Chapter 15
Extrusion and Drawing of Metals

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Introduction

What is extrusion of metals?
- Forcing of a billet through a die
- Can create solid and hollow cross sections
- A semi-continuous process (each billet is extruded)
- Can produce products with a consistent diameter

What is drawing of metals?
- Changing or reduction of the cross section of a rod, wire, or tube by pulling it through a die

What products are made using drawing?
- Rivets, bolts, screws
- Round and non-round profiles

What is the difference between extrusion and drawing?
- Extrusion involves pushing the material, while drawing involves pulling.

Example of products made using extrusion

Figure 15.2 Extrusions, and examples of products made by sectioning off extrusions. Source: Kaiser Aluminum.

The extrusion process

Names of the process
- Extrusion
- Direct extrusion
- Forward extrusion

What are the process steps?
- Round billet is placed in a chamber
- The billet is forced through the die using a hydraulically driven ram or a pressing stem
- Die opening may have round or non-round cross section

Other types of extrusion processes
- Indirect extrusion
- The die moves toward the billet
- Hydrostatic extrusion
- The billet is smaller in diameter than the chamber
- The pressure is supplied by a ram
- Friction is low
- Impact extrusion

Extrusion Variables

Geometric Variables
- Die angle, \( \alpha \)
- Extrusion Ratio: \( R = \frac{A_o}{A_f} \) Ratio of the cross sectional area of the billet to the A of the extruded part
- Circumferential circle diameter (CCD)
- Diameter of the smallest circle that the cross section can fit within.
- Shape factor
- One of the variables determining the complexity of extrusion
- Ratio of perimeter of extruded product to the cross sectional

Temperature
- Speed of ram
- Lubricant type

Extrusion Force

The extrusion force required depends on
- Billet material strength
- Extrusion ratio
- Friction billet/chamber and billet/die
- Temperature
- Speed

\( F = A_o \cdot k \cdot \ln \left( \frac{A_o}{A_f} \right) \)

\( k = \) extrusion constant

Metal and temperature dependent
Metal Flow in Extrusion

- Effects the mechanical properties of the part
- The metal flows longitudinally, resulting in an elongated grain structure

![Dead zone](a) Metal at corners is almost stationary

Extrusion Practice

- What materials are extruded?
  - Aluminum, copper, magnesium, alloys, steels
  - Extrusion ratio \( R = \frac{A_i}{A_f} \)
    - 10 to 100
    - Lower for less ductile materials
  - Length of extruded materials
    - > 7.5 meters typically
    - 30 meters max
  - CCD (circum scribed diameters)
    - 8 mm – ins for Aluminum
- Dead zone
- Metal at corners is almost stationary

- Die angle causes a butt end
- Strain hardening required for small cross sections
- Cuts off as scrap

Why hot extrusion?
- For metals that don’t have sufficient ductility at room temperature
- Reduce the required extrusion force

Disadvantages and problems
- Die wear due to high operating temperatures
- Cooling the billet in the chamber – non-uniform extrusion
- Reduce effects of problem by heating the die prior to extrusion
- Oxide film develops on surface
  - May be abrasive
  - Affects the flow pattern of the metal
  - Remove this problem by using a dummy block in front of the ram
- Oxidized layer is left in the container
- Reduce/remove this problem by heating the billet in an inert-atmosphere furnace

Hot Extrusion

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Cold Extrusion

- Metal divides and flows around the supports of the internal mandrel.
- This results in strands
- Rewelding of the strands occur within the chamber after the supports and before the die
- High pressure makes this possible

Hollow Sections

- Welding chamber methods using special dies.
- How does this method work?
  - Metal divides and flows around the supports of the internal mandrel.
    - This results in strands
    - Rewelding of the strands occur within the chamber after the supports and before the die
    - High pressure makes this possible

- What materials does this work for?
  - Materials that reweld well under high pressure
  - Aluminum
  - Lubricants can’t be used
  - Prevents rewelding

Die Designs and Die Materials

- Square dies
  - Used for non-ferrous metals
  - Dead metal zones develop
  - Creates a die angle
- Die design: tapered

Die Materials

- Tubes
  - Created by fitting a mandrel to the ram
  - Wall thickness, typically
    - > 1 mm Al
    - > 3 mm carbon steel
    - > 5 mm stainless steels

Good vs. Bad Cross Section

- Important
  - Symmetry of cross section
  - Eliminate sharp corners
  - Keep section thickness uniform
  - Avoid extreme change in the dimensions of the cross section

Die Materials and Lubrication

- **Die materials**
  - Hot worked die steels
  - Coatings may be applied to extend life
- **Lubrication**
  - Glass: a glass cylinder is placed in the die entrance of the chamber. The billet heats the glass and the molten glass acts as a lubricant at the die interface.
  - Jacketing or canning
    - If the metal is likely to stick to the container walls, then the billet can be enclosed by a thin-walled container of a softer metal.

