Metal Forming Processes (ME5807)

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Extrusion

- **Extrusion:** a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape.
- Imagine squeezing toothpaste out of toothpaste tube.
- Advantages include:
  - A variety of shapes are possible (especially in hot extrusion).
  - Microstructure and strength are enhanced in cold and warm extrusion.
  - Close tolerances are possible, especially in cold extrusion.
  - in some extrusion operations, little or no wasted material is created.

Types of Extrusion

- Extrusion can be classified in various ways:
    - By physical configuration: **Direct Extrusion** and **Indirect Extrusion**.
    - By working temperature: **Cold**, **Warm**, or **Hot Extrusion**.
    - Finally, it is performed as either a **Continuous** or **Discrete process**.

Direct Extrusion

- **Direct extrusion** (also called **forward extrusion**)

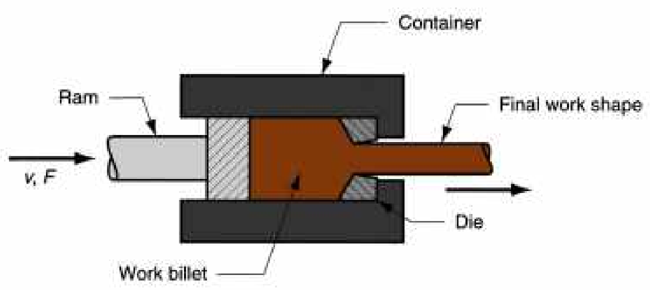

Figure: Direct extrusion

Direct Extrusion

- 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.
- Friction between container's walls and workpiece is one big problem in extrusion (so higher forces are needed to accomplish the process).
- The problem is aggravated in hot extrusion due to formation of oxide layer.

Direct Extrusion

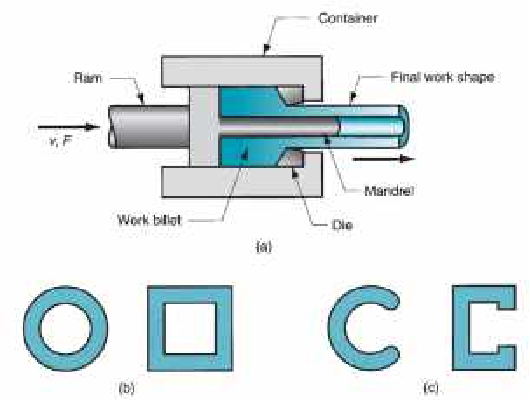

Figure: (a) Direct extrusion to produce a hollow or semi-hollow cross section; (b) hollow and (c) semi-hollow cross sections.

Indirect Extrusion

- **Indirect extrusion** (also called **backward extrusion**)

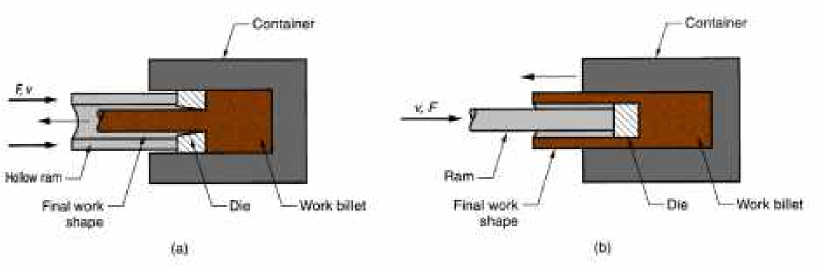

Figure: Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section.

Indirect Extrusion

- The die is mounted to the ram rather than at the opposite end of the container.
- As the ram penetrates into the work, 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.

Types of Extrusion

- **Hot** versus **Cold** Extrusion:
  - Extrusion can be performed either hot or cold, depending on work metal and amount of strain to which it is subjected during deformation.
  - Hot extruded metals include: Al, Cu, Mg, Zn, Sn, and their alloys (sometimes extruded cold as well).
  - Steel alloys are usually extruded hot, although the softer, more ductile grades are sometimes cold extruded (e.g. low C-steels).
  - Al is probably the most ideal metal for extrusion (hot and cold).
  - Products include: doors and window frames.

Hot Extrusion

- Involves prior heating of the billet to a temperature above its recrystallization temperature.
- This reduces strength and increases ductility.
- Additional advantages include reduction of ram force, and increased ram speed.

Cold Extrusion

- Used to produce discrete parts, in finished (or near finished) form.
- Impact Extrusion: indicates high-speed cold extrusion.
- Advantages: increased strength due to strain hardening, close tolerances, improved surface finish, absence of oxide layers, and high production rates.

Types of Extrusion

- **Continuous** versus **Discrete** Extrusion:
  - **Continuous Extrusion:** producing very long sections in one cycle, but these operations are limited by the size of the starting billet that can be loaded into the extrusion container. In nearly all cases, the long section is cut into smaller lengths in a subsequent sawing or shearing operation.
  - **Discrete Extrusion:** a single part is produced in each extrusion cycle. Impact extrusion is an example of the discrete processing case.

Analysis of Extrusion (Ideal Case – No Friction considered)

Extrusion Ratio: $r_x = \frac{A_o}{A_f}$.

True Strain: $\epsilon = ln\frac{A_o}{A_f}$.

