Forging

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- Deformation process in which work is compressed between two dies
- Used to make a variety of high strength components for automotive, aerospace etc.
- Components: engine crankshafts, connecting rods, gears, aircraft structural components, jet engine turbine parts
- Basic metals industries use forging to establish basic form of large parts that are subsequently machined to final shape and size

Classification of Forging Operations

Cold vs. hot forging:

- 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: increased strength that results from strain hardening

Impact vs. press forging:

- Forge hammer - applies an impact load
- Forge press - applies gradual pressure

Types of Forging Dies

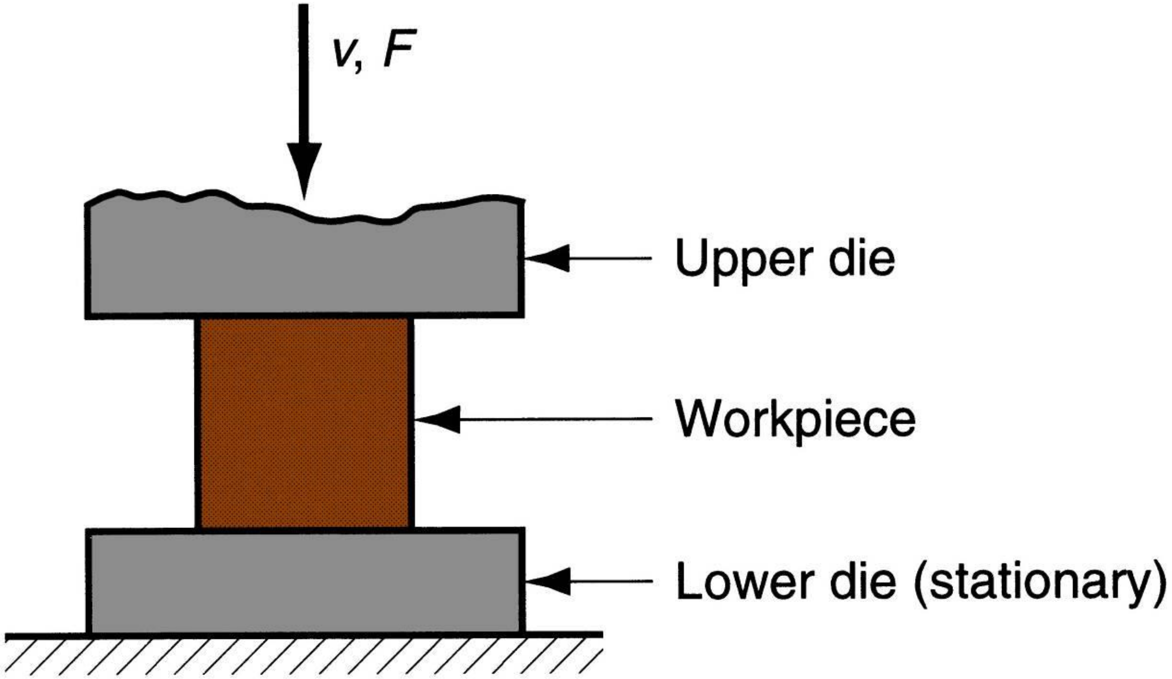
- **Open-die forging** - work is compressed between two flat dies, allowing metal to flow laterally with minimum constraint

- **Impression-die forging** - die contains cavity or impression that is imparted to workpart

  - Metal flow is constrained so that flash is created

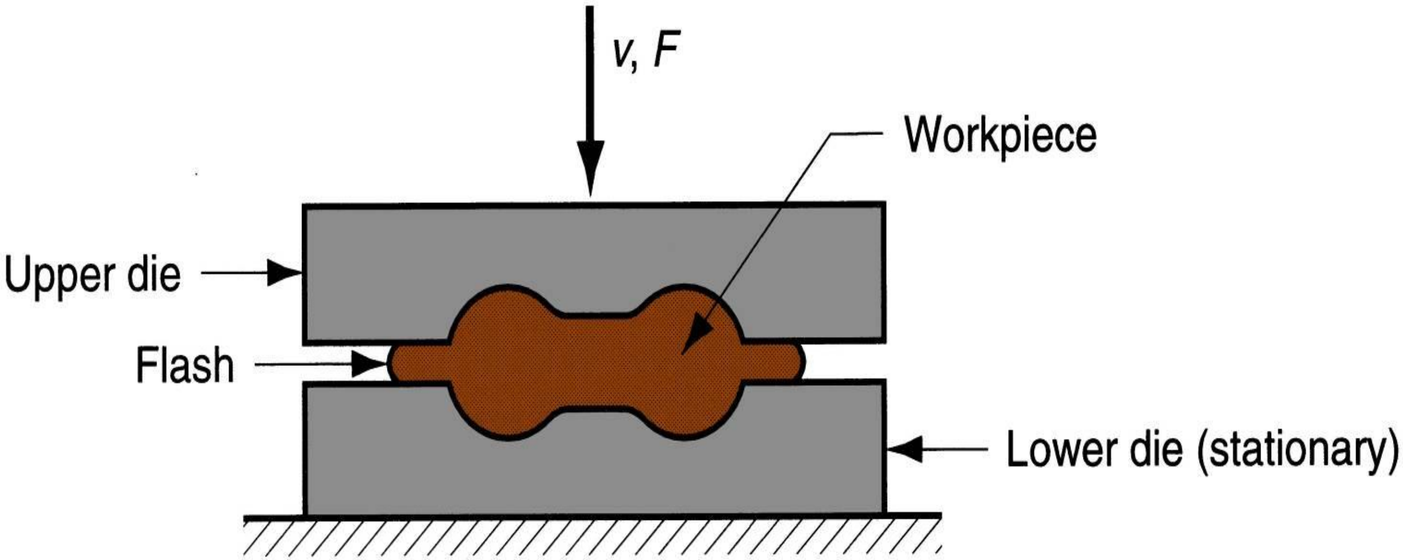
- **Flashless forging** - workpart is completely constrained within die
  - No excess flash is created

