WIRE AND BAR DRAWING

Drawing is an operation in which the cross section of a bar, rod, or wire is reduced by pulling it through a die opening, as in Figure (1). The general features of the process are similar to those of extrusion. The difference is that the work is pulled through the die in drawing, whereas it is pushed through the die in extrusion. Although the presence of tensile stresses is obvious in drawing, compression also plays a significant role because the metal is squeezed down as it passes through the die opening. For this reason, the deformation that occurs in drawing is sometimes referred to as indirect compression. Drawing is a term also used in sheet metal working. The term wire and bar drawing is used to distinguish the drawing process discussed here from the sheet metal process of the same name.

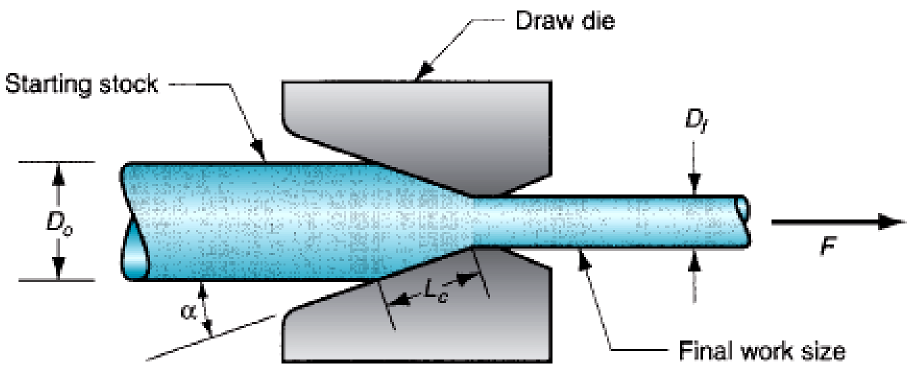

Figure (1) Wire and bar drawing

The basic difference between bar drawing and wire drawing is the stock size that is processed. Bar drawing is the term used for large diameter bar and rod stock, while wire drawing applies to small diameter stock. Wire sizes down to (0.03 mm) are possible in wire drawing. Although the mechanics of the process are the same for the two cases, the methods, equipment, and even the terminology are somewhat different.

Bar drawing is generally accomplished as a single-draft operation—the stock is pulled through one die opening. Because the beginning stock has a large diameter, it is in the form of a straight cylindrical piece rather than coiled. This limits the length of the work that can be drawn, necessitating a batch type operation. By contrast, 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.

The number of dies varies typically between 4 and 12. The term continuous drawing is used to describe this type of operation because of the long production runs that are achieved with the wire coils, which can be butt-welded each to the next to make the operation truly continuous.

In a drawing operation, the change in size of the work is usually given by the area reduction, defined as follows:

$$r = \frac{A_o - A_f}{A_o} \quad \ldots\ldots\ldots\ldots\ldots\ 1$$

where r: area reduction in drawing; A_o: original area of work(mm^2) ; and A_f: final area, (mm^2). Area reduction is often expressed as a percentage.

In bar drawing, rod drawing, and in drawing of large diameter wire, the term draft is used to denote the before and after difference in size of the processed work. The draft is simply the difference between original and final stock diameters:

$$d = D_o - D_f \quad \ldots\ldots\ldots\ 2$$

where d : draft, (mm); D_o : original diameter of work, (mm); and D_f : final work diameter, (mm).

DRAWING PRACTICE

Drawing is usually performed as a cold working operation. It is most frequently used to produce round cross sections, but squares and other shapes are also drawn. Wire drawing is an important industrial process, providing commercial products such as electrical wire and cable; wire stock for fences, coat hangers, and shopping carts; and rod stock to produce nails, screws, rivets, springs, and other hardware items. Bar drawing is used to produce metal bars for machining, forging, and other processes.

Advantages of drawing in these applications include (1) close dimensional control, (2) good surface finish, (3) improved mechanical properties such as strength and hardness, and (4) adaptability to economical batch or mass production. Drawing speeds are as high as (50 m/s) for very fine wire.

Drawing Equipment Bar drawing is accomplished on a machine called a draw bench, consisting of an entry table, die stand (which contains the draw die), carriage, and exit rack. The arrangement is shown in Figure (2).The carriage is used to pull the stock through the draw die. It is powered by hydraulic cylinders or motor-driven chains. The die stand is often designed to hold more than one die, so that several bars can be pulled simultaneously through their respective dies.

