Extrusion Process

6.1 Introduction:
Extrusion is a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape. As shown in figure (6.1)

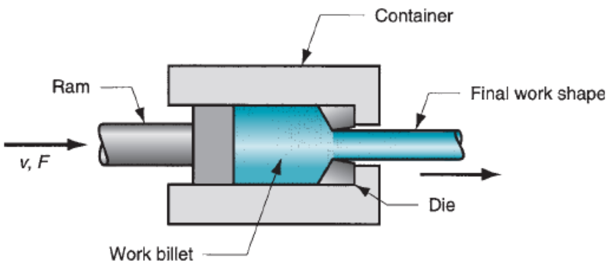


Figure (6.1) Extrusion process (direct extrusion)

6.2 advantages of the extrusion process:
There are several advantages of the modern extrusion process

1. A variety of shapes are possible, especially with hot extrusion.
2. Grain structure and strength properties are enhanced in cold and warm extrusion.
3. Fairly close tolerances are possible, especially in cold extrusion.
4. Little or no wasted material is created.

However, a limitation is that the cross section of the extruded part must be uniform throughout its length.

6.3 types of extrusion process:
There are many classifications for the extrusion processes, it may classify depending on the extrusion direction as direct and indirect another classification is by working temperature as cold or warm or hot extrusion.

6.3.1 Direct extrusion (also called forward extrusion) is illustrated in Figure(6.1). A metal billet is loaded into a container, and a ram compresses the material, forcing it to flow through one or more openings in a die at the opposite end of the container. As the ram approaches the die, a small portion of the billet remains that cannot be forced through the die opening. This extra portion, called the butt, is separated from the product by cutting it just beyond the exit of the die. One of the problems in direct extrusion is the significant **friction that exists between the work surface and the walls of the container** as the billet is forced to slide toward the die opening. This friction causes a substantial increase in the ram force required in direct extrusion.
In hot extrusion, the friction problem is aggravated by the presence of an oxide layer on the surface of the billet. This oxide layer can cause defects in the extruded product. To solve these problems, a **dummy block** is often used between the ram and the work billet. The diameter of the dummy block is slightly smaller than the billet diameter, so that a narrow ring of work metal (mostly the oxide layer) is left in the container, leaving the final product free of oxides.
Hollow sections (e.g., tubes) are possible in direct extrusion by the process setup in

Figure (6.2). The starting billet is prepared with a hole parallel to its axis .This allows passage of a mandrel that is attached to the dummy block. As the billet is compressed, the material is forced to flow through the clearance between the mandrel and the die opening

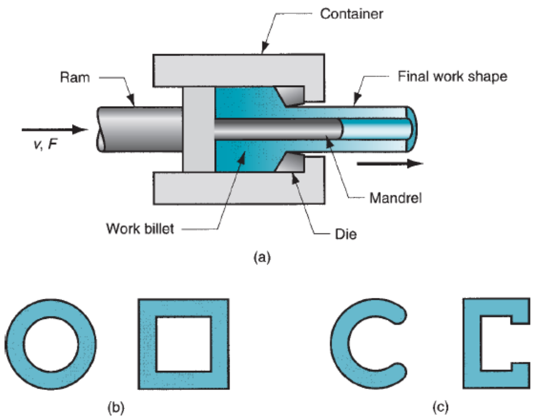


Figure (6.2) (a) Direct extrusion to produce a hollow or semi –hollow cross section;
(b) Hollow and (c) Semi-hollow cross sections.

6.3.2 Indirect extrusion, also called backward extrusion and reverse extrusion, Figure 6.3(a), the die is mounted to the ram rather than at the opposite end of the container. As the ram move, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram. Since the billet is not forced to move relative to the container**, there is no friction at the container walls**, and the ram force is therefore lower than in direct extrusion. **Limitations** of indirect extrusion are imposed by **the lower rigidity of the hollow ram and the difficulty in supporting the extruded product as it exits the die**.