Open-Die Forging



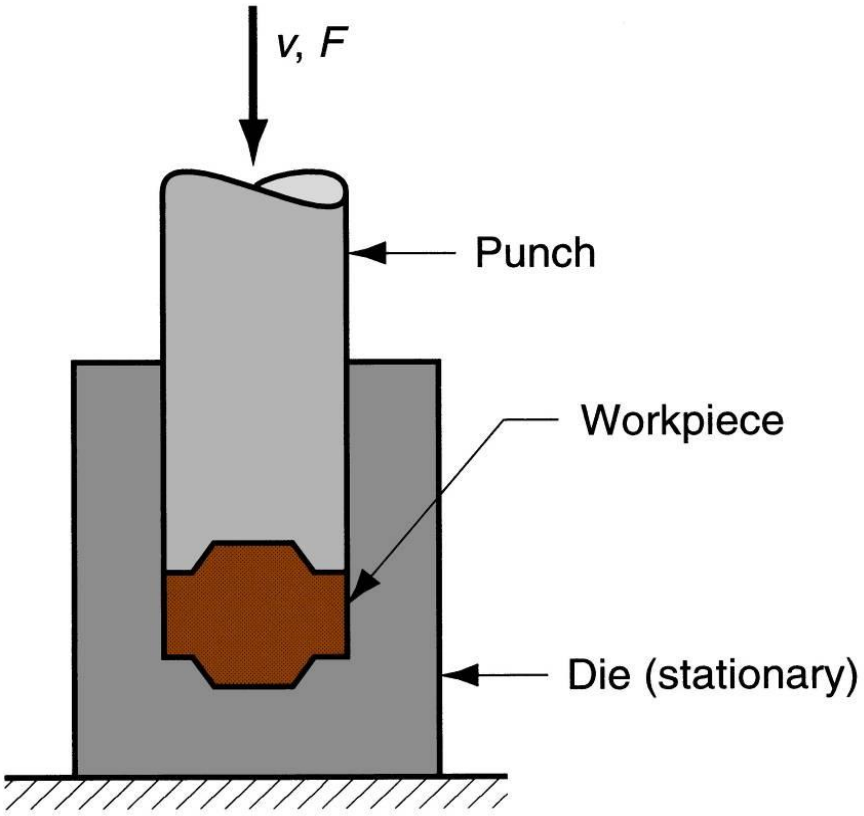
(a)

Impression-Die (Close) Forging



(b)

Flashless Forging



(c)

Open-Die Forging

- Compression of work part between two flat dies
- Similar to compression test when work part has cylindrical cross section and is compressed along its axis
  - Deformation operation reduces height and increases diameter of work
  - Common names include *upsetting* or *upset forging*

Open-Die Forging with No Friction

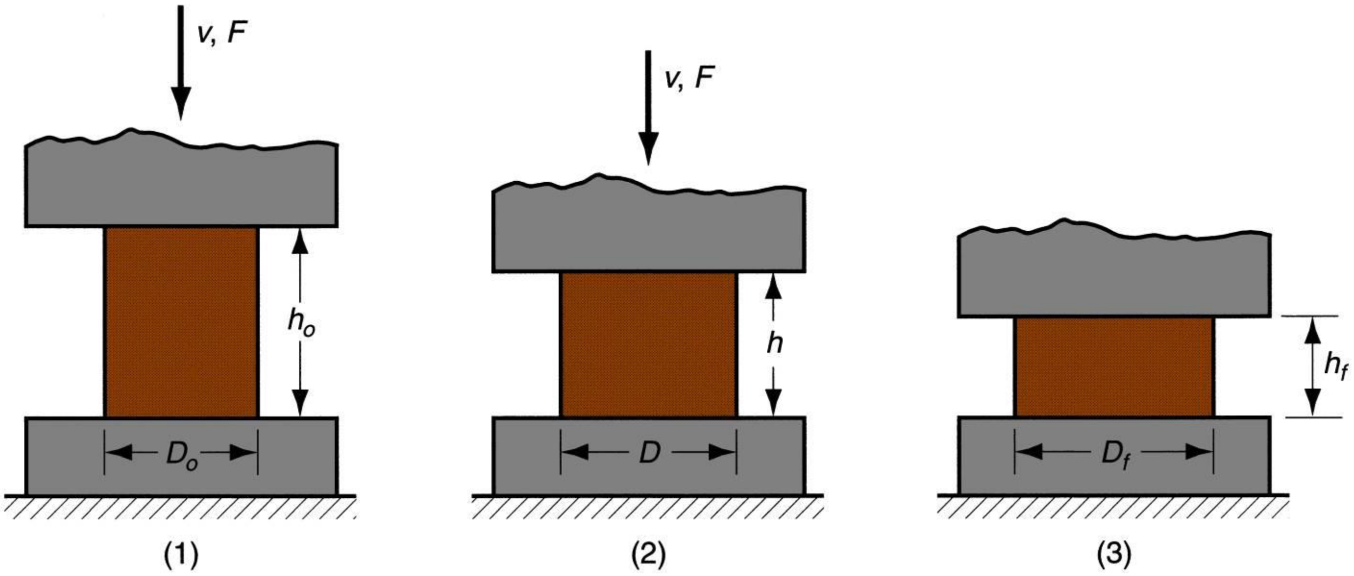
- If no friction occurs between work and die surfaces, then homogeneous deformation occurs, so that radial flow is uniform throughout workpart height and true strain is given by:

