Rolling of Metals

- **Rolling**
  - The process of reducing thickness of changing the cross-section
  - 90% of all metals produced by metalworking
- **Changes microstructure**
  - Larger grains – small grains
    - Enhanced properties
- **Temperatures**
  - High temperature rolling
    - Takes less energy for deformation
  - Cold (Room) temperature rolling
    - Takes more energy for deformation
Rolling Processes

- Cast metals are rolled to form wrought metals

Flat Rolling Process

- Simplest rolling process / can be modeled
  - Maximum possible draft
    - $h_0 - h_f = \mu^2R$
  - Roll force
    - $F = L \cdot w \cdot Y_{avg}$
  - Total power consumed
    - Power = $2\pi FLN$
    - $60,000 \text{ kW}$
4-High Rolling Mill

- Used in cold rolling
  - Finishing passes
  - More stability than “2-High”

Camber

- Camber - grinding of the roller in a way such that the diameter in the center is slightly larger in the center

Strip thicker at center

Strip with uniform thickness
Spreading between Rollers

- Hot rolling performed above $T_{\text{recrystallization}}$
  - Smaller grains
  - Enhanced properties
Flat Rolling Defects

(a) Rolling direction

(b)

(c)

(d)

Induced Stresses from Flat Rolling

(a)

(b)

Sheet thickness

Tension

Compression

Tension

Compression

Figure 13.9 (a) Residual stresses developed in rolling with small rolls or at small reductions in thickness per pass. (b) Residual stresses developed in rolling with large rolls or at high reductions per pass. Note the reversal of the residual stress patterns.

• What if a layer of the rolled material is removed?
Layout of a Rolling Mill

Tandem-Rolling Operation

Stand 1 2 3 4 5
30 17.7 10.7 6.6 4.1 m/s

Take-up reel
0.26 0.34 0.56 0.90 1.45 2.25 mm

Pay-off reel
Chapter 14

Forging of Metals
## Overview of Forging Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open die</td>
<td>Simple, inexpensive dies; useful for small quantities; wide range of sizes available; good strength characteristics</td>
<td>Limited to simple shapes; difficult to hold close tolerances; machining to final shape necessary; low production rate; relatively poor utilization of material; high degree of skill required</td>
</tr>
<tr>
<td>Closed die</td>
<td>Relatively good utilization of material; generally better properties than open-die forgings; good dimensional accuracy; high production rates; good reproducibility</td>
<td>High die cost for small quantities; machining often necessary</td>
</tr>
<tr>
<td>Blocker type</td>
<td>Low die costs; high production rates</td>
<td>Machining to final shape necessary; thick webs and large fillets necessary</td>
</tr>
<tr>
<td>Conventional type</td>
<td>Requires much less machining than blocker type; high production rates; good utilization of material</td>
<td>Somewhat higher die cost than blocker type</td>
</tr>
<tr>
<td>Precision type</td>
<td>Close tolerances; machining often unnecessary; very good material utilization; very thin webs and flanges possible</td>
<td>Requires high forces, intricate dies, and provision for removing forging from dies</td>
</tr>
</tbody>
</table>
Open Die Forging

- Forging force
  \[ F = Y_f \pi r^2 (1 + \frac{2\mu r}{3h}) \]

Sequence of Operations in Forging a Connecting Rod

(a) Blank (bar stock)
(b) Edging
(c) Blocking
(d) Finishing
(e) Trimming

Fullering

Edging
Trimming Operation

- Impression-Die Forging
  - Flash – helps in process
- Closed Die Forging
  - Flashless Forging
- Precision Forging
  - Less post forging processes
Heading Operation

- Typical process of forming bolts

Defects in Forged Parts

- Blocked forging
- Die cavities are being filled
- Cracks develop in ribs
- Cracks propagate through ribs
Economics of Forging

Cost Comparison of Casting and Forging a Connecting Rod