Cold Extrusion

- Often involves different manufacturing operations such as direct and indirect extrusion and forging.
- **Used in making**
  - Tools and components in cars, motorcycles, bicycles, appliances...
- **Advantages over hot extrusion**
  - Improved mechanical properties through work-hardening
  - Good control of dimensional tolerances
  - Improved surface finish
  - Elimination of need for billet heating
- **Disadvantages**
  - Stress magnitudes on the tools are high
  - Wears the die
- **Lubrication**
  - Applied to the workpiece

Examples of Cold Extrusion

![Workpiece](image)

Impact Extrusion

- Typically considered a cold extrusion process
- **Components**
  - Die
  - Blank (or slug)
  - Punch
- **Punch forces the blank to extrude backward**

Hydrostatic Extrusion

- Incompressible fluid surrounds the billet
  - Vegetable oils are used
- **Billet is a little smaller than the container**
- **Usually at room temperature**
- **Advantage**
  - No container wall friction
  - Brittle materials can be extruded using this method since the ductility increases with the hydrostatic pressure
  - Small die angles and high extrusion ratios can be used
- **Disadvantage**
  - Tooling is complex
  - Results in minimal industrial applications

Extrusion Defects

- **Surface cracking**
  - At high temperatures:
    - Resulting from too high temperature, friction, speed
  - Surface starts to crack and then tears
- **At lower temperatures**
  - Bamboo defect
    - The billet may temporarily stick, the pressure increases and the billet moves forward
- **Pipe effect**
  - Surface oxides and impurities are drawn to the center of the billet (like a funnel)
  - Minimize by making the flow pattern more uniform (reduce friction and temperature gradients)
- **Internal Cracking**
  - Due to tensile stresses at the center line in the deformation zone
  - Tendency of center cracking
  - Increases with increased die angle
  - Increases with increased amount of impurities
  - Decreases with increasing extrusion ratio and friction
Extrusion Equipment

- Most common are horizontal hydraulic presses
  - Speed of the operation can be controlled
- Cold extrusion
  - Typically vertical hydraulic presses
  - More economical as they require less floor space

The Drawing Process

- What is it?
  - The cross-section of a round wire/rod is reduced in size or changed in shape by pulling it through a die.
- Variables
  - Amount of reduction in cross-sectional area
  - Die angle
  - Optimum angle for minimum drawing force can be computed.
  - Other product quality dimensions—may require a different angle.
  - Friction along die/workpiece
  - Drawing speed

- Drawing force (F)
  \[ F = \frac{A_o Y_{avg}}{A_f} \cdot \ln \frac{A_f}{A_o} \]

Drawing Process / Practice

- Drawing of other shapes
  - Initial cross section is typically round or square
  - Mandrels can be used for internal cavities
  - Ironing can be used to obtain flat sheets (a wedge shaped die is used)

Die Design

- Die angles usually range from 6° to 15°
- Typically have two angles: approach and relieve angle
  - Basic design has been developed through trial and error
  - The land gives the final dimension of the product
  - Bundle drawing
    - Numerous wires can be drawn at the same time.
    - Can result in wires as fine as 4µm.

Lubrication

- Wet drawing
  - Dies and the rods are completely immersed in the lubricant
- Dry drawing
  - The surface of the rod is coated with the lubricant (soap)
- Coating
  - Rod or wire is coated with a soft metal acting as lubricant
  - Ultrasonic vibration of the dies and mandrel
  - Reduce forces, improve surface finish, and improve die life

Defects and Residual Stresses

- Defects
  - Similar to those of extrusion
  - Common is center cracking
  - Seams are common
  - Longitudinal scratches or folds in the material

- Residual Stresses
  - Common in cold drawn products
  - Sometimes to an advantage; sometimes to a disadvantage
  - Warping may occur if material is removed
**Drawing Equipment**

- **Draw bench**
  - A single die
  - Used for diameters > 20 mm
  - Lengths < 30 m

- **Bull block**
  - Usually multiple dies are used
  - Lengths = several kilometers

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**Roll Straightening**

Figure 15.22: Schematic illustration of roll straightening of a drawn round rod (see also Fig. 13.7).