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

where h_o= starting height; and h = height at some point during compression

At h = final value h_f, true strain is maximum value

- Force required = F = Y_f A



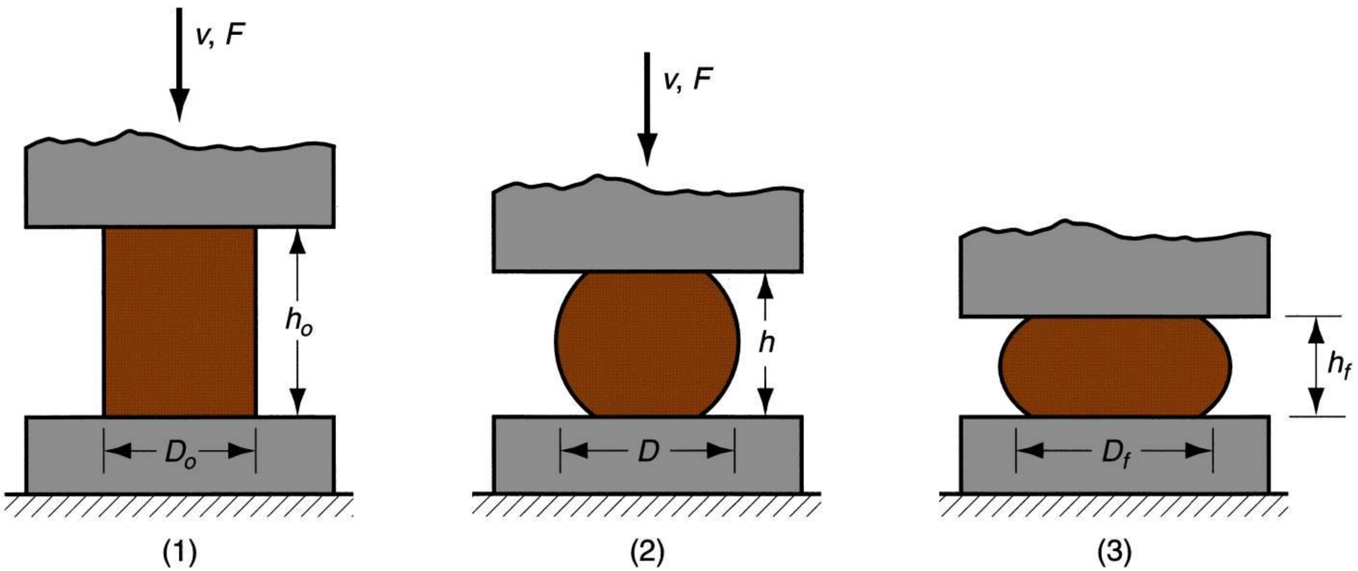
Homogeneous deformation of a cylindrical workpart under ideal conditions in an open-die forging operation: (1) start of process with work piece at its original length and diameter, (2) partial compression, and (3) final size.

Open-Die Forging with Friction

- Friction between work and die surfaces constrains lateral flow of work, resulting in barreling effect

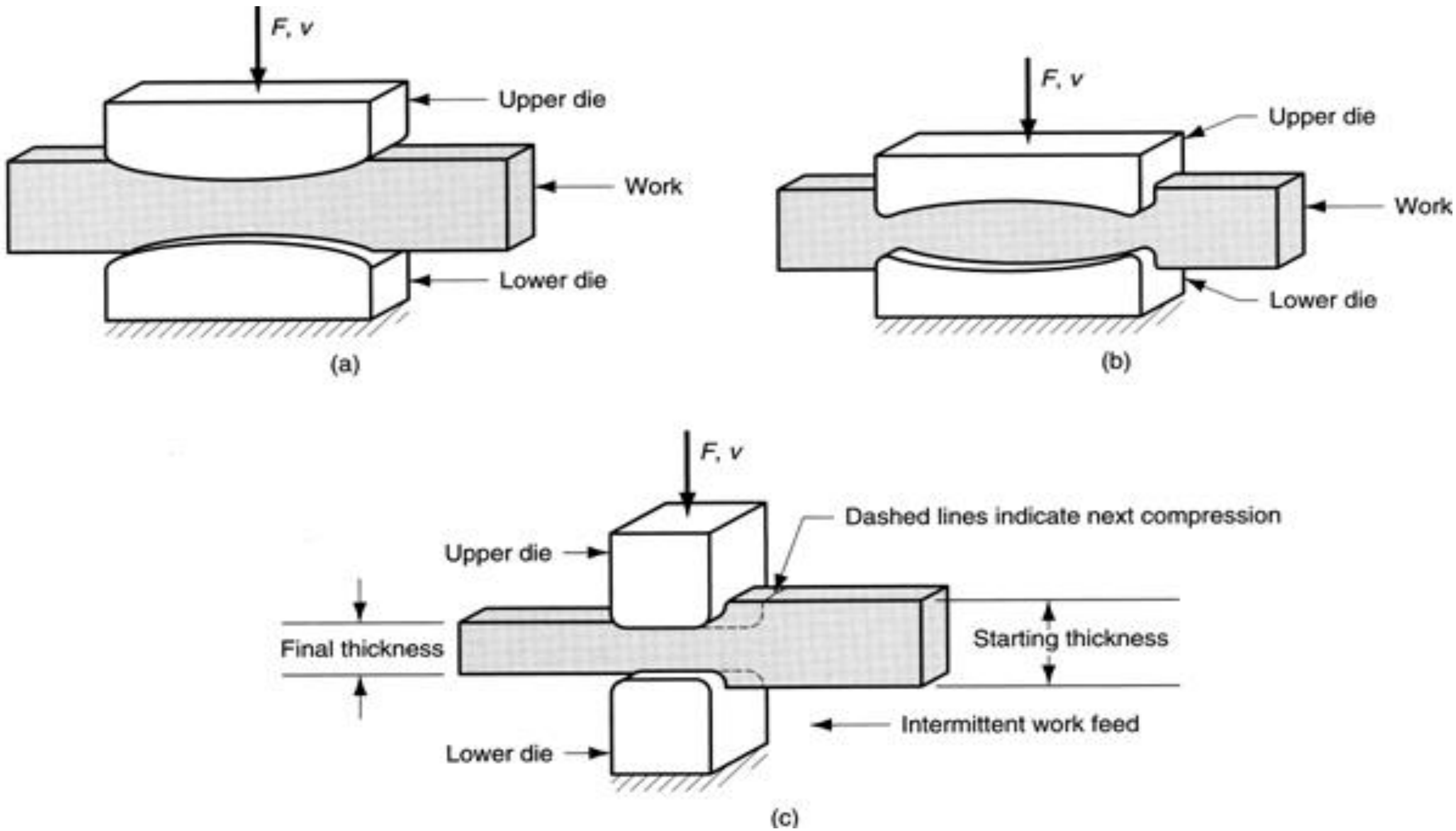
- In hot open-die forging, effect is even more pronounced due to heat transfer at and near die surfaces, which cools the metal and increases its resistance to deformation

- Upsetting force $F = k_f Y_f A$
- Shape factor $K_f = 1 + 0.4\ \mu D/h$



Actual deformation of a cylindrical workpart in open-die forging, showing pronounced *barreling*: (1) start of process, (2) partial deformation, and (3) final shape.

