Wire Drawing

7.1 Introduction:

In drawing, the cross section of a long rod or wire is reduced or changed by pulling (hence the term drawing) it through a die called a draw die (Fig. 7.1). Thus, the difference between drawing and extrusion is that in extrusion the material is pushed through a die, whereas in drawing it is pulled through it. 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 metalworking. The term wire and bar drawing is used to distinguish the drawing process discussed here from the sheet metal process of the same name. Rod and wire products cover a very wide range of applications, including shafts for power transmission, machine and structural components, blanks for bolts and rivets, electrical wiring, cables,..Etc.

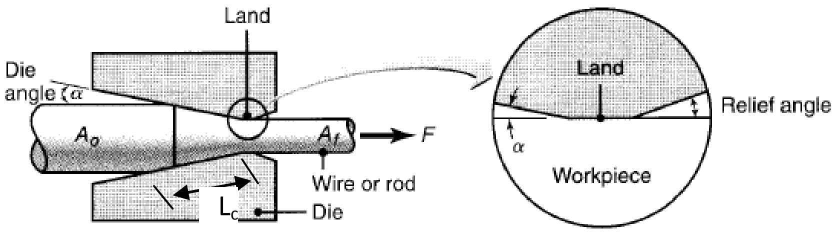


Fig (7.1) Process variables in wire drawing. The die angle, the reduction in cross sectional area per pass, the speed of drawing, the temperature and the lubrication all affect the drawing force, F.

The major processing variables in drawing are similar to those in extrusion that is, reduction in cross-sectional area, die angle, friction along the die-workpiece interface, and drawing speed. The die angle influences the drawing force and the quality of the drawn product.

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 (0.001 in) are possible in wire drawing.

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. 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.

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

$$r = \frac{A_\circ - A_f}{A_\circ} \qquad 7\text{-}1$$

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

In bar drawing, rod drawing, and in drawing of large diameter wire for upsetting and heading operations, 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:

$$d = D_\circ - D_f \qquad 7\text{-}2$$

Where d = draft, mm (in); D_o = original diameter of work, mm (in); and D_f = final work diameter, mm (in).

7.2 Analysis of drawing:

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

$$\epsilon = \ln \frac{A_\circ}{A_f} = \ln \frac{1}{1-r} \qquad 7\text{-}3$$

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. (7-1). The stress that results from this ideal deformation is given by:

$$\sigma = \bar{Y}_f \epsilon = \bar{Y}_f \ln \frac{A_\circ}{A_f} \qquad 7\text{-}4$$

Where $\bar{Y}_f = \frac{K\epsilon^n}{1+n}$ = average flow stress based on the value of strain given by Eq. (7-3). Because friction is present in drawing and the work metal experiences inhomogeneous deformation, the actual stress is larger than provided by Eq. (7-4). 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**:

$$\sigma_d = \bar{Y}_f \left(1 + \frac{\mu}{tan\ \alpha}\right) \emptyset \ln \frac{A_\circ}{A_f} \qquad 7\text{-}5$$

Where σ_d = draw stress, MPa (lb/in^2); μ = die-work coefficient of friction; α = die angle (approach angle) (half-angle) as defined in Figure (7.1); and $\emptyset$ is a factor that accounts for inhomogeneous deformation which is determined as follows **for a round cross section**:

$$\emptyset = 0.88 + 0.12 \frac{D}{L_c} \qquad 7\text{-}6$$

Where D= average diameter of work during drawing, mm(in); and L_c = contact length of the work with the draw die in Figure (7.1),mm(in).Values of D and L_c can be determined from the following:

$$D = \frac{D_\circ + D_f}{2} \qquad 7\text{-}7$$

$$L_c = \frac{D_\circ - D_f}{2 sin\alpha} \qquad 7\text{-}8$$

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

$$F = A_f \sigma_d = A_f \overline{Y}_f \left(1 + \frac{\mu}{\tan \alpha}\right) \phi \ln \frac{A_o}{A_f} \qquad 7\text{-}9$$

Where F = draw force, N (lb); 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?

Solu:
The values of D and L_c for Eq. (7.6) can be determined using Eqs. (7-7 &7-8).
D= 2.25 mm and L_c = 0.966 mm. Thus,

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

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

$$\bar{Y}_f = \frac{205X0.446^{0.2}}{1+0.2} = 145.4\ Mpa$$

Draw stress is given by Eq. (7-5)

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

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

F=94.1(3.14) = 295.5 N

7.3 Tube Drawing:
Drawing can be used to reduce the diameter or wall thickness of seamless tubes and pipes, after the initial tubing has been produced by some other process such as extrusion. Tube drawing can be carried out either with or without a mandrel. The simplest method uses no mandrel and is used for diameter reduction, as in Figure 7.2. The term tube sinking is sometimes applied to this operation.

