Aspects of wire drawing and tube drawing

1. Further aspects of wire drawing and tube drawing:

1.1 Redundant work:

Redundant deformation happens during wire drawing due to shear of the material in the deformation zone. A redundant work factor can be employed to account for redundant work. The redundant work factor is defined as:

$\phi = \frac{\varepsilon^*}{\varepsilon}$------3.1

Where ε^* is the increased strain of the deformed material corresponding to the yield stress. ε^*can be obtained from stress-strain curve by superimposing the flow curve of the drawn material on the annealed flow curve for the same material.

The redundant factor is related to the deformation zone geometry parameter Δ as:

$\phi = 0.8+\frac{\Delta}{4.4}$-------3.2

where the deformation zone geometry for wire drawing is given by:

$\Delta = \frac{\alpha}{r}[1+(1-r)^{1/2}]^{1/2}$ ----3.3

As seen from the above expressions, the redundant work increases as the semi-die angle is increased. Similarly, it decreases for increase in reduction r.Practically, the semi-die angles employed is in the range 6 to 10^{o}. The reductions employed commercially are in the range 20 to 25%.Δranges from 2 to 3.

One method of including the redundant work in draw force is multiplying the draw stress by redundant work factor as given below:

$$p = \phi\bar{Y}\ln\left(\frac{Ao}{Af}\right)(1+\mu cot\alpha) \qquad \text{-----------3.4}$$

Another approach is similar to what has been discussed in extrusion chapter. We can determine the redundant work from the shear strain on the material both at entry and exit of the draw die. This work is then added to the draw stress obtained by the slab analysis.

$$\sigma_x = \bar{Y'}\frac{1+B}{B}\left(1-\left[\frac{d_f}{d_o}\right]^{2B}\right) + \frac{4}{3\sqrt{3}}\alpha\bar{Y'} \qquad \text{-----3.5}$$

1.2 Optimum die angle:

Similar to extrusion, there exists optimum die angle for drawing process. The optimum angle is determined based on the minimum total energy required for drawing. The total energy for drawing (or work for drawing) is the sum of ideal deformation work, redundant work and frictional work.

One can also define an optimum for the deformation zone geometry as:

$$\Delta_{opt} = 4.9\left[\frac{\mu}{\ln\left(\frac{1}{1-r}\right)}\right]^{1/2} \qquad \text{--------3.6}$$

1.3 Maximum reduction in drawing:

Number of drawing steps or passes required are more if larger reductions are desired. If the required reduction is attempted in a single step, the draw stress required may be too high.

If the draw stress applied reaches the material’s yield strength, then instead of getting drawn, the material will start yielding. The material will start elongating locally instead of getting drawn out. Therefore, the draw stress should not be allowed to reach the yield strength of the work material. For maximum drawing, we can say that the draw stress is just equal to the material yield strength. Considering frictionless, ideal deformation without any shear, we can write for maximum drawing:

$p = \bar{Y}\ln(\frac{A_0}{A_f}) = \bar{Y}$ -------3.7

Or, we have:

$\ln[\frac{A_0}{A_f}] = 1$

Or

$(A_o/A_f)_{max} = 2.718$

From which we get

$r_{max} = 0.632$ ------------3.8

The above analysis is based on the assumption that friction is absent and there are no redundant work and there is no work hardening during drawing.

If work hardening and friction are considered, the limiting reduction will be less than 63%.

1.4 Die pressure:

Applying the yield criterion for wire drawing, at any location within the deformation zone, we can write:

$p = Y - \sigma_x$, where Y is yield strength at the location considered and σ_x is the tensile stress at the location.

As we see from this equation, the draw stress = σ_x at exit.

i.e. $\sigma_d = Y - p$

Towards the die exit, the yield strength increases due to work hardening. Therefore, draw stress increases towards the exit, as shown in figure. Due to this reason the die pressure p decreases towards the die exit.

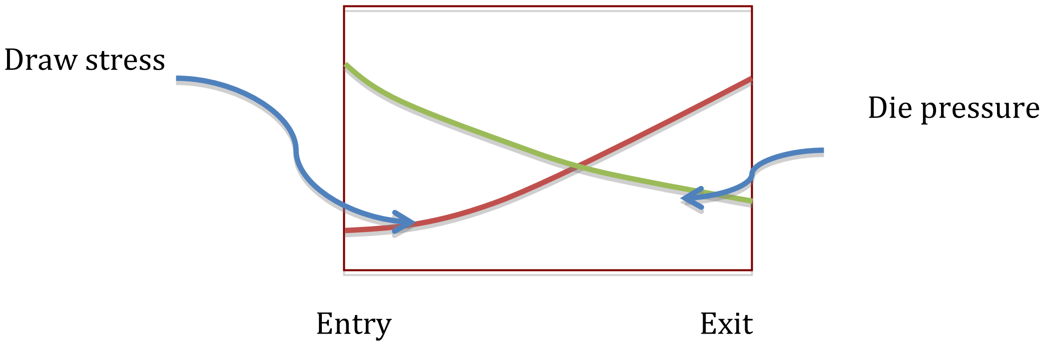

Fig. 1.4.1: Variation of die pressure and draw stress during drawing process

1.5 Tube drawing:

Tube drawing is a tube finishing process carried out on the tubes made through the other methods like Mannesmann mill. Tube sinking is done without using a mandrel, to reduce the diameter of the tube without affecting the thickness.

