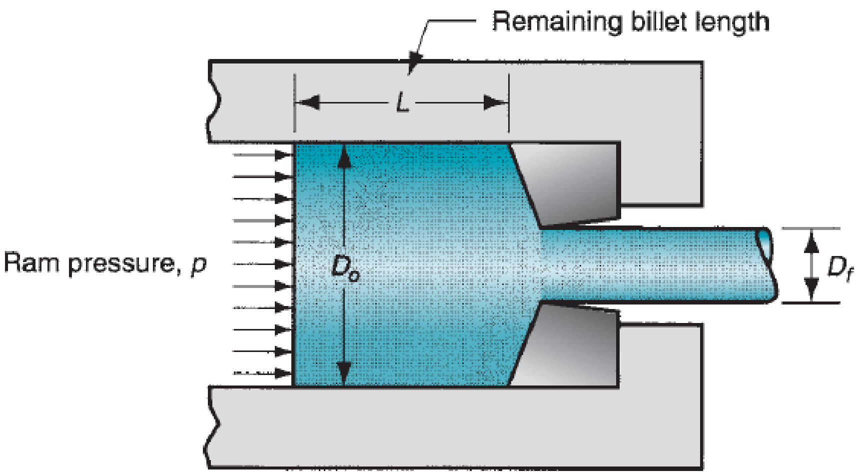
Indirect extrusion, backward extrusion



Impact extrusion – high-speed cold extrusion

Isothermal extrusion – heating of die

Analysis of Extrusion



Extrusion ratio or reduction ratio $r_x = \frac{A_o}{A_f}$

True strain in extrusion $\epsilon = \ln r_x = \ln \frac{A_o}{A_f}$

The average flow stress $\bar{Y}_f = \frac{K\,\epsilon^n}{1+n}$

Extrusion pressure (Ideal deformation)

$$p = \bar{Y}_f \ln r_x$$

Various methods have been suggested to calculate the actual true strain $\epsilon_x = a + b \ln r_x$

Johnson formula

The ram pressure to perform **indirect extrusion** $p = \bar{Y}_f \epsilon_x$

In **direct extrusion**, the effect of friction between the container walls and the billet causes the ram pressure to be greater than for indirect extrusion

Friction force in the direct extrusion container $\frac{p_f \pi {D_0}^2}{4} = \mu p_c \pi D_0 L$

p_f - additional pressure required to overcome friction

In the worst case, sticking occurs so that friction stress

$$\mu p_c = Y_s$$

Y_s - shear yield strength

Assume $Y_s = \bar{Y}_f/2$

$$\Rightarrow p_f = \bar{Y}_f \frac{2L}{D_0}$$

Thus the ram pressure

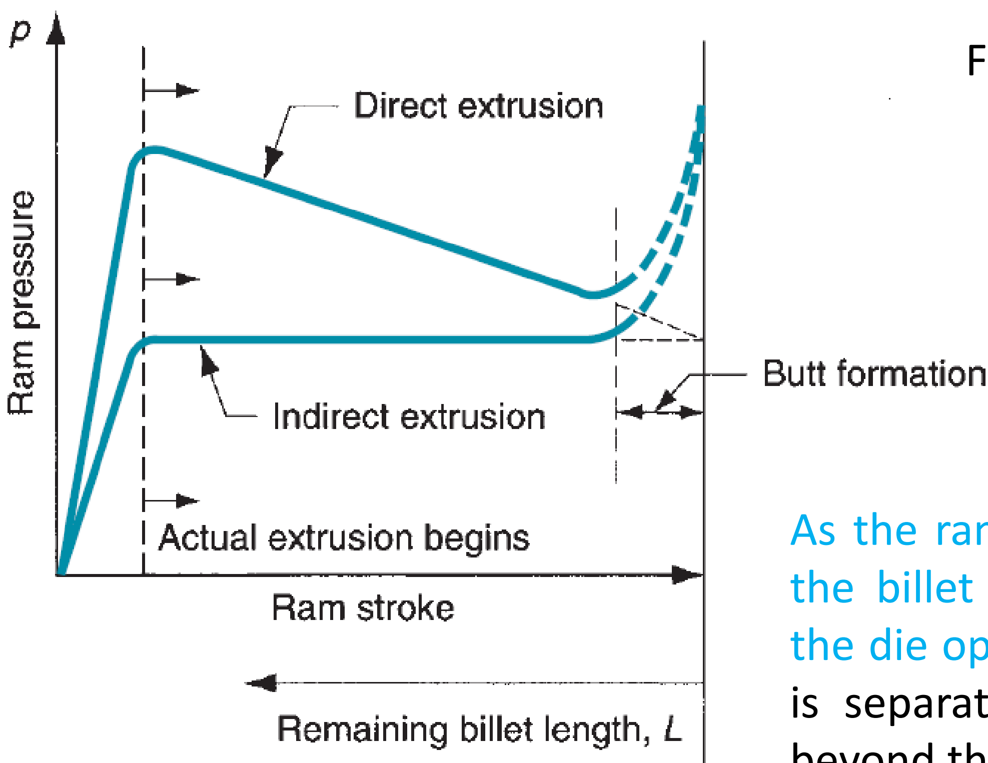
$$p = \bar{Y}_f \left(\epsilon_x + \frac{2L}{D_0} \right)$$