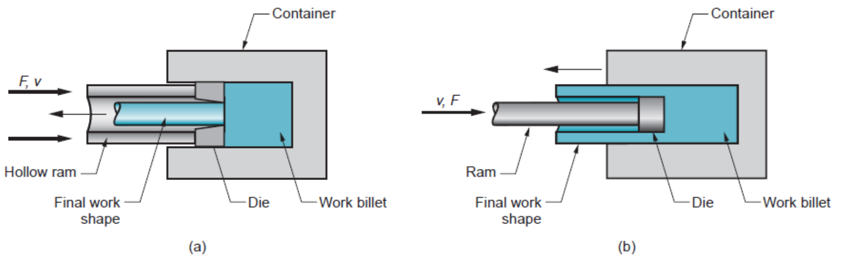


Figure (6.3) indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section

Indirect extrusion can produce hollow (tubular) cross sections, as in Figure 6.3(b)**.** There are practical limitations on the length of the extruded part that can be made by this method. Support of the ram becomes a problem as work length increases.

6.3.3. Hot extrusion involves prior heating of the billet to a temperature above ($0.5T_m$). This **reduces strength and increases ductility of the metal**, **permitting more extreme size reductions and more complex shapes** to be achieved in the process. Additional advantages include **reduction of ram force**, **increased ram speed**. Cooling of the billet as it contacts the container walls is a problem, and **isothermal extrusion** is sometimes used to overcome this problem.

6.3.4. Cold extrusion and warm extrusion are generally used to produce discrete parts, often in finished (or near finished) form. Some important **advantages** of cold extrusion include **increased strength due to strain hardening, close tolerances, improved surface finish**, **absence of oxide layers**, and **high production rates**. Cold extrusion at room temperature also eliminates the need for heating the starting billet.

***6.4 Analysis of extrusion*:**

Let us use Figure 6.4 as a reference in discussing some of the parameters in extrusion. The diagram assumes that both billet and extrudate are round in cross section. One important parameter is the **extrusion ratio**, also called the **reduction ratio**. The ratio is defined:

$$r_x = \frac{A_\circ}{A_f} \qquad 6\text{-}1$$

Where r_x= extrusion ratio; A_o= cross-sectional area of the starting billet, mm^2 (in^2); and A_f = final cross-sectional area of the extruded section,mm^2 (in^2). The ratio applies for both direct and indirect extrusion the value of r_x can be used to determine true strain in extrusion, given that ideal deformation occurs with **<u>no friction and no redundant work</u>**:

$$\epsilon = \ln r_x = \ln \frac{A_\circ}{A_f} \qquad 6\text{-}2$$

Under the assumption of ideal deformation (no friction and no redundant work), the pressure applied by the ram to compress the billet through the die opening depicted in our figure can be computed as follows:

$$p = \bar{Y}_f \ln r_x \qquad 6\text{-}3$$

Where Y_f = average flow stress during deformation, MPa (lb/in2)

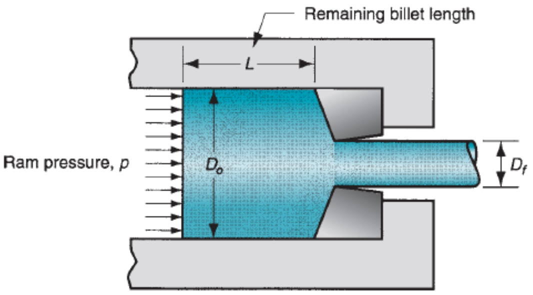


Figure (6.4) Pressure
And other variables in direct extrusion.

Friction exists between the die and the work as the billet squeezes down and passes through the die opening. In direct extrusion, friction also exists between the container wall and the billet surface.
The following empirical equation proposed by Johnson for estimating extrusion strain (in friction condition):

$$\epsilon_x = a + b \ln r_x \qquad 6\text{-}4$$

Where $\boldsymbol{\epsilon_x}$ = extrusion strain; and **a** and **b** are empirical constants for a given die angle. Typical values of these constants are: a = 0.8 and b = 1.2 to 1.5. Values of a and b tend to increase with increasing die angle.

Indirect extrusion the ram pressure to perform can be estimated based on Johnson's extrusion strain formula as follows:

$$p = \bar{Y}_f \epsilon_x \qquad 6\text{-}5$$

Where $\bar{Y}_f$ is calculated based on **ideal strain from Eq. (6-2)**, rather than extrusion strain in Eq. (6-4).