Tube drawing is used to reduce thickness and diameter using mandrels.

Mandrel or plug may be cylindrical or conical in shape. Using a plug ensures uniform thickness. The mandrel may be kept stationary or moved along with the tube.

Floating mandrel are used where the length of the tubes are long. Drawing forces involved in tube drawing with plug are always higher. With moving mandrel, there is a forward frictional drag which pulls the metal into the die, at the entry.

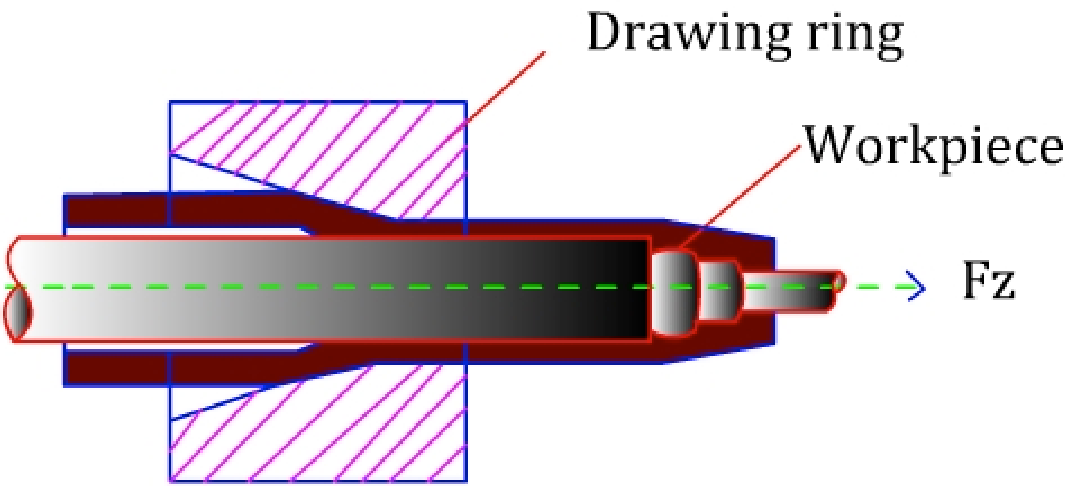

Fig.1.5.1: Tube drawing with mandrel

Draw stress for tube drawing with fixed plug is given by:

$$\sigma = \bar{Y}'\frac{1+B}{B}\left[1-\left(\frac{h_f}{h_o}\right)^B\right] \text{ ---------3.9}$$

where B = $\frac{\mu_1+\mu_2}{tan\alpha - tan\beta}$

h is tube wall thickness.

α is angle of the die and $\beta$is the angle of mandrel.

For moving mandrel, B = $\frac{\mu_1-\mu_2}{tan\alpha - tan\beta}$

Because the friction at die tube interface acts against the direction of drawing while at tube – mandrel interface friction acts so as to drag the tube towards the exit.

For tube sinking the draw stress is given by:

$$\sigma = \bar{Y}'\frac{1+B}{B}\left[1-\left(\frac{A_f}{A_o}\right)^B\right] \text{ --------3.10}$$

1.6 Strain rate in hot drawing:

Similar to hot extrusion, the average strain rate during hot drawing can be written as:

$$\bar{\varepsilon} = \frac{6V_o}{D_o}\ln\left(\frac{Af}{Ao}\right) \text{ -------3.11}$$

The average flow stress can be determined from the stress-strain rate relation for the work material.

1.7 Drawing defects:

Center cracks can occur in drawn products due to larger die angle, lower reduction per pass, friction etc.

Longitudinal cracks or folds occur on surface of the drawn wire which may open out during the use of the drawn product.

Residual stresses are induced in drawn bars or wires during cold drawing. If the reductions are low, the surface of the drawn part is subjected to compressive residual stress. Compressive residual stress on surface improves the fatigue life and corrosion resistance of the product.

For larger reductions, surface stress is tensile while the center has compressive residual stress. Increase in die angle increases the surface tensile stress. For reductions between 20 and 35%, highest surface tensile residual stresses are reported.

Example: Derive an expression for the maximum reduction during the drawing of a wire, which is made of a strain hardenable material.

Solution: We can write the flow stress for strain hardenable material as

$$\sigma = k\varepsilon^n$$

Assuming frictionless drawing, the draw stress is given by: $\bar{Y}\varepsilon$

Where $\bar{Y}$is average flow stress and = $\frac{k\varepsilon^n}{1+n}$

Equating draw stress to the yield strength of the material:

$\frac{k\varepsilon^n}{1+n}\varepsilon$=k$\varepsilon^n$

Or, $\varepsilon = 1 + n$ = ln(Ao/Af)

We can write reduction r = (A0-Af)/A0

Or Ao/Af = 1/(1-r)

Therefore, maximum reduction = r_{max} = 1-exp$^{-(1+n)}$

Note: If we substitute n = 0, above we get r_{max} = 0.632, which was proved earlier in the lecture.

Source:
http://nptel.ac.in/courses/112106153/28