Ram force in indirect or direct extrusion

$$F = pA_o$$

Power required to carry out the extrusion operation

$$P = Fv$$



For different cross-section:

Indirect extrusion $p = K_x \bar{Y}_f \epsilon_x$

Direct extrusion $p = K_x \bar{Y}_f \left(\epsilon_x + \frac{2L}{D_0} \right)$

K_x – shape factor
$K_x = 1$ circular cross-section

As the ram approaches the die, a small portion of the billet remains that cannot be forced through the die opening. This extra portion, called the **butt**, is separated from the product by cutting it just beyond the die-exit.

Problem

A billet 75 mm long and 25 mm in diameter is to be extruded in a direct extrusion operation with extrusion ratio $r_x = 4.0$. The extrudate has a round cross section. The die angle (half-angle) = 90°. The work metal has a strength coefficient = 415 MPa, and strain-hardening exponent = 0.18. Use the Johnson formula with $a = 0.8$ and $b = 1.5$ to estimate extrusion strain. Determine the pressure applied to the end of the billet as the ram moves forward.

Solution: Let us examine the ram pressure at billet lengths of $L = 75$ mm (starting value), $L = 50$ mm, $L = 25$ mm, and $L = 0$. We compute the ideal true strain, extrusion strain using Johnson's formula, and average flow stress:

$$\epsilon = \ln r_x = \ln 4.0 = 1.3863$$

$$\epsilon_x = 0.8 + 1.5(1.3863) = 2.8795$$

$$\overline{Y}_f = \frac{415(1.3863)^{0.18}}{1.18} = 373 \text{ MPa}$$

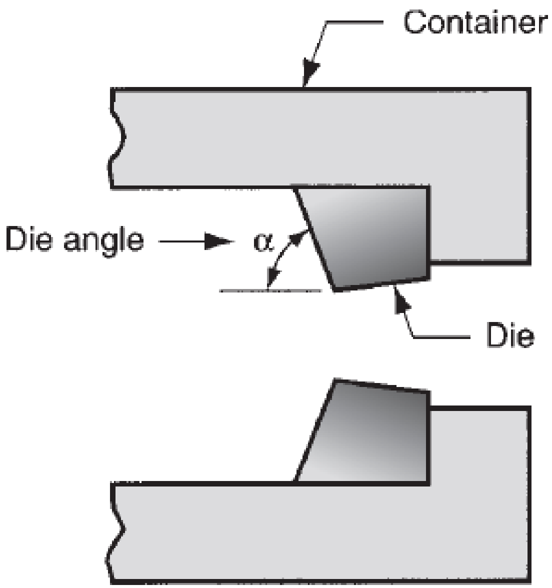
$$p = 373\left(2.8795 + 2\frac{75}{25}\right) = 3312 \text{ MPa}$$

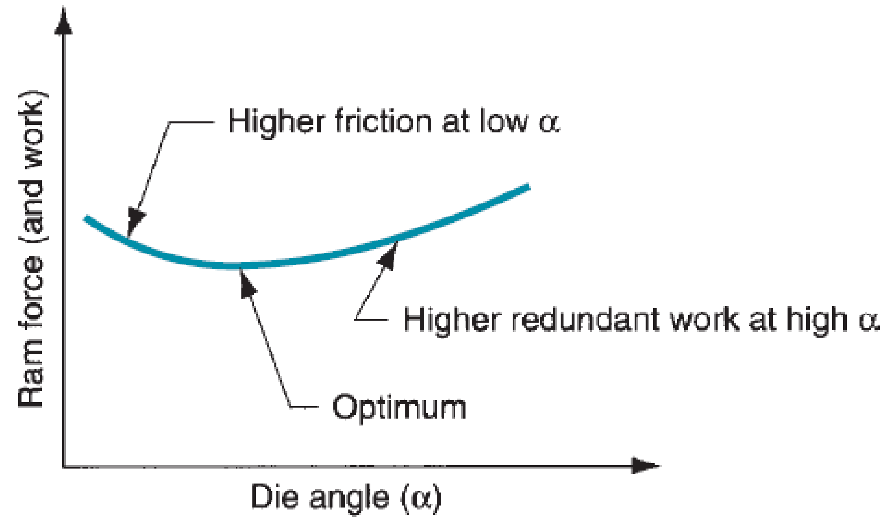
$$L = 50 \text{ mm: } p = 373\left(2.8795 + 2\frac{50}{25}\right) = 2566 \text{ MPa}$$

$$L = 25 \text{ mm: } p = 373\left(2.8795 + 2\frac{25}{25}\right) = 1820 \text{ MPa}$$

