Outline

- Forging
- Types of forging
- Forging analysis
- Examples

Forging

- Oldest of the metal forming operations, dating from about 5000 BC
- Components: engine crankshafts, connecting rods, gears, aircraft structural components, jet engine turbine parts
- In addition, basic metals industries use forging to establish basic form of large components that are subsequently machined to final shape and size
- Hot or warm forging – most common, due to the significant deformation and the need to reduce strength and increase ductility of work metal
- Cold forging - advantage is increased strength that results from strain hardening
- Forge hammer (impact) - applies an impact load
- Forge press (press) - applies gradual pressure

Types of Forging Dies

Open-die forging: work is compressed between two flat dies, allowing metal to flow laterally without constraint

Open-Die Forging

- Compression of work with cylindrical cross-section between two flat dies
- Similar to compression test
- Deformation operation reduces height and increases diameter of work
- Common names include upsetting or upset forging
- If no friction occurs between work and die surfaces, then ………………… deformation occurs, so that radial flow is uniform throughout workpart height and true strain is given by:

\[ \varepsilon = \ln \left( \frac{h_o}{h} \right) \]

Where:
- \( h_o \) = starting height
- \( h \) = height at some point during compression
Open-Die Forging with Friction

- Friction between work and die surfaces constrains lateral flow of work, resulting in …………… effect
- In hot open-die forging, effect is even more pronounced due to heat transfer at and near die surfaces, which cools the metal and increases its resistance to deformation

Impression-Die Forging

- Flash must be later trimmed from part, but it serves an important function during compression:
  - As flash forms, friction resists continued metal flow into gap, forcing material to fill die cavity
  - In hot forging, metal flow is further restricted because the thin flash cools quickly against the die plates
- Several forming steps often required, with separate die cavities for each step:
  - Beginning steps redistribute metal for more uniform deformation and desired metallurgical structure in subsequent steps
  - Final steps bring the part to its final geometry
  - Impression-die forging is often performed manually by skilled operator under adverse conditions

Impression-Die

- Advantages compared to machining from solid stock:
  - Higher production rates
  - Conservation of metal (*less waste*)
  - …………. strength
  - Favorable grain orientation in the metal
- Limitations:
  - Not capable of close tolerances
  - Machining often required to achieve accuracies and features needed, such as holes, threads, and mating surfaces that fit with other components

Trimming

- Cutting operation to remove flash from workpart in impression-die forging
- Usually done while work is still hot, so a separate trimming press is included at the forging station
- Trimming can also be done by alternative methods, such as grinding or sawing
Flashless Forging

- Starting workpart volume must equal die cavity volume within very close tolerance
- Process control more demanding than impression-die forging
- Best suited to part geometries that are simple and symmetrical
- Often classified as a precision forging process

Forging Hammers (Drop Hammers)

- Apply an impact load against workpart - two types:
  - Gravity drop hammers - impact energy from falling weight of a heavy ram
  - Power drop hammers - accelerate the ram by pressurized air or steam
- **Disadvantage**: impact energy transmitted through anvil into floor of building
- Most commonly used for impression-die forging

Forging Presses

- Apply gradual pressure to accomplish compression operation - types:
  - Mechanical presses - converts rotation of drive motor into linear motion of ram
  - Hydraulic presses - hydraulic piston actuates ram
  - Screw presses - screw mechanism drives ram

Upsetting and Heading

- Forging process used to form heads on nails, bolts, and similar hardware products
- More parts produced by upsetting than any other forging operation
- Performed cold, warm, or hot on machines called headers or formers
- Wire or bar stock is fed into machine, end is headed, then piece is cut
Upsetting and Heading

- Wire or bar stock is fed into machine, end is headed, then piece is cut
- For bolts and screws, thread rolling is then used to form threads

Swaging – Radial Forging

- Accomplished by rotating dies that hammer a workpiece radially inward to taper it as the piece is fed into the dies
- Used to reduce diameter of tube or solid rod stock
- Mandrel sometimes required to control shape and size of internal diameter of tubular parts
- Radial forging is similar to swaging except that the workpiece rotates instead of the forging dies.

Other Forging Processes

- Roll forging
- Orbital forging

Forging - Analysis

Force required:

\[ F = K_f Y_f A \]

Where:
- \( F \): force
- \( A \): cross-sectional area
- \( K_f \): forging shaping factor

\[ K_f = 1 + \frac{0.4 \mu D}{h} \]

Where:
- \( \mu \): coefficient of friction
- \( D \): work-part diameter (or other dimension representing contact length with die surface)
- \( h \): work-part height

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<th>Process</th>
<th>( K_f )</th>
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<tr>
<td>Impression</td>
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<tr>
<td>Simple w/ flash</td>
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<tr>
<td>Coining</td>
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<tr>
<td>Complex shape</td>
<td>8.0</td>
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Hot Forging - Analysis

- Theoretically, a metal in hot working behaves like a perfectly plastic material, with strain hardening exponent $n = 0$
  - However, an additional phenomenon occurs during deformation, especially at elevated temperatures: \textit{(strain rate becomes important)}

Strain rate is defined:

$$\varepsilon = \frac{V}{h}$$

Where:

- $V = \text{deformation velocity}$
- $h = \text{instantaneous height of workpiece being deformed}$

- As strain rate increases, resistance to deformation increases
- This effect is known as \textit{strain-rate sensitivity}

$$Y_f = C\dot{\varepsilon}^m$$

where

- $C = \text{strength constant}$
- $m = \text{strain-rate sensitivity exponent}$

Example 1: Cold Upsetting

A 302 stainless steel cylinder of height 12 cm and diameter 7 cm at room temperature is compressed to a height of 2 cm between large platens. Mineral oil is used as a lubricant between the cylinder and platens. Calculate the force necessary and stress on the platens.

Example 2: Hot Upsetting

The 302 stainless steel cylinder of the previous example is hot upset at 1000°C to a height of 2 cm by a platen moving at 2 cm/s. Graphite is used as a lubricant between the platens and workpiece. Calculate the forging force.
Next time

Rolling