Wire Drawing

Wire drawing is a metalworking process used to reduce the cross-section of a wire by pulling the wire through a single, or series of, drawing die(s).

Fig. 1 identifies the features of a typical draw die.

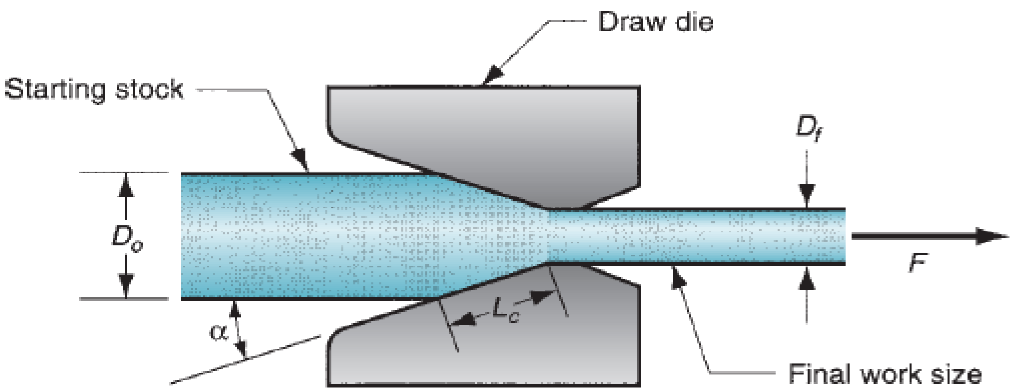

Fig. 1: Wire drawing.

Wire is drawn from coils consisting of several hundred (or even several thousand) feet of wire and is passed through a series of draw dies as shown in Fig. 2. The number of dies varies typically between 4 and 12.

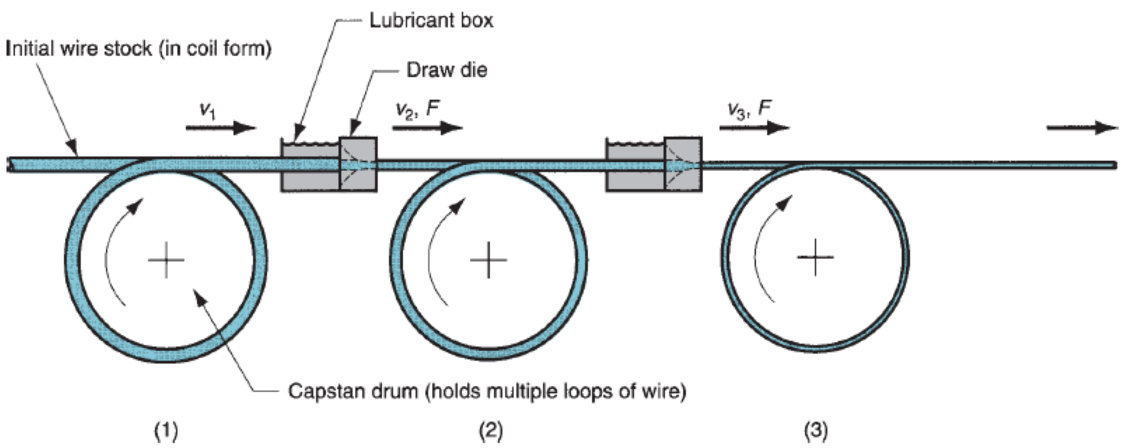

Fig. 2: Continuous drawing of wire.

Work formula for wire drawing

For uniaxial tension as in Fig. 3, the principal stresses are

$$\sigma 1 = Y, \sigma 2 = \sigma 3 = 0 \dots\dots\dots\dots\dots\dots\dots(1)$$

Y = uniaxial yield stress.

