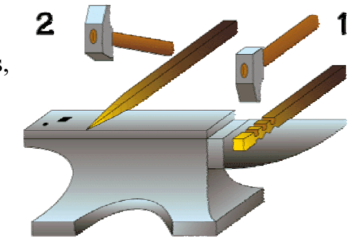
Outline

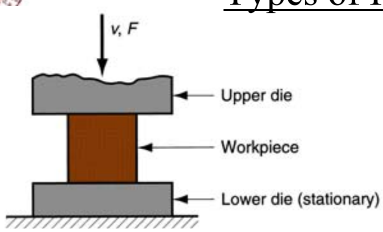
- Forging
- Types of forging
- Forging analysis
- Examples

Forging



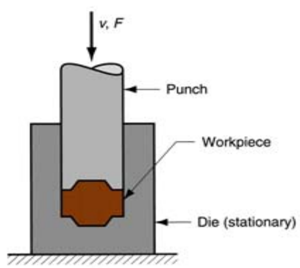
- Oldest of the metal forming operations, dating from about 5000 B C
- Components: engine crankshafts, connecting rods, gears, aircraft structural components, jet engine turbine parts
- In addition, basic metals industries use forging to establish basic form of large components that are subsequently 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

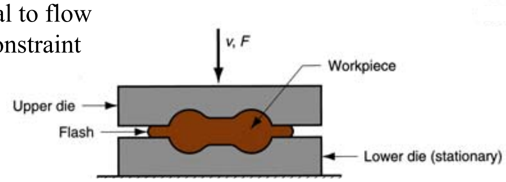
Types of Forging Dies



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

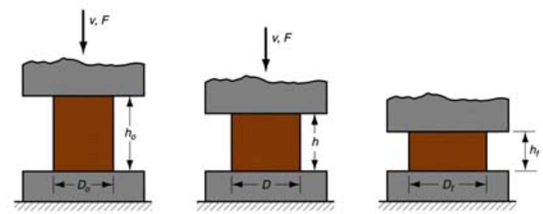
Flashless forg'g: piece is completel constrained in die and no excess flash is produced





Impression-die forging: die contains a cavity or impression that is imparted to workpiece, thus constraining metal flow - *flash is created*

Open-Die Forging

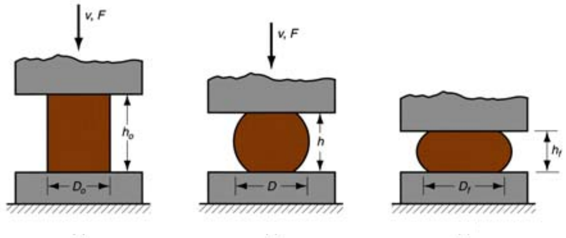


- Compression of work with cylindrical cross-section between two flat dies
- Similar to compression test
- Deformation operation reduces height and increases diameter of work
- Common names include upsetting or upset forging
- If no friction occurs between work and die surfaces, then ……………….. deformation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

$$\varepsilon = \ln \frac{h_o}{h}$$

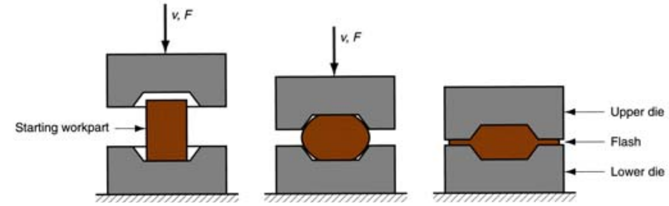
Where:
h_o = starting height
h = height at some point during compression

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

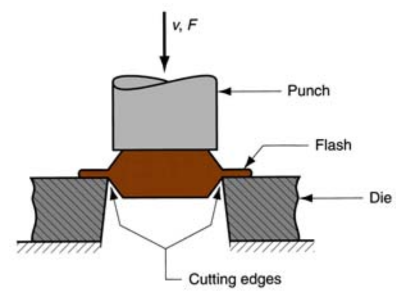


- Flash must be later trimmed from part, but it serves an important function during compression:
  - As flash forms, friction resists continued metal flow into gap, forcing material to fill die cavity
  - In hot forging, metal flow is further restricted because the thin flash cools quickly against the 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