In direct extrusion, the effect of friction between the container walls and the billet causes the ram pressure to be greater than for indirect extrusion, the following formula can be used to compute ram pressure in direct extrusion:

$$p = \bar{Y}_f \left(\epsilon_x + \frac{2L}{D_\circ}\right) \qquad 6\text{-}6$$

Where the term 2L/Do accounts for the additional pressure due to friction at the container–billet interface. L is the portion of the billet length remaining to be extruded, and Do is the original diameter of the billet. Note that **p** is reduced as the remaining billet length decreases during the process.

Ram force in indirect or direct extrusion is simply pressure p from Eqs. (6-5) or (6-6), respectively, multiplied by billet area A_o:

$$F = pA_\circ \qquad 6.7$$

Where F = ram force in extrusion, N (lb).

Example: A billet 75mmlong and 25mmin diameter is to be extruded in a direct extrusion operation with extrusion ratio r_x = 4.0. The extrudate has a round cross section. The die angle (half angle) = 90° The work metal has a strength coefficient = 415 MPa, and strain-hardening exponent = 0.18. Use the Johnson formula with a = 0.8 and b = 1.5 to estimate extrusion strain. Determine the pressure applied to the end of the billet as the ram moves forward.

Sol.:

Let us examine the ram pressure at billet lengths of L= 75mm (starting value), L= 50 mm, L= 25 mm, and L= 0.We compute the ideal true strain, extrusion strain using Johnson's formula and average flow stress:

$$\epsilon = \ln r_x = \ln 4.0 = 1.3863$$

$$\epsilon_x = 0.8 + 1.5(1.3863) = 2.8795$$

$$\bar{Y}_f = \frac{415(1.3863)^{0.18}}{1.18} = 373 \text{ MPa}$$

L=75mm,With a die angle of 90°, the billet metal is assumed to be forced through the die opening almost immediately; thus, our calculation assumes that maximum pressure is reached at the billet length of 75mm. For die angles less than 90°, the pressure would build to a maximum as the starting billet is squeezed into the cone-shaped portion of the extrusion die.

$$p = 373\left(2.8795 + 2\frac{75}{25}\right) = 3312 \text{ MPa}$$

$$L = 50 \text{ mm: } p = 373\left(2.8795 + 2\frac{50}{25}\right) = 2566 \text{ MPa}$$

$$L = 25 \text{ mm: } p = 373\left(2.8795 + 2\frac{25}{25}\right) = 1820 \text{ MPa}$$

L=0, Zero length is a **hypothetical value** in direct extrusion. In reality, it is impossible to squeeze all of the metal through the die opening. Instead, a portion of the billet (the "butt") remains unextruded and the pressure begins to increase rapidly as L approaches zero.

$$p = 373\left(2.8795 + 2\frac{0}{25}\right) = 1074 \text{ MPa}$$

6.5 Other extrusion processes:

6.5.1Impact Extrusion: Impact extrusion is performed at higher speeds and shorter strokes than conventional extrusion. It is used to make individual components. As the name suggests, the punch impacts the work part rather than simply applying pressure to it. Impacting can be carried out as forward extrusion, backward extrusion, or combinations of these. Some representative examples are shown in Figure (6.5). Impact extrusion is usually done cold on a variety of metals. Backward impact extrusion is most common. Products made by this process include toothpaste tubes and battery cases. As indicated by these examples, very thin walls are possible on impact extruded parts. The high-speed characteristics of impacting permit large reductions and high production rates, making this an important commercial process.

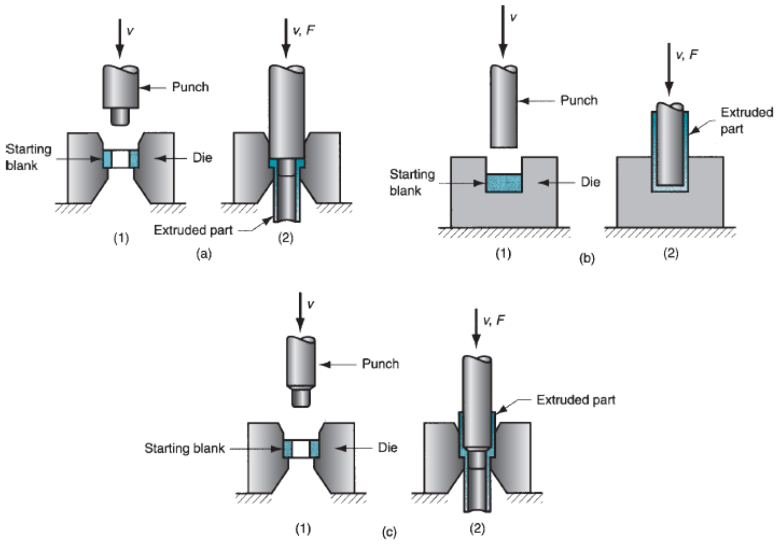


Fig (6.5) several examples of impact extrusion: (a) forward,
(b) Backward, and (c) combination of forward and backward.