Fig. 3: uniaxial tension $\sigma_1 = Y, \sigma_2 = \sigma_3 = 0$

The increment of work done in increasing the length of specimen by (dL) is given by the product of force and displacement

$$\delta W = (YA)dL \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(2)$$

The increment of work done per unit volume (V) is

$$\frac{\delta W}{V} = \frac{\delta W}{AL} = Y\frac{dL}{L} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(3)$$

We may assume no volume change, and integrate this expression between the original length L_o and the final length L_1:

$$\frac{W}{V} = \int_{L_\circ}^{L_1} Y\frac{dL}{L} = \int_{\epsilon_\circ}^{\epsilon_1} Y d\epsilon \dots\dots\dots\dots\dots\dots\dots\dots(4)$$

This gives the well-known result that the work done per unit volume in homogeneous deformation is equal to the area of the stress-strain curve, between the appropriate strain values.

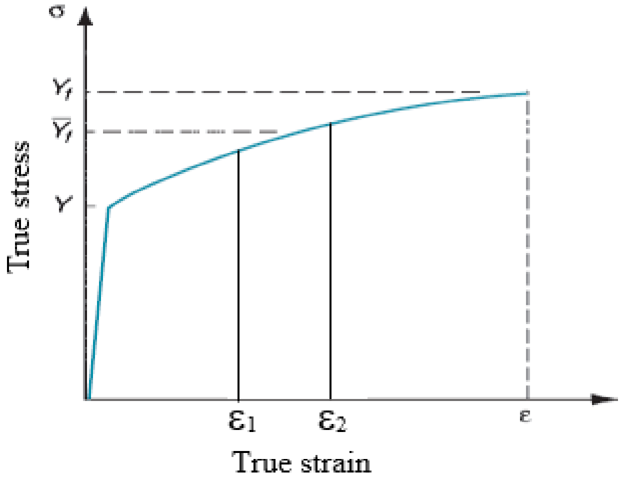

Fig. 4: Stress–strain curve, showing the average flow stress $\bar{Y}$ for an ideal process deformation metal from ϵ_1 to ϵ_2.

This may be evaluated directly from the dimension change, assuming an average yield stress $\bar{Y}$

$$\frac{W}{V} = \bar{Y}\int_{L_\circ}^{L_1} \frac{dL}{L} = \bar{Y}\ln\frac{L_1}{L_\circ} \dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

The work done by the drawing force F_1 to the full length L_1 of drawn wire is given by

$$W = F_1 \times L \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (6)$$

Assuming homogenous deformation and from eq. (5)

$$W = V\bar{Y}\ln\frac{L_1}{L_\circ} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (7)$$

In the absence of friction, these will be equal:

$$F_1 = \frac{V}{L_1}\bar{Y}\ln\frac{L_1}{L_\circ} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (8)$$

Since $V = A_o \times L_o = A_1 \times L_1$ then

$$F_1 = A_1 \bar{Y} \ln \frac{L_1}{L_\circ} \ldots \ldots \ldots . \ldots . \ldots \ldots \ldots \ldots . \ldots \ldots \ldots (9)$$

It is usual to consider reduction of area in wire drawing rather than increase in length, then equation (9) becomes

$$F_1 = A_1 \bar{Y} \ln \frac{A_o}{A_1} \ldots \ldots \ldots . \ldots . \ldots \ldots \ldots \ldots . \ldots \ldots \ldots (10)$$

The reduction in area (r) is given by

$$r = \frac{A_o - A_1}{A_o} = 1 - \frac{A_1}{A_o} \ldots \ldots \ldots \ldots . \ldots \ldots \ldots . . (11)$$

Thus

$$F_1 = A_1 \bar{Y} \ln \frac{1}{1-r} \ldots \ldots \ldots . \ldots \ldots \ldots \ldots . \ldots \ldots \ldots (12)$$

The drawing stress σ_1 is consequently

$$\sigma_1 = \frac{F}{A} = \bar{Y} \ln \frac{1}{1-r} \ldots \ldots \ldots . \ldots \ldots \ldots \ldots . \ldots \ldots \ldots (13)$$

