Tutorial 4

Extrusion

INTRODUCTION

Extrusion is a process in which a block of metal is reduced in cross section by forcing it to flow through a die orifice under high pressure.

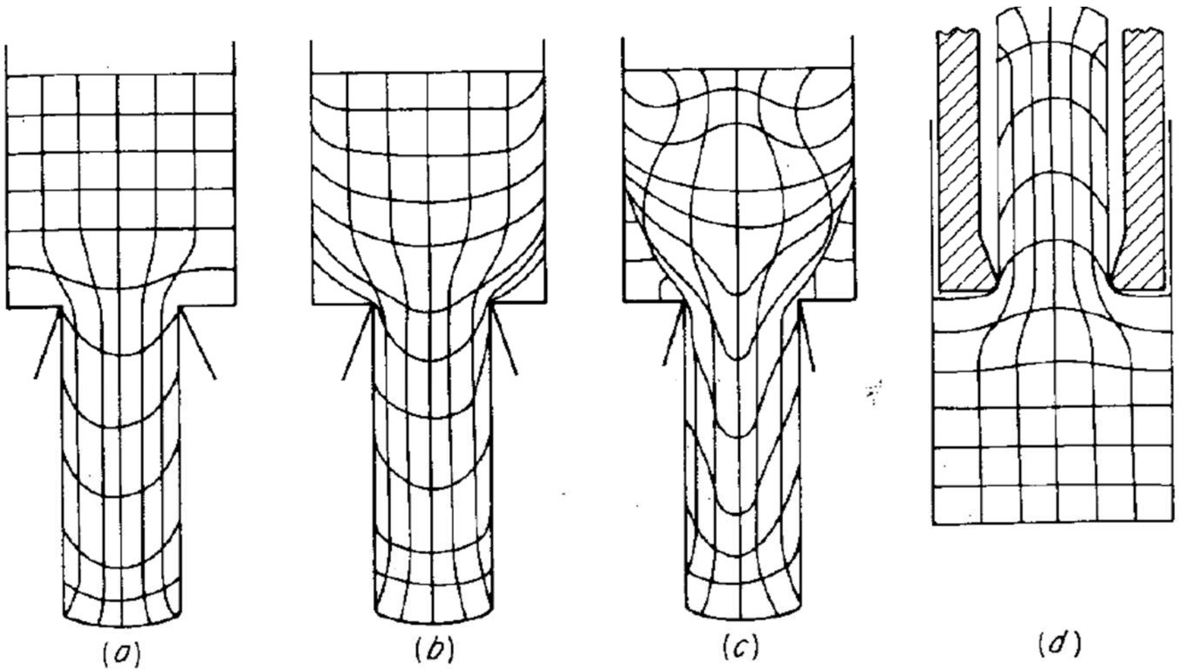
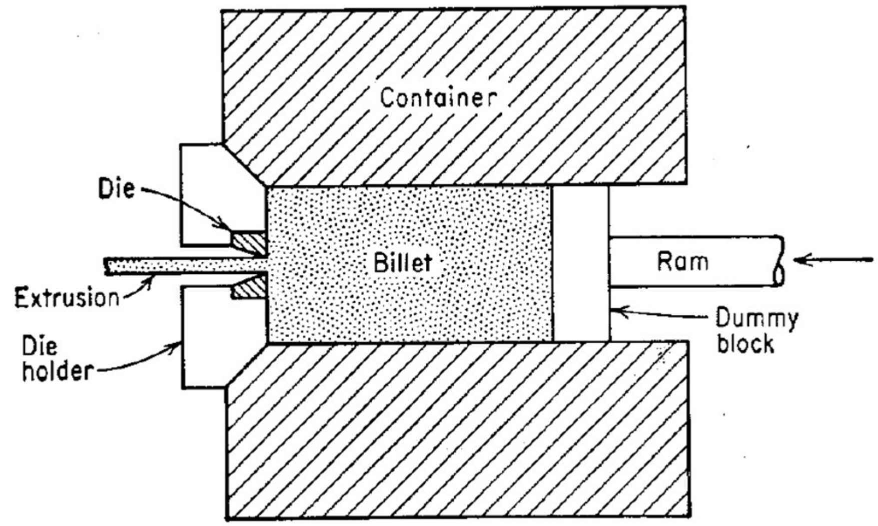
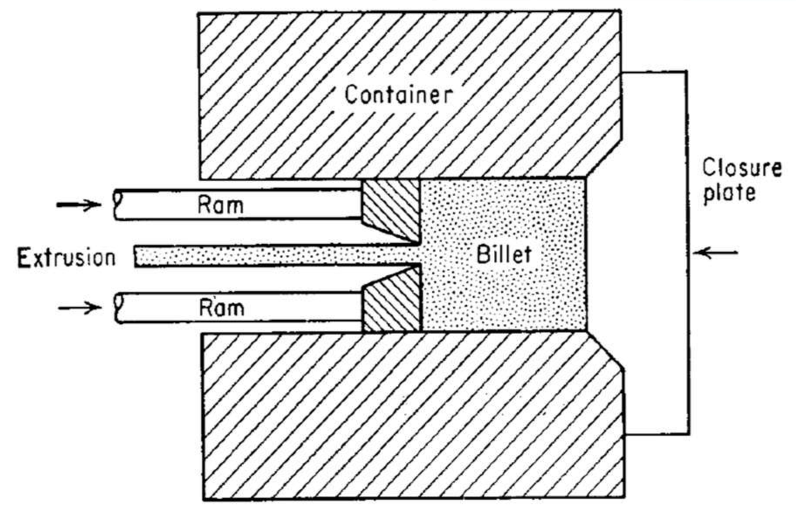