Idea (no friction) case, pressure $p = \overline{Y}_f ln(r_x)$

Average flow stress (MPa) $\overline{Y}_f = \frac{K\epsilon^n}{1+n}$

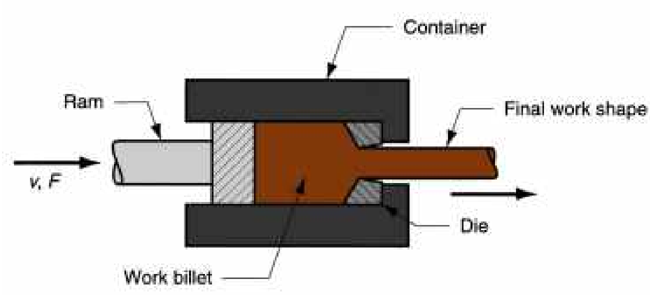

Figure: Direct extrusion ideal case

Analysis of Extrusion (Friction considered)

Extrusion strain: $\epsilon_x = a + b.ln.(r_x)$.
Where a & b are constants for a given die angle: a = 0.8 & b = 1.2 to 1.5.

For indirect extrusion: $p = \overline{Y}_f \epsilon_x$
For direct extrusion, friction is higher, so: $p = \overline{Y}_f(\epsilon_x + \frac{2L}{D_o})$

Ram forces in indirect or direct extrusion, $F = pA_o$
Power required $P = Fv$
Where, v is velocity in m/s

Extrusion Dies and Presses

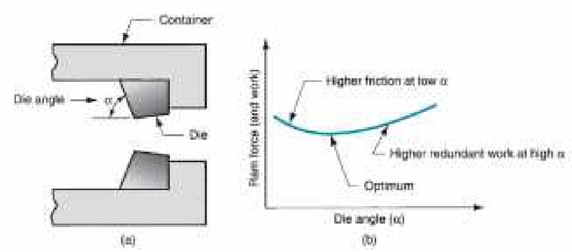

Figure: (a) Definition of die angle in direct extrusion; (b) effect of die angle on ram force.

- Low die angles (α): high friction so high ram force.
- High die angles (α): more turbulence, so increased ram force.
- An optimum die angle exists.

The effect of the die orifice shape can be assessed by the die shape factor, can be expressed as follows:

$$K_x = 0.98 + 0.02\left(\frac{C_x}{C_c}\right)^{2.25}$$

Where $K_x =$ die shape factor in extrusion; $C_x =$ perimeter of the extruded cross section, mm; and $C_c =$ perimeter of a circle of the same area as the extruded shape, mm

K_x for circular shape = 1

K_x for hollow, thin-walled sections is higher.

For shapes other than round

For indirect extrusion: $p = K_x(\overline{Y}_f)\epsilon_x$

For direct extrusion: $p = K_x\overline{Y}_f(\epsilon_x + \frac{2L}{D_o})$

Extrusion Dies and Presses

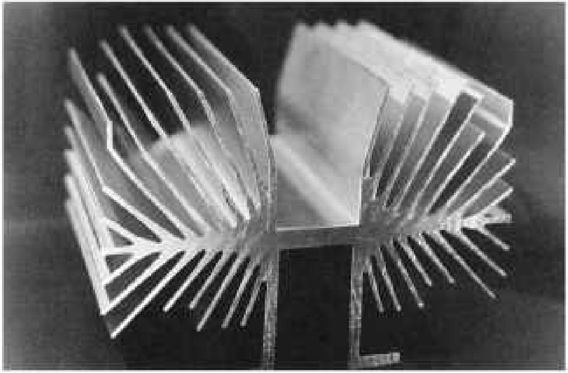

Figure: A complex extruded cross section for a heat sink.

Extrusion Dies and Presses

- Extrusion presses: either horizontal or vertical, depending on orientation of the work axis.
- Usually hydraulically driven.
- This drive is especially suited to semi-continuous production of long sections, as in direct extrusion.
- Mechanical drives are often used for cold extrusion of individual parts, such as in impact extrusion.

Defects in Extrusion

- **Centerburst:** an internal crack that develops as a result of tensile stresses along the centerline of the workpart during extrusion. Conditions that promote centerburst are high die angles, low extrusion ratios, and impurities.
- **Piping:** a defect associated with direct extrusion. 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.
- **Surface cracking:** 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.

Defects in Extrusion

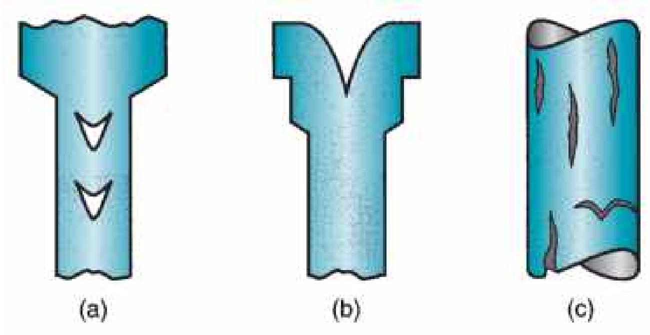

Figure: Some common defects in extrusion: (a) centerburst, (b) piping, and (c) surface cracking

Thank You