Metal Forming - 3

(Forging of Metals)

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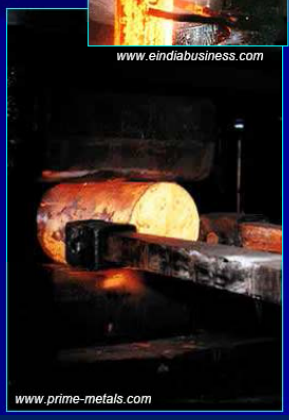
Lecture Outline

1. Introduction
2. Forging operations
3. Classification of forging processes
4. Closed and open die forging process
5. Effect of forging on microstructure
6. Other forging related processes
   - Coining
   - Swaging
   - Roll forging
7. Typical forging defects

1. Introduction

- ***Forging*** is the working of metal into a useful shape by hammering or pressing.
- The oldest of the metalworking arts (***primitive blacksmith***).
- Replacement of machinery occurred during early the ***Industrial revolution***.
- Forging machines are now capable of making parts ranging in size of ***a bolt to a turbine rotor***.
- Most forging operations are carried out ***hot***, although certain metals may be ***cold-forged***.

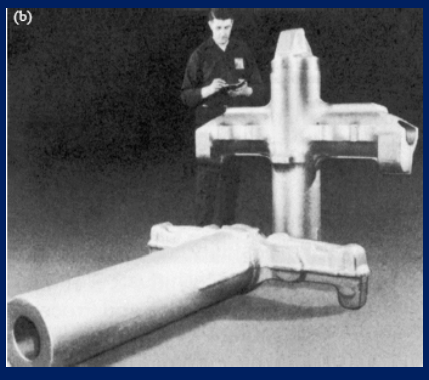
www.eindiabusiness.com



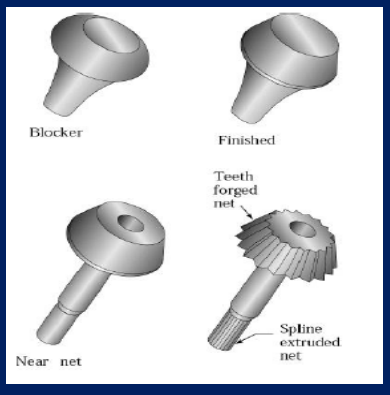
www.prime-metals.com

Introduction

- Typical forged products are such as gears, connecting rods, bolts

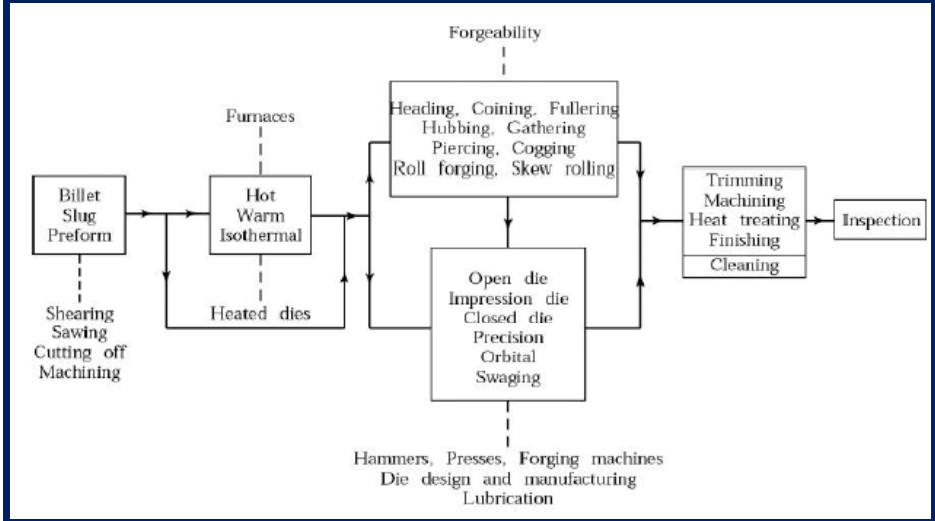


Landing-gear components for the C5A and C5B transport aircraft made by forging

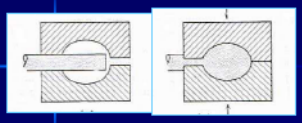


Steps involved in forging a bevel gear with a shaft.