Maximum Reduction per Pass

To determine maximum possible reduction that can be made in one pass, under certain assumptions. Let us assume a perfectly plastic metal (n=0), no friction, and no redundant work. In this ideal case, the maximum possible draw stress is equal to the yield strength of the work material. Expressing this using the equation for draw stress under conditions of ideal deformation, Eq. (13), and setting $\bar{Y} = Y$ (because n = 0),

$$\sigma = Y$$

$$\frac{\sigma}{Y} = 1; \;\; \sigma = \; Y \ln \frac{1}{1 - r_{max.}}$$

$$1 = \; \ln \frac{1}{1 - r_{max.}}$$

$$e^1 = \; \frac{1}{1 - r_{max.}}$$

$$2.7183 = \; \frac{1}{1 - r_{max.}}$$

$$r_{max.} = \; 1 - \frac{1}{2.7183} = 0.632$$

The maximum possible reduction about 63%

<u>Note:</u> The frictional contribution always increases the drawing stresses

$$\frac{\sigma}{Y} = \frac{1 + B}{B}[1 - (1 - r)^B]$$

Where $B = \mu cot\alpha$

$\mu = coefficint\ of\ friction.$

$\alpha = die\ angle.$

Example 1

A copper wire is annealed at (**2.12** mm) diameter. What is the smallest diameter to which it could theoretically be drawn in:

a. One pass.

b. Three passes.

Solution

a.

$$\sigma_1 = \bar{Y} \ln \frac{Ao}{A_1}$$

$$\frac{\sigma_1}{\bar{Y}} = \ln \frac{Ao}{A_1}$$

$$1 = \ln \frac{Ao}{A_1}$$

$$2.7 = \frac{\frac{\pi}{4}(2.12)^2}{\frac{\pi}{4}(d_1)^2}$$

$$d_1 = 1.28\, mm$$

b.

$$3 = \ln \frac{Ao}{A_1}$$

$$20.08 = \frac{\frac{\pi}{4}(2.12)^2}{\frac{\pi}{4}(d_3)^2}$$

$$d_3 = 0.47\, mm$$

Example 2

Estimate the maximum reduction in area per pass for wire drawing process for some typical practical values coefficient of friction 0.05 and die angle 15^{o}

Solution

$$B = \mu cot\alpha$$

$$B = \frac{0.05}{\tan 15} = 0.1865$$

$$\frac{\sigma}{Y} = \frac{1+B}{B}\left[1-(1-r)^{B}\right]$$

$$1 = \frac{1+0.1865}{0.1865}\left[1-(1-r)^{0.1865}\right]$$

$$r \approx 0.60 \;\; or\; r \approx 60\%$$

Example 3

Determine the drawing stress to produce a 20% reduction in a 10 mm stainless steel wire and the average flow stress is 637 MPa. The die angle is 6° and coefficient of friction is 0.09?

If the wire is moving through the die at 3 m/sec. determine the horsepower required to produce the deformation?

$$B = \mu cot\alpha = \frac{0.09}{\tan 6} = 0.857$$

$$\frac{\sigma}{Y} = \frac{1+B}{B}[1-(1-r)^B]$$

$$\frac{\sigma}{637} = \frac{1+0.857}{0.857}[1-(1-0.2)^{0.857}]$$

$$\sigma = 240.254\ MPa.$$

$$Power = Force \times \frac{distance\ moved}{time}$$

$$F = \sigma \times A_1 = 240 \times \frac{\pi}{4}(8)^2$$

$$F = 12.06\ KN$$

$$Power = 12.06 \times 3 = 36.18\ KW$$

$$1\ \text{hp} = 0.746\ \text{KW}$$

$$Horse\ power = \frac{36.18}{0.746} = 48.5\ hp$$

Home work

Brass wire of 2.5 mm diameter is drawn to 2.15 mm diameter. Calculate the approximate minimum drawing load?

What would be this if the wire had been annealed at 3.20 mm diameter and drawing to 2.5 mm before this pass?

Note

ϵ	$\bar{Y}\ (KN/mm^2)$
0.301	0.338
0.794	0.634