Open- die forging operations



(a) Fullering (b) edging (c) Cogging

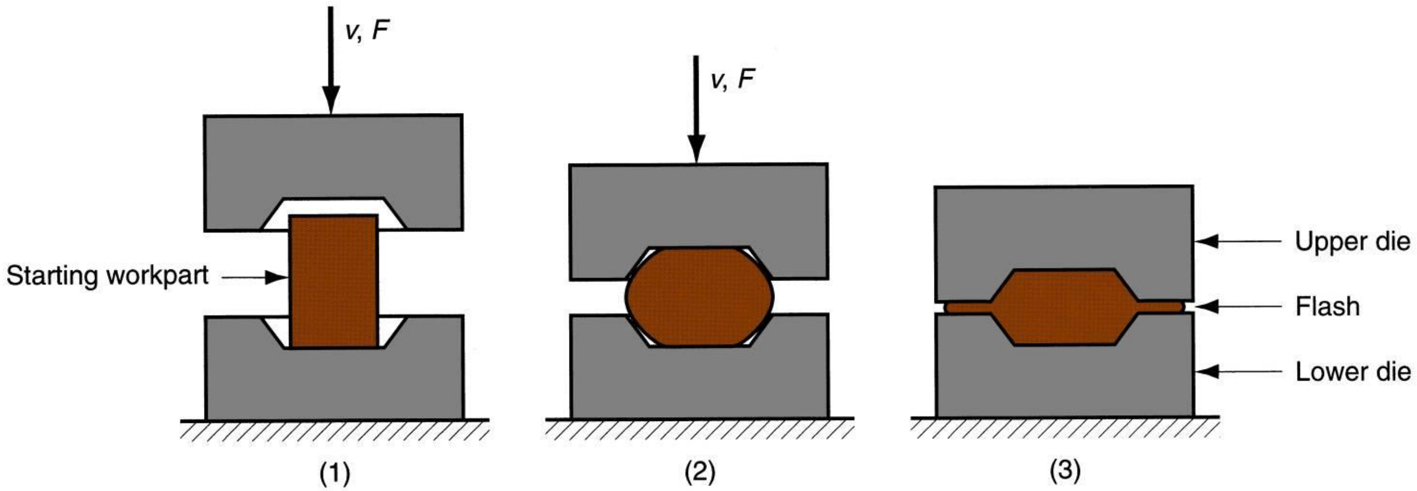
- **Fullering :-** To reduce the cross section and redistribute the metal in a work part in preparation for subsequent shape forging.

- **Edging** :- similar to fullering, except that the dies have concave surfaces

- **Cogging** :- Sequence of forging compressions along the length of a work piece to reduce cross section and increase length.

Impression-Die (close) Forging

- Compression of workpart by dies with inverse of desired part shape
- Flash is formed by metal that flows beyond die cavity into small gap between die plates
- Flash must be later trimmed, but it serves an important function during compression:
  - As flash forms, friction resists continued metal flow into gap, constraining material to fill die cavity
  - In hot forging, metal flow is further restricted by cooling against die plates



Sequence in impression-die forging: (1) just prior to initial contact with raw workpiece, (2) partial compression, and (3) final die closure, causing flash to form in gap between die plates.

Impression-Die Forging Practice

- 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 final geometry
- Impression-die forging is often performed manually by skilled operator under adverse conditions

TABLE 19.1 Typical K_f values for various part shapes in impression-die and flashless forging.

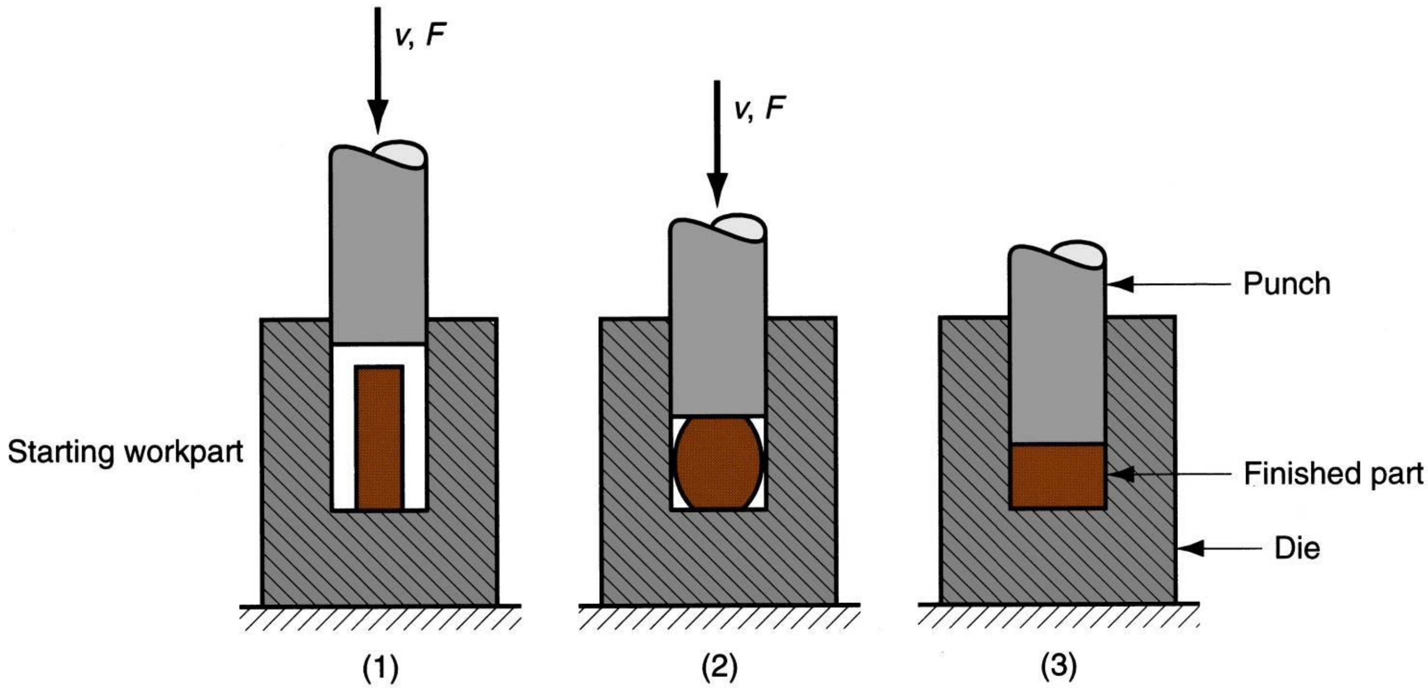
Part Shape	K_f	Part Shape	K_f
Impression-die forging:		Flashless forging:	
Simple shapes with flash	6.0	Coining (top and bottom surfaces)	6.0
Complex shapes with flash	8.0	Complex shapes	8.0
Very complex shapes with flash	10.0		