Figure 18-6 Patterns of metal deformation in extrusion. (*After Schey.*)



Direct extrusion



Indirect extrusion

METHODS OF ANALYSIS

1. The slab method: assumes homogeneous deformation
2. **Uniform - deformation energy method**: calculates average forming stress from the work of plastic deformation
3. Slip - line field theory: permits point by point calculation of stress for plane-strain condition only
4. Upper - and lower - bound solutions: based on theory of limit analysis, uses reasonable stress and velocity fields to calculate the bounds within which the actual forming load must lie
5. Finite element methods: a technique called the matrix method allows large increments of deformation for rigid plastic materials, with considerable reduction in computational time

EXTRUSION - ANALYSIS

Extrusion - Analysis

From uniform deformation energy approach, plastic work of deformation per unit volume for direct extrusion,

$$U_p = \bar{\sigma} \int d\varepsilon = \bar{\sigma} \int_{A_o}^{A_f} d(\ln A) = \bar{\sigma} \ln \frac{A_f}{A_o} = -\bar{\sigma} \ln R$$

where $\bar{\sigma}$ = effective flow stress in compression

ε = true strain

R - extrusion ratio, $R = \frac{A_o}{A_f}$

EXTRUSION - ANALYSIS

Work can be expressed as,

$$W = U_p V = V \bar{\sigma} \ln R = p A L = \text{force} \times \text{distance}.$$

Rewriting for pressure, $p = \frac{V}{AL} \bar{\sigma} \ln R = \bar{\sigma} \ln R$ ... idealized extrusion pressure.

If efficiency, $\eta = \frac{p}{p_e}$; p - ideal extrusion pressure

p_e - actual extrusion pressure

$$\Rightarrow \quad p_e = \frac{\bar{\sigma}}{\eta} \ln R$$

EXTRUSION - ANALYSIS

$p_e = p_d + p_f$; where p_d = die pressure, p_f = frictional pressure

$p_f = \frac{4\tau L}{D}$; τ - uniform interface shear stress between billet & container liner.

L - length of billet in container liner

D - inside diameter of container liner

EXTRUSION - ANALYSIS

$$P_d = \sigma_0 \left(\frac{1+B}{B}\right)\left(1 - R^B\right) \; ; \quad B = \mu \cot \alpha$$

α = semidie angle

$$\boxed{P_e = \sigma_0 \left(\frac{1+B}{B}\right)\left(1 - R^B\right) + \frac{4\tau L}{D}}$$

Time average mean strain rate, $\dot{\varepsilon}_t = \dfrac{\bar{\varepsilon}}{t} = \dfrac{6v \ln R}{D_b}$;

v - rate of extrusion

D_b - billet diameter

QUESTION 1

Example An aluminum alloy is hot extruded at 400°C at 50 mm s^{-1} from 150 mm diameter to 50 mm diameter. The flow stress at this temperature is given by $\bar{\sigma} = 200(\dot{\varepsilon})^{0.15}$ (MPa). If the billet is 380 mm long and the extrusion is done through square dies without lubrication, determine the force required for the operation.

Given:

$T = 400°C$

$v = 50\ mm/s$

$D_o = 150\ mm = D_b$

$D_f = 50\ mm = D_e$

Flow stress $= \bar{\sigma} = 200(\dot{\varepsilon})^{0.15}$ MPa

$L = 380\ mm$

$F = ?$

$$R = \frac{A_o}{A_f} = \frac{\frac{\pi}{4} D_o^2}{\frac{\pi}{4} D_f^2} = \frac{150^2}{50^2} = 9$$

$$\dot{\bar{\varepsilon}} = \frac{6v \ln R}{D_b} = \frac{6 \times 50 \times \ln 9}{150} = 4.39\ s^{-1}$$

$$\bar{\sigma} = 200(\dot{\varepsilon})^{0.15} = 200(4.39)^{0.15} = 250\ MPa$$

Metal flow pattern $\Rightarrow \alpha = 60^\circ$

Assume $\mu = 0.1$ [hot ~~extrusion~~ extrusion, low friction]

$B = \mu \cot\alpha = 0.1 \cot 60^\circ = 0.0577$

$$P_d = \sigma_0 \left(\frac{1+B}{B}\right) \left|\left(1 - R^B\right)\right|$$

$$= 250 \left(\frac{1+0.0577}{0.0577}\right) \left|\left(1 - 9^{0.0577}\right)\right|$$

$$P_d = \cancel{797}\ 611 \text{ MPa}$$

$$\tau = \frac{\sigma_0}{\sqrt{3}} = \frac{250}{\sqrt{3}} = 144 \text{ MPa}$$

$$P_f = \frac{4\tau L}{D} = \frac{4 \times 144 \times 380}{150} = 1459 \text{ MPa}$$

$$P_e = P_d + P_f = 611 + 1459 = 2070 \text{ MPa}$$

$$F = P_e A = 2070 \times \frac{\pi}{4} (150)^2$$

$$= 36579919.46 \text{ N}$$

$$\boxed{F = 36.58 \text{ MN}}$$

THANK YOU!