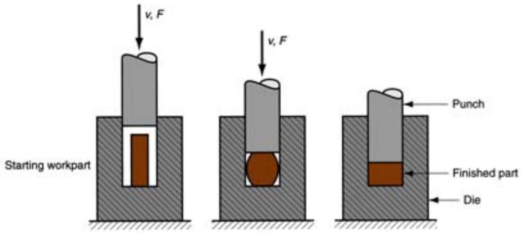
- Advantages compared to machining from solid stock:
  - Higher production rates
  - Conservation of metal (*less waste*)
  - ……….. strength
  - Favorable grain orientation in the metal
- Limitations:
  - Not capable of close tolerances
  - Machining often required to achieve accuracies and features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

Trimming



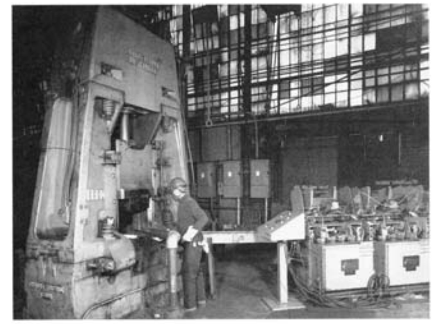
- Cutting operation to remove flash from workpart in impression-die forging
- Usually done while work is still hot, so a separate trimming press is included at the forging station
- Trimming can also be done by alternative methods, such as grinding or sawing

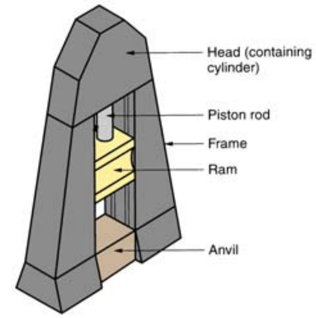
Flashless Forging



- 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)



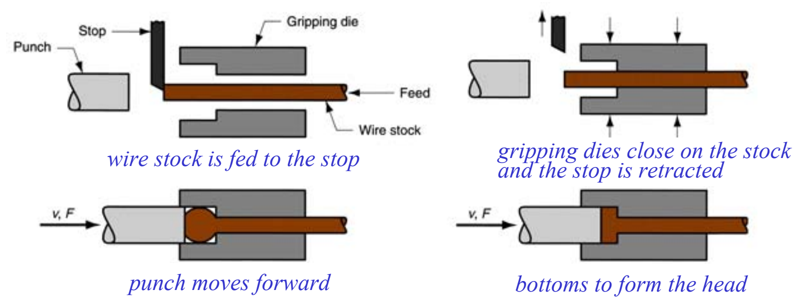


- Apply an impact load against workpart - two types:
  - Gravity drop hammers - impact energy from falling weight of a heavy ram
  - Power drop hammers - accelerate the ram by pressurized air or steam
- Disadvantage: impact energy transmitted through anvil into floor of building
- Most commonly used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

Forging Presses

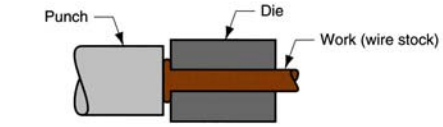
- Apply gradual pressure to accomplish compression operation - types:
  - Mechanical presses - converts rotation of drive motor into linear motion of ram
  - Hydraulic presses - hydraulic piston actuates ram
  - Screw presses - screw mechanism drives ram

Upsetting and Heading

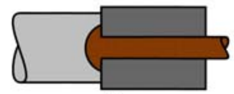


- Forging process used to form heads on nails, bolts, and similar hardware products
- More parts produced by upsetting than any other forging operation
- Performed cold, warm, or hot on machines called headers or formers
- Wire or bar stock is fed into machine, end is headed, then piece is cut