Advantages and Limitations

- Advantages of impression-die forging compared to machining from solid stock:
  - Higher production rates
  - Less waste of metal
  - Greater strength
  - Favorable grain orientation in the metal
- Limitations:
  - Not capable of close tolerances
  - Machining often required to achieve accuracies and features needed

Flashless Forging

- Compression of work in punch and die tooling whose cavity does not allow for flash
- Starting work part 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



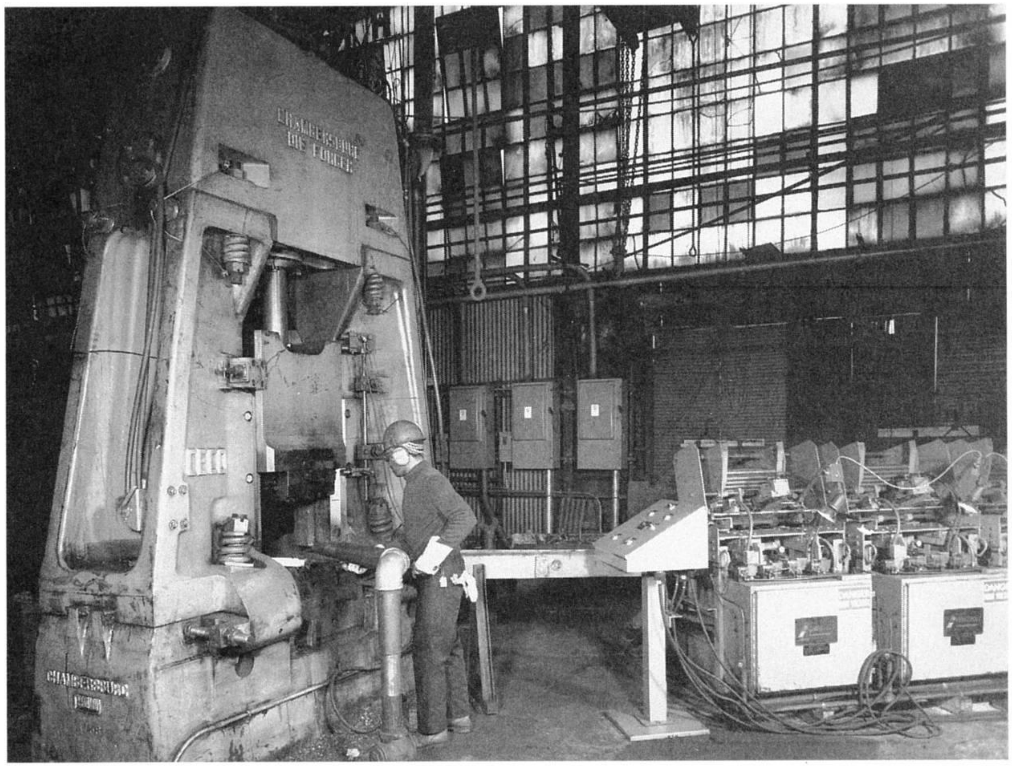
Flashless forging: (1) just before initial contact with workpiece, (2) partial compression, and (3) final punch and die closure.

Types of forging

- Smith forging
- Drop forging
- Press forging
- Upset forging
- Swaging
- Trimming

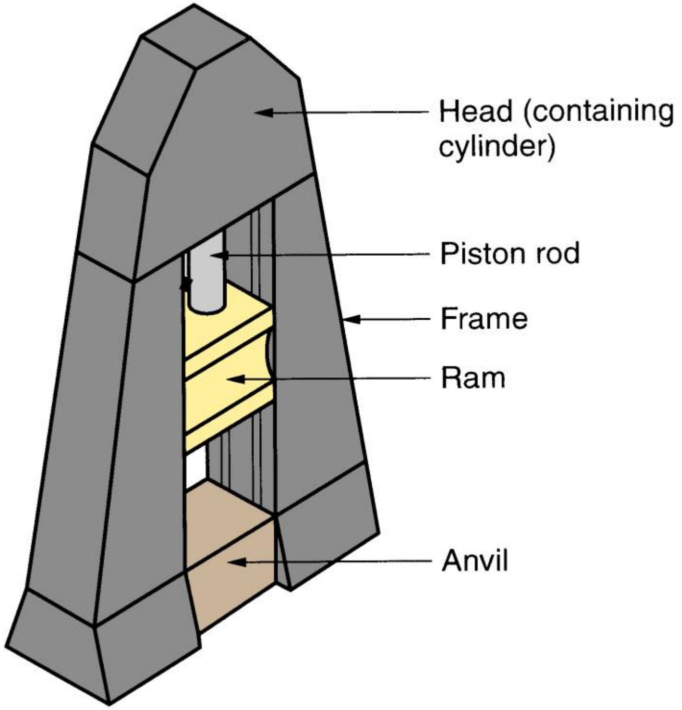
Forging Hammers (Drop Hammers)

- Apply impact load against work part
- 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
- Commonly used for impression-die forging



Drop forging hammer, fed by conveyor and heating units at the right of the scene (photo courtesy of Chambersburg Engineering Company).

Drop Hammer Details



Drop hammer for impression-die forging.