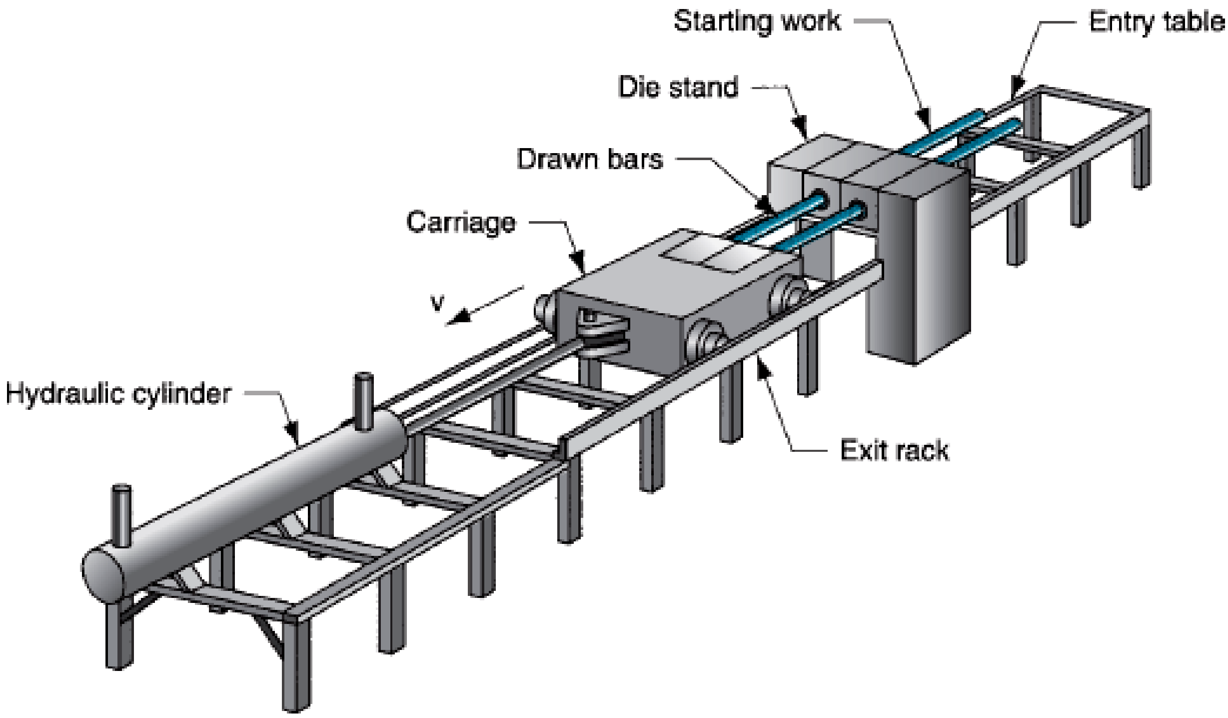

Figure (2) Hydraulically operated draw bench for drawing metal bars.

Wire drawing is done on continuous drawing machines that consist of multiple draw dies, separated by accumulating drums between the dies, as in Figure 19.42. Each drum, called a capstan, is motor driven to provide the proper pull force to draw the wire stock through the upstream die. It also maintains a modest tension on the wire as it proceeds to the next draw die in the series. Each die provides a certain amount of reduction in the wire, so that the desired total reduction is achieved by the series. Depending on the metal to be processed and the total reduction, annealing of the wire is sometimes required between groups of dies in the series.

Draw Dies Figure (3) identifies the features of a typical draw die. Four regions of the die can be distinguished: (1) entry, (2) approach angle, (3) bearing surface (land), and (4) back relief. The entry region is usually a bell-shaped mouth that does not contact the work. Its purpose is to funnel the lubricant into the die and prevent scoring of work and die surfaces.

The approach is where the drawing process occurs. It is cone-shaped with an angle (half angle) normally ranging from about 6º to 20º. The proper angle varies according to work material. The bearing surface, or land, determines the size of the final drawn stock. Finally, the back relief is the exit zone. It is provided with a back relief angle (half-angle) of about 30º. Draw dies are made of tool steels or cemented carbides. Dies for high-speed wire drawing operations frequently use inserts made of diamond (both synthetic and natural) for the wear surfaces.