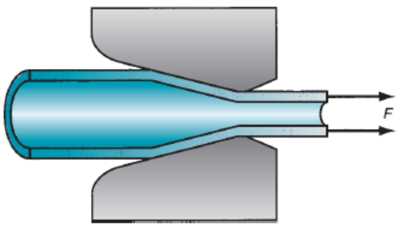
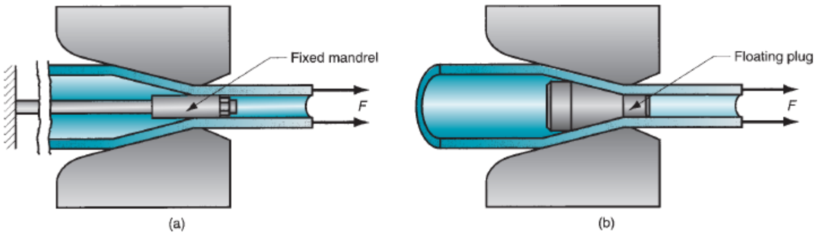


Figure 7.2 Tube drawing with no mandrel (tube sinking).

The problem with tube drawing in which no mandrel is used, as in Figure 7.2, is that it lacks control over the inside diameter and wall thickness of the tube. This is why mandrels of various types are used, two of which are illustrated in Figure 7.3.The first, Figure 7.3
(a) Uses a fixed mandrel attached to a long support bar to establish inside diameter and wall thickness during the operation. Practical limitations on the length of the support bar in this method restrict the length of the tube that can be drawn. The second type, shown in (b), uses a floating plug whose shape is designed so that it finds a ‘‘natural’’ position in the reduction zone of the die. This method removes the limitations on work length present with the fixed mandrel.

Figure 7.3 (a) Fixed mandrel
(b) Floating plug.



7.4 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; and rod stock to produce nails, screws, rivets, springs. 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.
(4) Adaptability to economical batch or mass production.

Drawing speeds are as high as 50 m/s (10,000 ft/min) for very fine wire. In drawing, reductions in the cross-sectional area per pass range up to about 45 %. **Usually, the smaller the initial cross section, the smaller the reduction per pass**. Fine wires usually are drawn at 15 to 25% reduction per pass and larger sizes at 20 to 45%.
A light reduction (**sizing pass**) also may be taken on rods to improve their surface finish and dimensional accuracy.

7.5 Bundle Drawing:

Although very fine wire can be produced by drawing, the cost can be high. One method employed to increase productivity is to draw many wires (a hundred or more) simultaneously as a bundle.
Bundle drawing produces wires that are somewhat polygonal, rather than round, in cross-section. In addition to producing continuous lengths, techniques have been developed to produce fine wire that is chopped into various sizes and shapes. These wires are then used in applications such as electrically conductive textiles. The wires produced can be as small as 4 µm in diameter and can be made from such materials as stainless steels, titanium, and high-temperature alloys.

7.6 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 7.4.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.

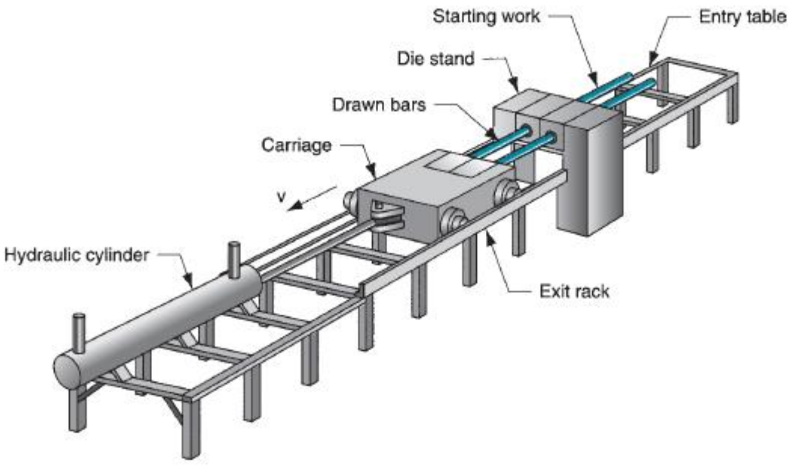


Figure 7.4
Hydraulically operated draw bench for drawing metal bars.

Wire drawing is done on continuous drawing machines that consist of multiple draw dies, separated by accumulating drums between the dies, as in Figure 7.5. 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.