Forging Presses

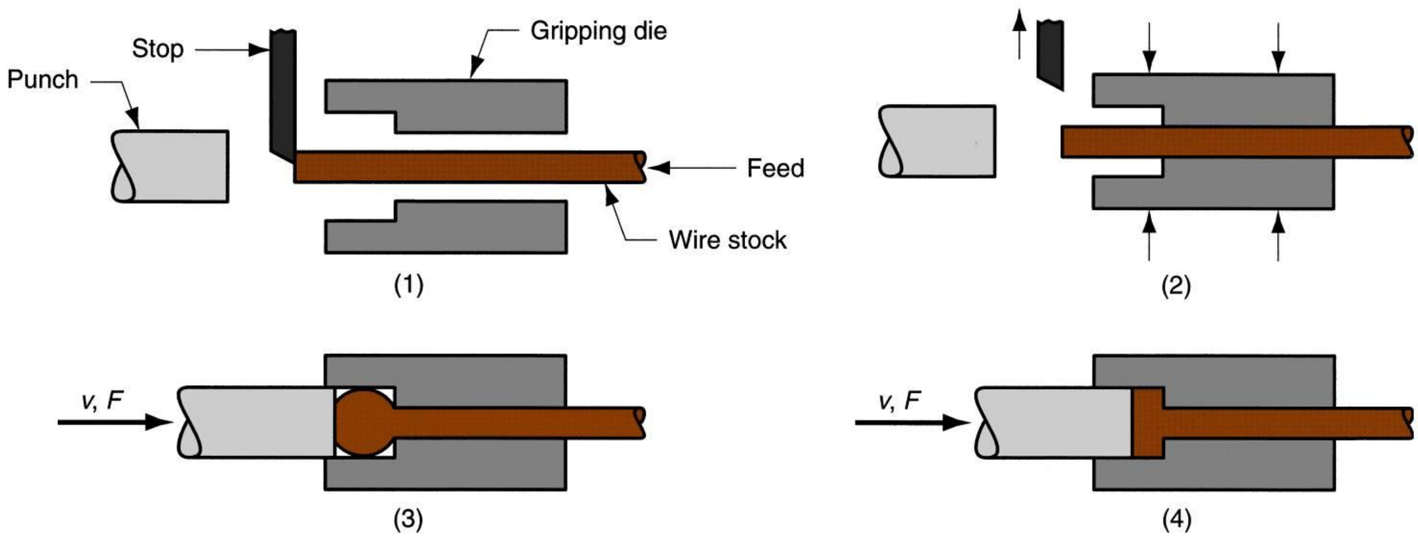
- Apply gradual pressure to accomplish compression operation

- Types:
  - Mechanical press - converts rotation of drive motor into linear motion of ram
  - Hydraulic press - hydraulic piston actuates ram
  - Screw press - screw mechanism drives ram

Upsetting and Heading

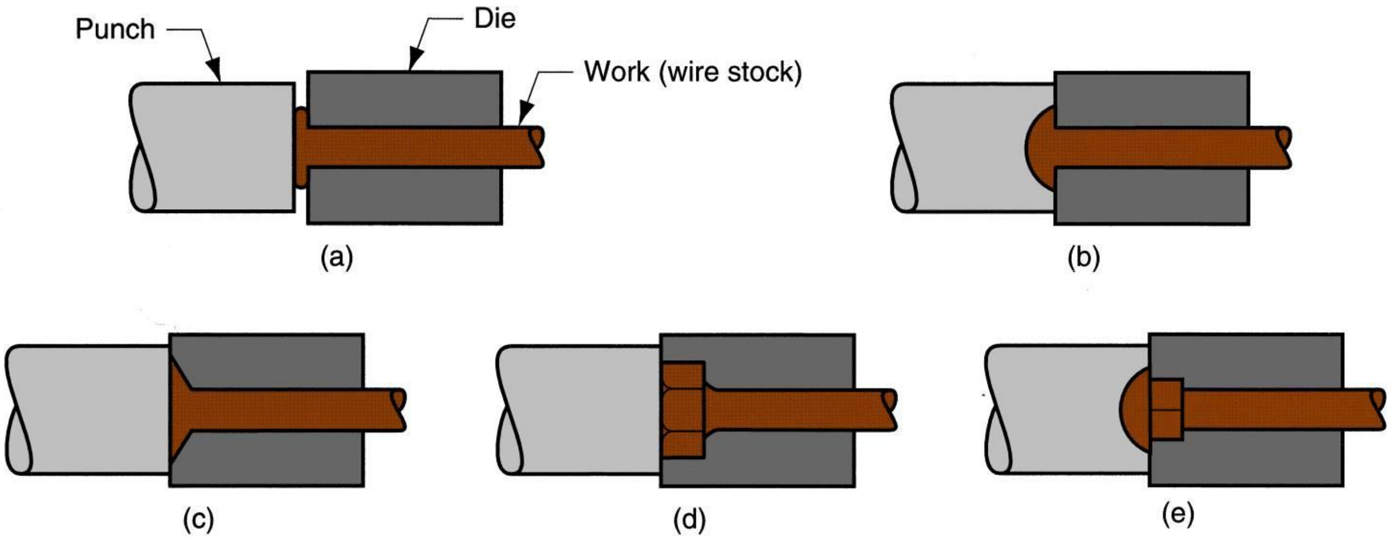
- Forging process used to form heads on nails, bolts, and similar hardware products
- More parts produced by upsetting than any other forging operation
- Performed cold or hot on machines called *headers* or *formers*
- Wire or bar stock is fed into machine, end is headed, then piece is cut to length

Upset Forging



An upset forging operation to form a head on a bolt or similar hardware item The cycle consists of: (1) wire stock is fed to the stop, (2) gripping dies close on the stock and the stop is retracted, (3) punch moves forward, (4) bottoms to form the head.