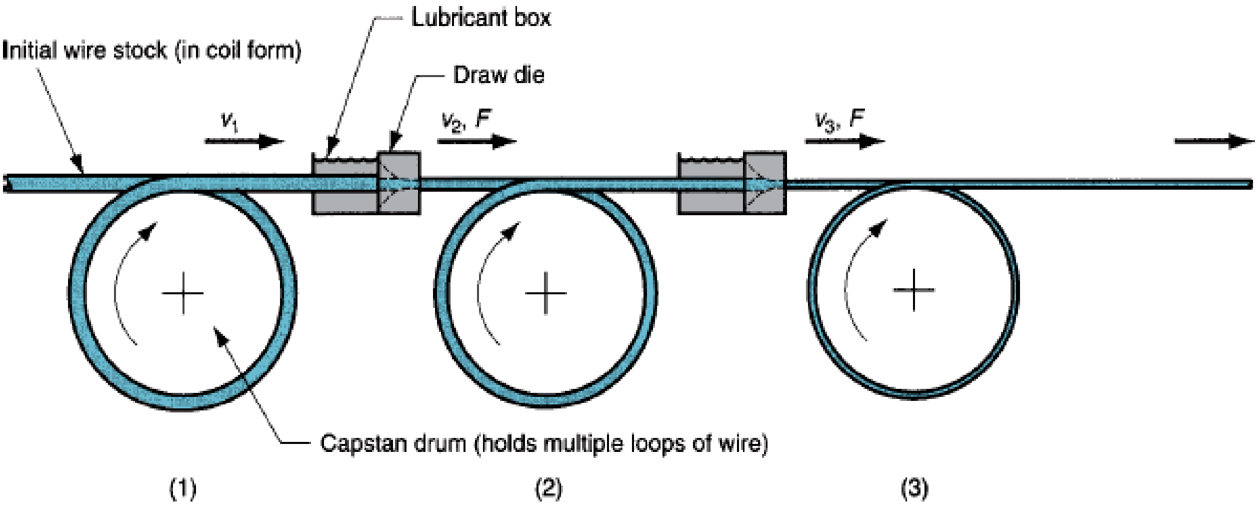

Figure (2) Continuous drawing of wire.

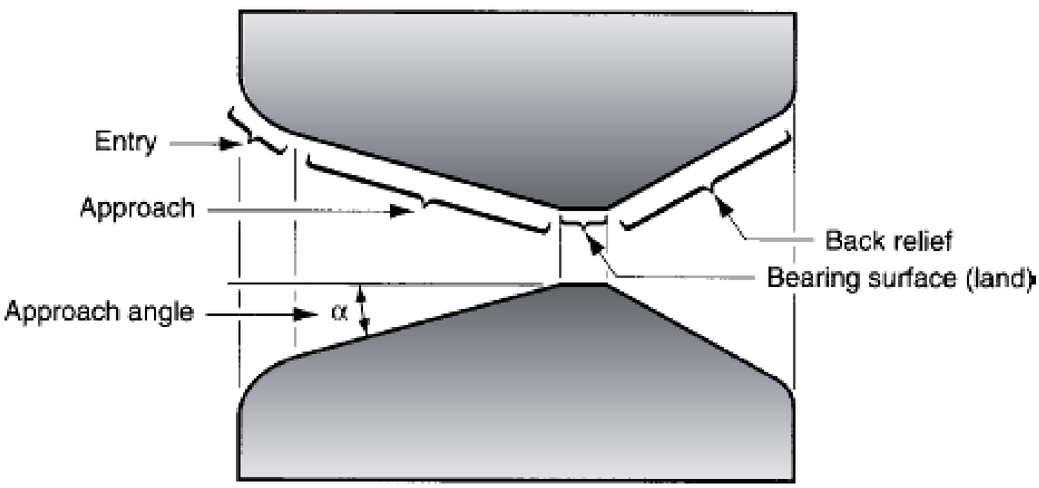

Figure (3) Draw die for drawing of round rod or wire.

Preparation of the Work Prior to drawing, the beginning stock must be properly prepared. This involves three steps: (1) annealing, (2) cleaning, and (3) pointing. The purpose of annealing is to increase the ductility of the stock to accept deformation during drawing. As previously mentioned, annealing is sometimes needed between steps in continuous drawing. Cleaning of the stock is required to prevent damage of the work surface and draw die. It involves removal of surface contaminants (e.g., scale and rust) by means of chemical pickling or shot blasting. In some cases, prelubrication of the work surface is accomplished subsequent to cleaning.

ANALYSIS OF DRAWING

In this section, we consider the mechanics of wire and bar drawing. How are stresses and forces computed in the process? We also consider how large a reduction is possible in a drawing operation.