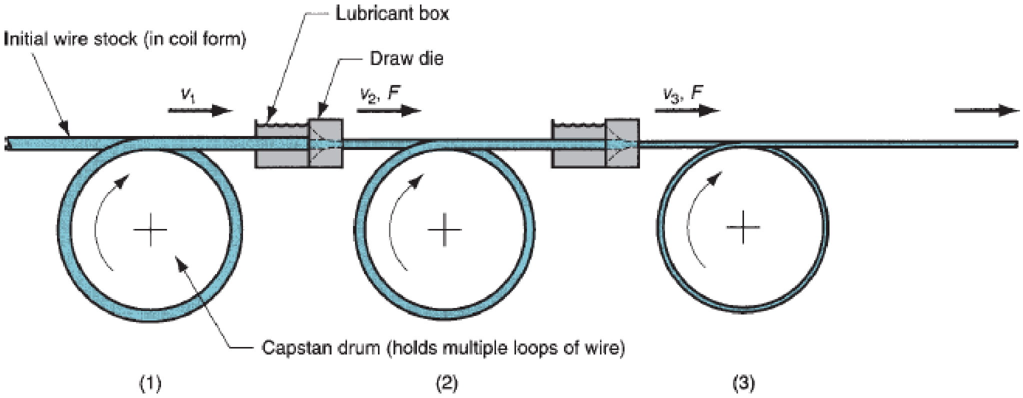


Figure 7.5 Continuous drawing of wire.

7.7 Draw Dies:

Figure 7.6 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 6° to 20°. 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 30°. 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.

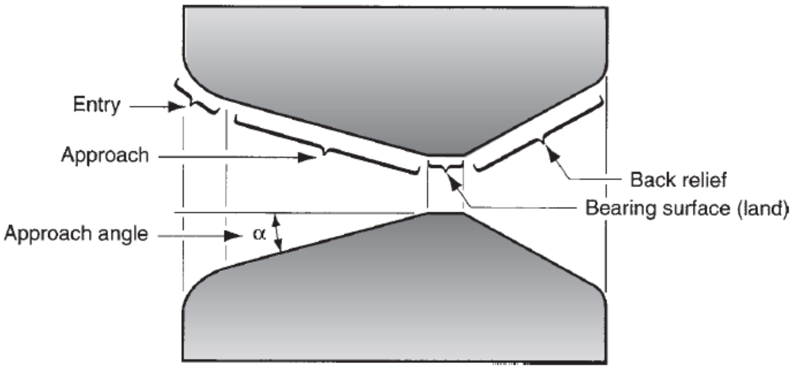


Figure 7.6 Draw die for drawing of round rod or wire.

7.8 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. **Pointing** involves the reduction in diameter of the starting end of the stock so that it can be inserted through the draw die to start the process. This is usually accomplished by swaging, rolling, or turning. The pointed end of the stock is then gripped by the carriage jaws or other device to initiate the drawing process.

7.9 Die Material:
Die materials for drawing typically are tool Steels and carbides. For hot drawing, cast-steel dies are used because of their high resistance to wear at elevated temperatures. Diamond dies are used for drawing fine wire with diameters ranging from 2 µm to 1.5 mm. They may be made from a single-crystal diamond or in polycrystalline form with diamond particles in a metal matrix (compacts). Because of their very low tensile strength and toughness, carbide and diamond dies typically are used as inserts or nibs, which are supported in a steel casing. Figure (7.7)

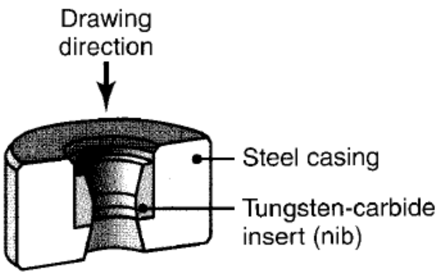


Figure (7.7) tungsten-carbide die insert in a steel casting.
Diamond dies used in drawing thin wire are encased in a similar manner

7.10 Drawing Defects and Residual Stresses:
Typical defects in a drawn rod or wire are **similar to those observed in extrusion** especially center cracking another major type of defect in drawing is **seams**, which are longitudinal scratches or folds in the material. Seams may open up during subsequent forming operations (such as upsetting, heading, thread rolling, or bending of the rod or wire), and they can cause serious quality-control problems. Various other surface defects (such as scratches and die marks) also can result from improper selection of the process parameters, poor lubrication, or poor die condition.
Because they undergo nonuniform deformation during drawing, cold-drawn products usually have residual stresses. For light reductions, such as only a few percent, the longitudinal-surface residual stresses are compressive (while the bulk is in tension) and fatigue life is thus improved. Conversely, heavier reductions induce tensile surface stresses (while the bulk is in compression). Residual stresses can be significant in causing stress-corrosion cracking of the part over time. Moreover, they cause the component to warp if a layer of material subsequently is removed such as by slitting, machining, or grinding.
Rods and tubes that are not sufficiently straight (or are supplied as coil) can be straightened by passing them through an arrangement of rolls placed at different axe.