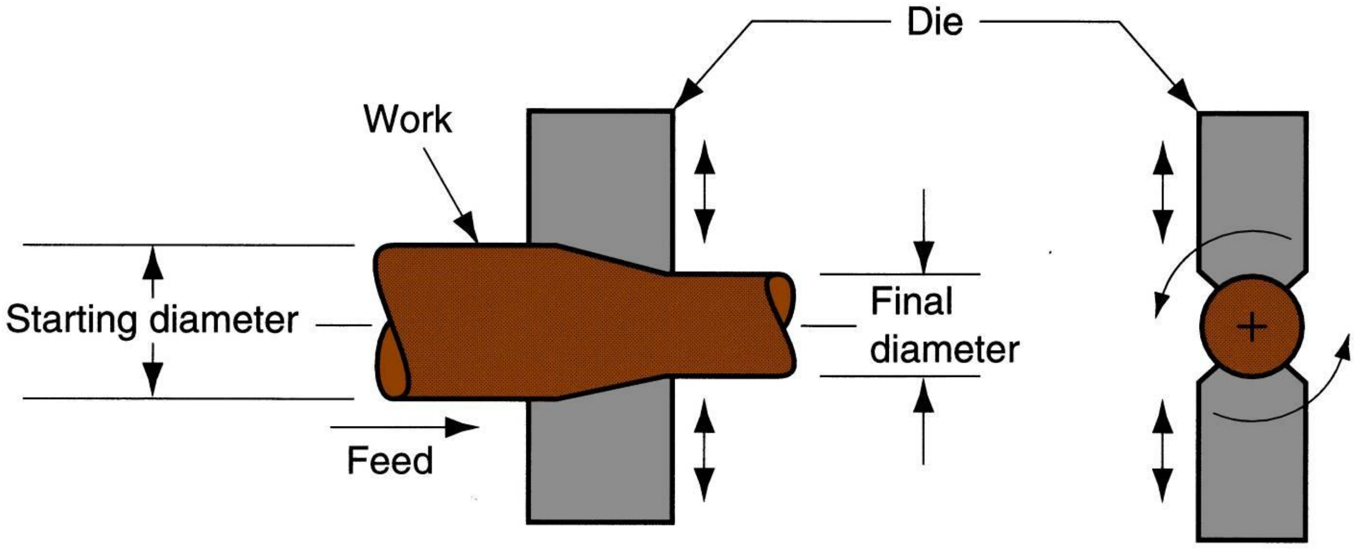
Heading (Upset Forging)



Examples of heading (upset forging) operations: (a) heading a nail using open dies, (b) round head formed by punch, (c) and (d) two common head styles for screws formed by die, (e) carriage bolt head formed by punch and die.