Mechanics of Drawing If no friction or redundant work occurred in drawing, true strain could be determined as follows:

$$\epsilon = \ln\frac{A_o}{A_f} = \ln\frac{1}{1-r} \quad \text{..................3}$$

where A_o and A_f are the original and final cross-sectional areas of the work, as previously defined; and r : drawing reduction as given by Eq. (1). The stress that results from this ideal deformation is given by

$$\sigma = \overline{Y}_f\epsilon = \overline{Y}_f \ln\frac{A_o}{A_f} \quad \text{................4}$$

Because friction is present in drawing and the work metal experiences inhomogeneous deformation, the actual stress is larger than provided by Eq. (4). In addition to the ratio A_o/A_f, other variables that influence draw stress are die angle and coefficient of friction at the work–die interface. A number of methods have been proposed for predicting draw stress based on values of these parameters. We present the equation suggested by Schey:

$$\sigma_d = \overline{Y}_f\left(1+\frac{\mu}{\tan\alpha}\right)\phi\ln\frac{A_o}{A_f} \quad \text{...............5}$$

where σ_d : draw stress (MPa); μ : die-work coefficient of friction; α : die angle (half-angle) and ⌀ is a factor that accounts for inhomogeneous deformation which is determined as follows for a round cross section:

$$\phi = 0.88 \pm 0.12 \frac{D}{L_c} \quad \text{..................6}$$

Where D : average diameter of work during drawing (mm); and L_c : contact length of the work with the draw die (mm).Values of D and L_c can be determined from the following:

$$\left.\begin{aligned} D &= \frac{D_o + D_f}{2} \\ L_c &= \frac{D_o - D_f}{2 \sin \alpha} \end{aligned}\right] \quad \text{................7}$$

The corresponding draw force is then the area of the drawn cross section multiplied by the draw stress:

$$F = A_f \sigma_d = A_f \overline{Y}_f \left(1 + \frac{\mu}{\tan \alpha}\right) \phi \ln \frac{A_o}{A_f} \quad \text{................8}$$

where F : draw force (N); and the other terms are defined above. The power required in a drawing operation is the draw force multiplied by exit velocity of the work.

Example

Wire is drawn through a draw die with entrance angle = 15°. Starting diameter is 2.5 mm and final diameter = 2.0 mm. The coefficient of friction at the work–die interface = 0.07. The metal has a strength coefficient K = 205 MPa and a strain-hardening exponent n = 0.20. Determine the draw stress and draw force in this operation.

Solution: The values of D and L_c for Eq. ( ) can be determined using Eqs. ( ). D = 2.25 mm and L_c = 0.966 mm. Thus,

$$\phi = 0.88 + 0.12 \frac{2.25}{0.966} = 1.16$$

The areas before and after drawing are computed as $A_o = 4.91$ mm^2 and $A_f = 3.14$ mm^2. The resulting true strain $\epsilon = \ln(4.91/3.14) = 0.446$, and the average flow stress in the operation is computed:

$$\overline{Y}_f = \frac{205(0.446)^{0.20}}{1.20} = 145.4 \text{ MPa}$$

Draw stress is given by Eq. (   ):

$$\sigma_d = (145.4)\left(1 + \frac{0.07}{\tan 15}\right)(1.16)(0.446) = 94.1\,\text{MPa}$$

Finally, the draw force is this stress multiplied by the cross-sectional area of the exiting wire:

$$F = 94.1(3.14) = 295.5\,\text{N}$$

Maximum Reduction per Pass A question that may occur to the reader is: Why is more than one step required to achieve the desired reduction in wire drawing? Why not take the entire reduction in a single pass through one die, as in extrusion? The answer can be explained as follows. From the preceding equations, it is clear that as the reduction increases draw stress increases. If the reduction is large enough, draw stress will exceed the yield strength of the exiting metal. When that happens, the drawn wire will simply elongate instead of new material being squeezed through the die opening. For wire drawing to be successful, maximum draw stress must be less than the yield strength of the exiting metal.

It is a straightforward matter to determine this maximum draw stress and the resulting 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. (4), and setting $\bar{Y}_f = Y$ (because $n = 0$),

$$\sigma_d = \bar{Y}_f \ln\frac{A_o}{A_f} = Y \ln\frac{A_o}{A_f} = Y \ln\frac{1}{1-r} = Y$$

This means that $\ln(A_o/A_f) = \ln(1/(1-r)) = 1$. That is, $\epsilon_{max} = 1.0$. In order for ϵ_{max} to be zero, then $A_o/A_f = 1/(1-r)$ must equal the natural logarithm base e. Accordingly, the maximum possible area ratio is

$$\frac{A_o}{A_f} = e = 2.7183$$

and the maximum possible reduction is

$$r_{max} = \frac{e-1}{e} = 0.632$$