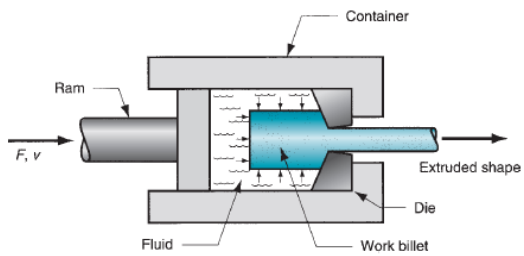
6.5.2Hydrostatic Extrusion

One of the problems in direct extrusion is friction along the billet– container interface. This problem can be addressed by surrounding the billet with fluid inside the container and pressurizing the fluid by the forward motion of the ram, as in Figure 6.6

This way, there is no friction inside the container, and friction at the die opening is reduced. Consequently, ram force is significantly lower than in direct extrusion. The fluid pressure acting on all surfaces of the billet gives the process its name. It can be carried out at room temperature or at elevated temperatures. Special fluids and procedures must be used at elevated temperatures. Hydrostatic extrusion is an adaptation of direct extrusion. Hydrostatic pressure on the work increases the material's ductility. Accordingly, this process can be used on metals that would be too brittle for conventional extrusion operations.

Ductile metals can also be hydrostatically extruded, and high reduction ratios are possible on these materials. One of the **disadvantages** of the process is the **required preparation of the starting work billet.** The billet must be formed with a taper at one end to fit snugly into the die entry angle. This establishes a seal to prevent fluid from squirting out the die hole when the container is initially pressurized.

Fig (6.6) Hydrostatic extrusion



6.6. Defects In Extruded Products

Owing to the considerable deformation associated with extrusion operations, a number of defects can occur in extruded products. The defects can be classified into the following categories, illustrated in Figure 6.7

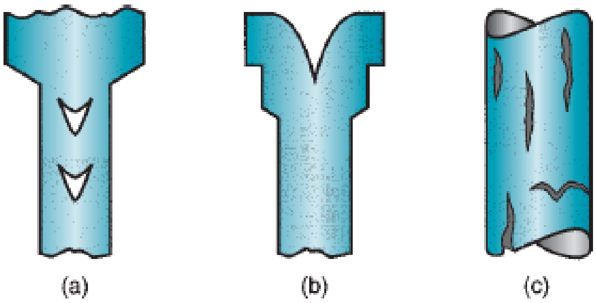


Fig (6.7) Some common defects in extrusion: (a) centerburst, (b) piping, and (c) surface cracking.

(a) Centerburst. This defect is an internal crack that develops as a result of tensile stresses along the centerline of the work part during extrusion. Although tensile stresses may seem unlikely in a compression process such as extrusion, they tend to occur under conditions that cause large deformation in the regions of the work away from the central axis. The significant material movement in these outer regions stretches the material along the center of the work. If stresses are great enough, bursting occurs. Conditions that promote centerburst are high die angles, low extrusion ratios, and impurities in the work metal that serve as starting points for crack defects. The difficult aspect of centerburst is its detection. It is an internal defect that is usually not noticeable by visual observation. Other names sometimes used for this defect include **arrowhead fracture**, **center cracking**, and **chevron cracking**.

(b) Piping. Piping is a defect associated with direct extrusion. As in Figure 6.7(b), it is the formation of a sink hole in the end of the billet. The use of a dummy block whose diameter is slightly less than that of the billet helps to avoid piping. Other names given to this defect include **tailpipe** and **fishtailing.**

(c) Surface cracking. This defect results from high workpart temperatures that cause cracks to develop at the surface. They often occur when extrusion speed is too high, leading to high strain rates and associated heat generation. Other factors contributing to surface cracking are high friction and surface chilling of high temperature billets in hot extrusion.