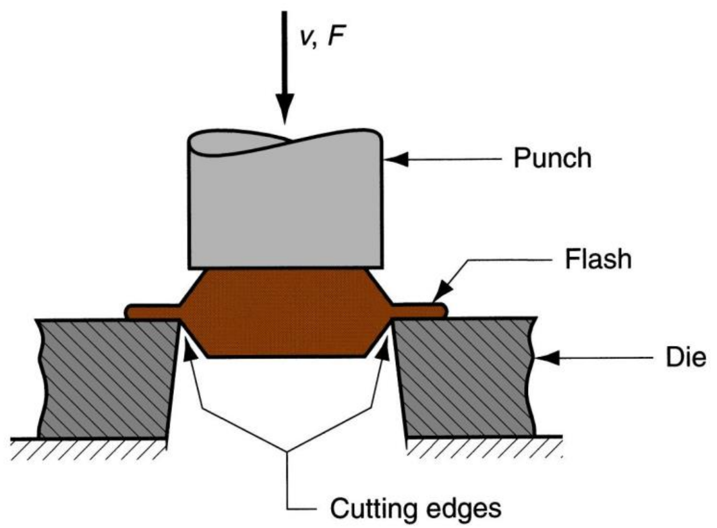
Swaging

- 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



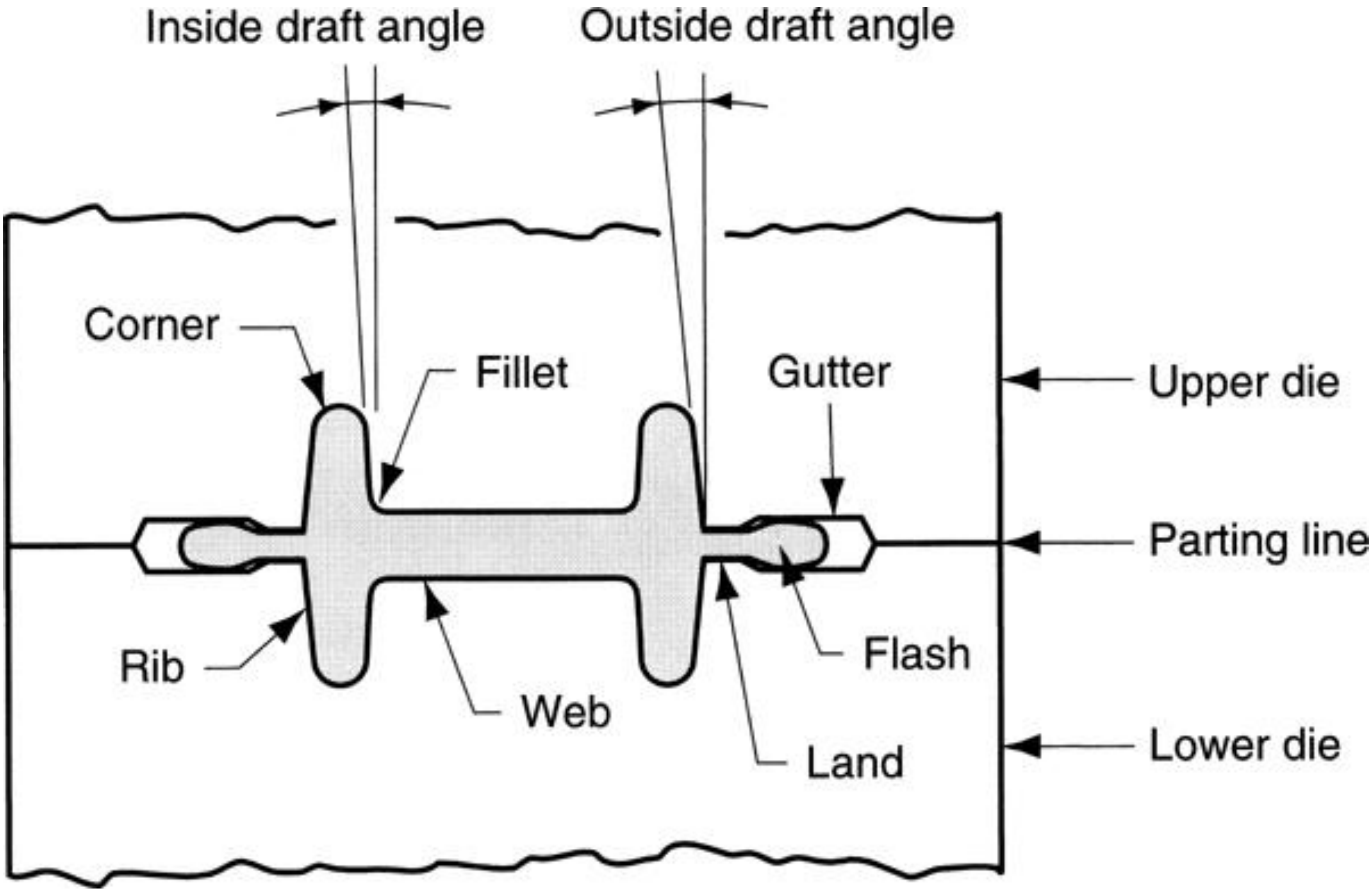
Trimming

- 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



Trimming operation (shearing process) to remove the flash after impression-die forging

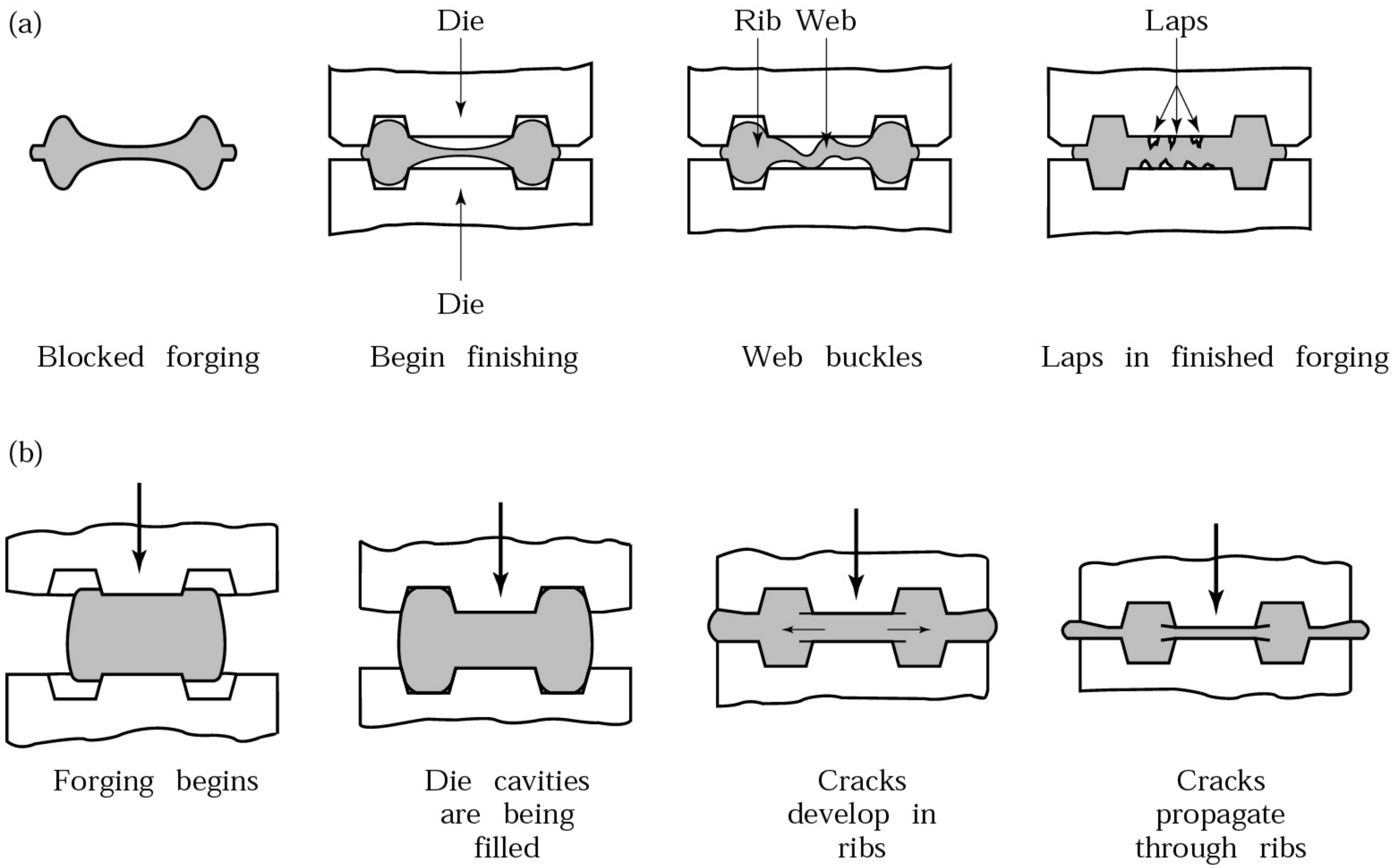
Forging die terminology



Forging Defects

- Unfilled sections – less metal, improper heating, misplacement of metal
- Scale pits – scale in die
- Mismatched forging – misalignment of two halves of die
- Barreling
- Laps – thin web
- Internal cracks – thick web

Forging Defects



(a) Laps formed by web buckling during forging; web thickness should be increased to avoid this problem.
(b) Internal defects caused by oversized billet; die cavities are filled prematurely, and the material at the center flows past the filled regions as the dies close.

Example

- A cylindrical work piece is subjected to a cold upset forging operation. The starting piece is 75 mm in height and 50mm in diameter. It is reduced in the operation to a height of 36mm.The work material has a flow curve defined by K = 350MPa and n = 0.17. Assume a coefficient of friction of 0.1.Determine the force as the process begins, at intermediate heights of 62mm, 49 mm, and at the final height of 36 mm.

Thanks