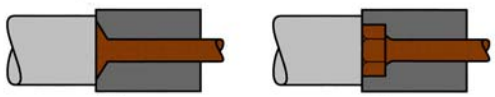
Upsetting and Heading



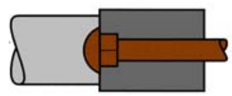
heading a nail using open dies



round head formed by punch



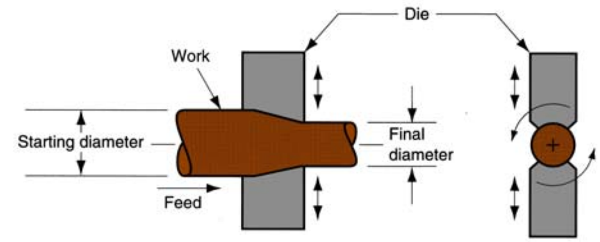
two common head styles for screws formed by die



carriage bolt head formed by punch and die

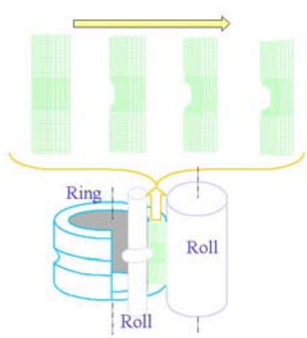
- Wire or bar stock is fed into machine, end is headed, then piece is cut
- For bolts and screws, thread rolling is then used to form threads

Swaging – Radial Forging

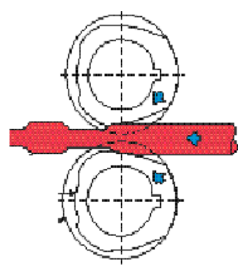


- Accomplished by rotating dies that hammer a workpiece radially inward to taper it as the piece is fed into the dies
- Used to reduce diameter of tube or solid rod stock
- Mandrel sometimes required to control shape and size of internal diameter of tubular parts
- Radial forging: is similar to swaging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

Other Forging Processes



Orbital forging



Roll forging

Forging - *Analysis*

Force required:

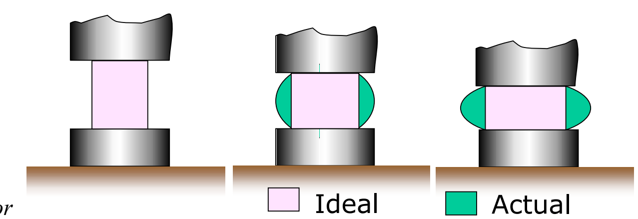
$$F = K_f Y_f A$$

Where:

F: force

A: cross-sectional area

K_f: forging shaping factor



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

Where:

μ: coefficient of friction

D: work-part diameter (or other dimension representing contact length with die surface)

h: work-part height

Impression	K_f
Simple w/ flash	6.0
Complex w/ flash	8.0
Very complex w/ flash	10.0
Flashless	
Coining	6.0
Complex shape	8.0

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: (*strain rate becomes important*)

Strain rate is defined:

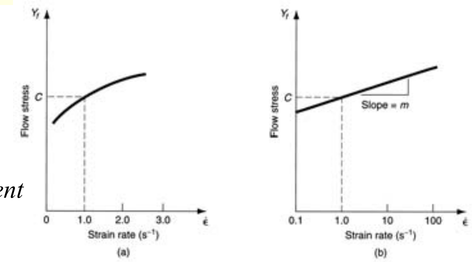
$$\dot{\varepsilon} = \frac{v}{h}$$

Where:
V = deformation velocity
h = instantaneous height of workpiece being deformed

– As strain rate increases, resistance to deformation increases
– This effect is known as *strain-rate sensitivity*

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

where
C = strength constant
m = strain-rate sensitivity exponent



Hot Forging - *Analysis*

the deformation force is:

$$F = C\left(\frac{v}{h_1}\right)^m A$$

the work is:

$$W = \int_{h_o}^{h} F\, dh$$

assume constant strain rate:

$$W = CV\dot{\varepsilon}^m \varepsilon_1$$

the power consumed is:

$$P = \frac{1}{t} CV\dot{\varepsilon}^m \varepsilon_1$$

Where:
V is the volume of the work piece
t is the time

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