MSE 440/540: Processing of Metallic Materials

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Lecture 10: Rolling and Extrusion
Rotating rolls perform two main functions:

- Pull the work into the gap between them by friction between workpart and rolls
- Simultaneously squeeze the work to reduce its cross section
Types of Rolling

• Based on workpiece geometry
  – Flat rolling - used to reduce thickness of a rectangular cross section
  – Shape rolling - square cross section is formed into a shape such as an I-beam

• Based on work temperature
  – Hot Rolling – can achieve significant deformation
  – Cold rolling – produces sheet and plate stock
Rolled Products Made of Steel

<table>
<thead>
<tr>
<th>Intermediate rolled form</th>
<th>Final rolled form</th>
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<tbody>
<tr>
<td>Bloom</td>
<td>Structural shapes</td>
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<tr>
<td>Slab</td>
<td>Plates, sheets</td>
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<tr>
<td>Billet</td>
<td>Bars, rods</td>
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<td>Rails</td>
<td>Coils</td>
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Diagram of Flat Rolling

- Side view of flat rolling, indicating before and after thicknesses, work velocities, angle of contact with rolls, and other features.

True rolling strain:

\[ \varepsilon = \ln \frac{t_0}{t_f} \]

\[ F = \bar{\sigma} w L, \]

\[ L = \sqrt{R(t_0 - t_f)} \]

\[ T = 0.5FL \]

\[ P = 2\pi NFL \]
Flat Rolling Terminology

- **Draft** = amount of thickness reduction
  \[ d = t_o - t_f \]
- **Reduction** = draft expressed as a fraction of starting stock thickness:
  \[ r = \frac{d}{t_o} \]
  Where \( t_o \) = starting thickness; \( t_f \) = final thickness
Shape Rolling

• Work is deformed into a contoured cross section rather than flat (rectangular)
  – Accomplished by passing work through rolls that have the reverse of desired shape

• Products
  – Construction shapes such as I-beams, L-beams, and U-channels
  – Rails for railroad tracks
  – Round and square bars and rods
**Rolling Mill Configurations**

- (a) Two-high, (b) three-high, (c) four-high

- (d) Cluster mill, (e) tandem rolling mill

[Diagram of rolling mill configurations]
Thread Rolling

- (1) Start of cycle, and (2) end of cycle

http://www.youtube.com/watch?v=iH8ujNE9ZIo
Ring Rolling

- As thick-walled ring is compressed, deformed metal elongates, causing diameter of ring to enlarge
- Hot working process for large rings and cold working process for smaller rings
- Products: ball and roller bearing races, steel tires for railroad wheels, and rings for pipes, pressure vessels, and rotating machinery

http://www.youtube.com/watch?v=GDyWyDP3cvs
Extrusion

Compression forming process in which work metal is forced to flow through a die opening to produce a desired cross-sectional shape.

- Process is similar to squeezing toothpaste out of a toothpaste tube.
- In general, extrusion is used to produce long parts of uniform cross sections.
- Two basic types:
  - Direct extrusion
  - Indirect extrusion
Direct Extrusion

- Also called *forward extrusion*
- As ram approaches die opening, a small portion of billet remains that cannot be forced through the die
  - This portion, called the *butt*, must be separated from the *extrudate* by cutting it off just beyond the die exit

https://www.youtube.com/watch?v=Y75IQksBb0M&t=10s 2:16 min
Hollow and Semi-Hollow Shapes

- (a) Direct extrusion to produce hollow or semi-hollow cross sections; (b) hollow and (c) semi-hollow cross sections.
Indirect Extrusion

- Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section
Comments on Indirect Extrusion

- Also called *backward extrusion* and *reverse extrusion*
- Limitations of indirect extrusion are imposed by
  - Lower rigidity of hollow ram
  - Difficulty in supporting extruded product as it exits die
Advantages of Extrusion

• Variety of shapes possible, especially in hot extrusion
  – Limitation: part cross section must be uniform throughout length

• Grain structure and strength enhanced in cold and warm extrusion

• Close tolerances possible, especially in cold extrusion

• In some operations, little or no waste of material
Hot vs. Cold Extrusion

• Hot extrusion - prior heating of billet to above its recrystallization temperature
  – Reduces strength and increases plasticity of the metal, permitting more size reductions and more complex shapes

• Cold extrusion - generally used to produce discrete parts
  – The term impact extrusion is used to indicate high speed cold extrusion
Extrusion Ratio

Also called the reduction ratio, it is defined as

\[ r_x = \frac{A_0}{A_f} \]

True strain:

\[ \varepsilon = \ln r_x = \ln \frac{A_0}{A_f} \]

Quiz: What is the engineering strain?
Extrusion Die Features

- **Low die angle** - surface area is large, which increases friction at die-billet interface
  - Higher friction results in larger ram force
- **Large die angle** - more turbulence in metal flow during reduction
  - Turbulence increases ram force required
- **Optimum angle** depends on work material, billet temperature, and lubrication
Complex Cross Section

- Extruded cross section for a heat sink (courtesy of Aluminum Company of America)
HW assignment

• Reading assignment: Chapters 13

• Review Questions: 13.2, 13.5, 13.8, 13.16, 13.17,

• Problems: 13.1, 13.3, 13.5, 13.8, 13.18, 13.20,