L= 0 mm $\quad p = 373\left(2.8795 + 2\frac{0}{25}\right) = 1074 \text{ MPa}$

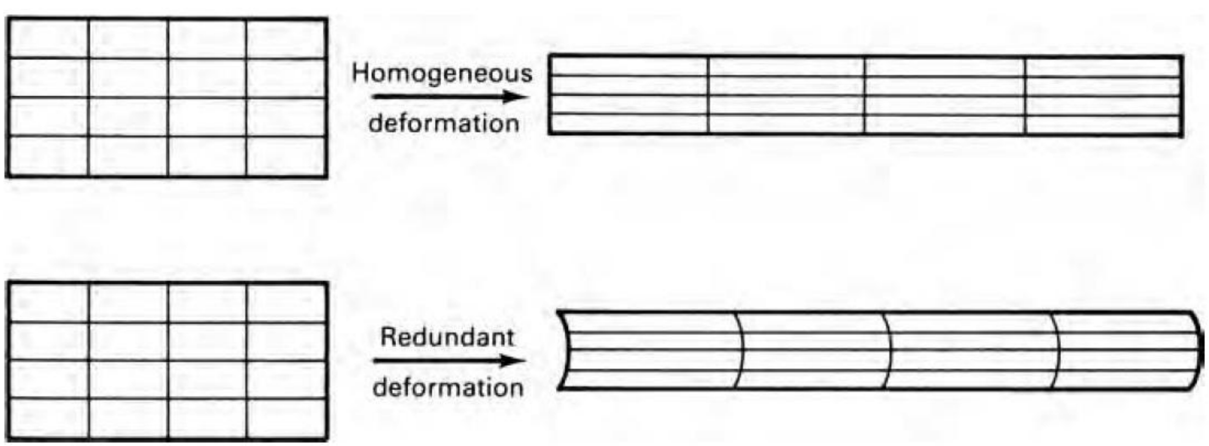
This is also the value of ram pressure that would be associated with indirect extrusion throughout the length of the billet.





DEFORMATION EFFICIENCY

Actual work $w_a = ideal\ work + frictional\ work + redundent\ work$

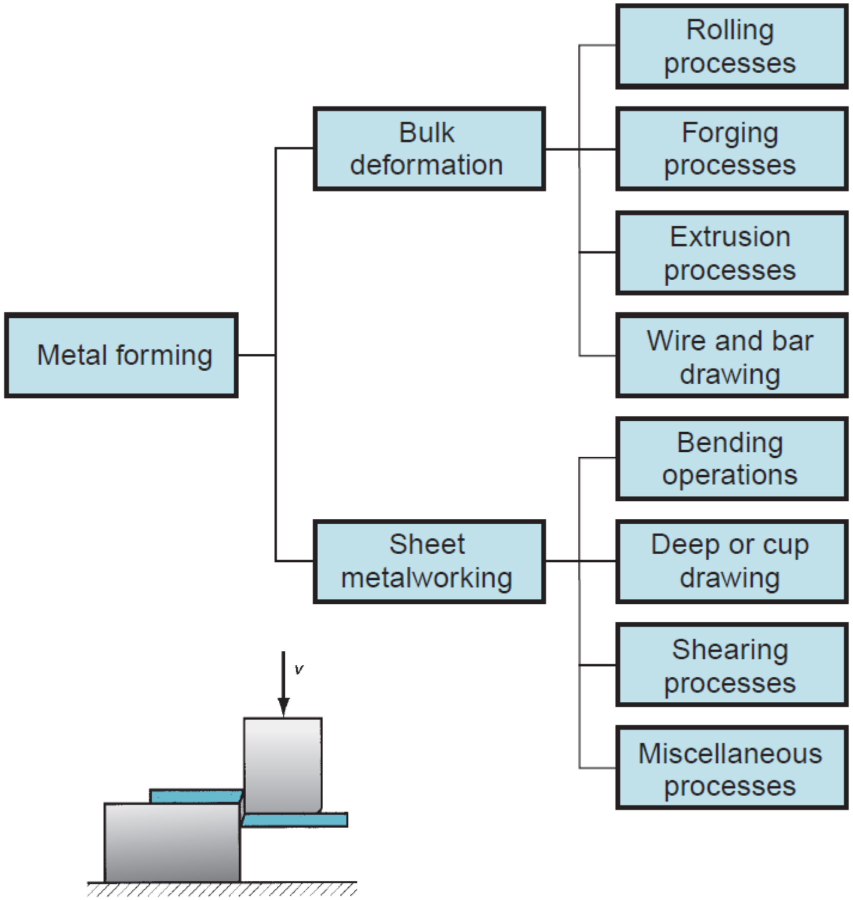


$$w_a = w_i + w_f + w_r$$

Deformation Efficiency

$$\eta \equiv w_i / w_a$$

Metal forming Processes



Metal forming includes a large group of manufacturing processes in which **plastic deformation is used to change the shape of metal** workpieces. Deformation results from the use of a tool, usually called a **die** in metal forming, which applies stresses that exceed the **yield strength of the metal**. The metal therefore deforms to take a shape determined by the geometry of the die.