2. Outline of Forging and Related Operations

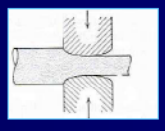


Forging Operations

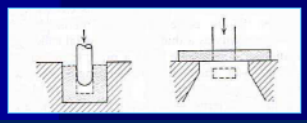


Edging is used to shape the ends of the bars and to gather metal. The metal flow is confined in the horizontal direction but it is free to flow laterally to fill the die.

www.jsc-pfm.com

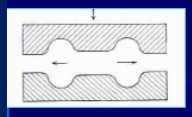


Drawing is used to reduce the cross-sectional area of the workpiece with concurrent increase in length.

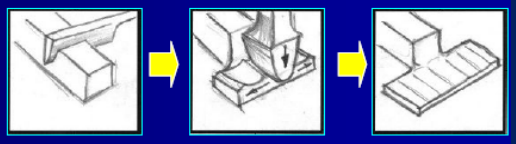


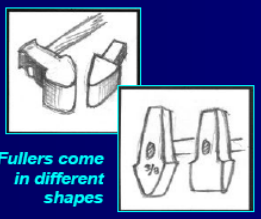
Piercing and punching are used to produce holes in metals.

Forging Operations



Fullering is used to reduce the cross-sectional area of a portion of the stock. The metal flow is outward and away from the centre of the fuller.
i.e., forging of connecting rod for an internal-combustion engine.





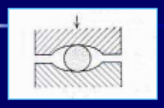
Fullers come in different shapes

www.anvilfire.com

- Fuller move fast and moves metal perpendicular to the face

Fullers

Forging Operations



Swaging is used to produce a bar with a smaller diameter (using concave dies).

- Swaging is a special type of forging in which metal is formed by a succession of rapid hammer blows

- Swaging provides a reduced round cross section suitable for tapping, threading, upsetting or other subsequent forming and machining operations.

Swaging at the ends, ready for next forming process.

3. Classifications of forging processes

- By equipment
  - Forging hammer or drop hammer
  - Press forging
- By process
  - Open die forging
  - Closed die forging

Forging machines

There are four basic types of forging machines

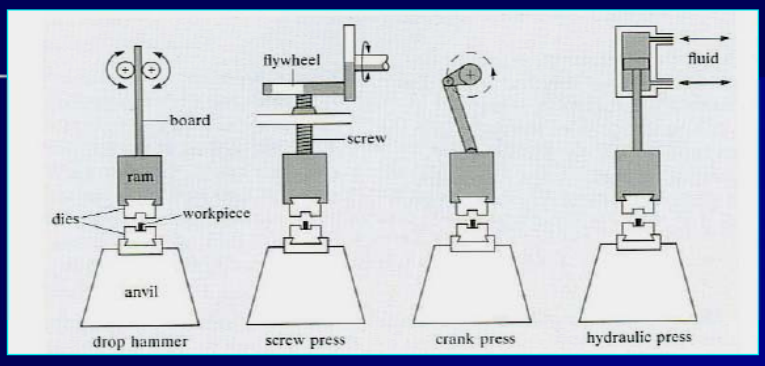


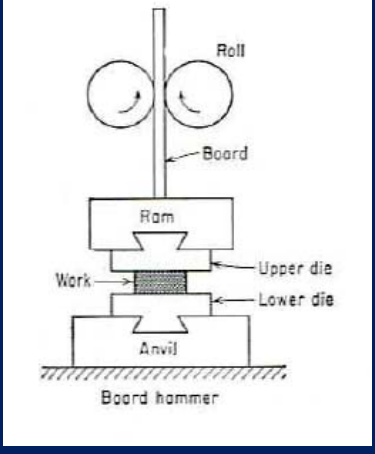
Table 3.3

Machine type	Load rating, F/kN	Available energy per blow, W/kJ	Ratio $W:F$ /m × 10^{-3}
drop hammer	12 250	1.6	1.3
friction screw press	12 250	8.0	6.4
crank press	12 250	20	16
hydraulic press	12 250	250	200

Hammer and press forging processes

- Forging hammers
  - Board hammer
  - Power hammer
- Forging presses
  - Mechanical press
  - Hydraulic press

Board hammer – forging hammer

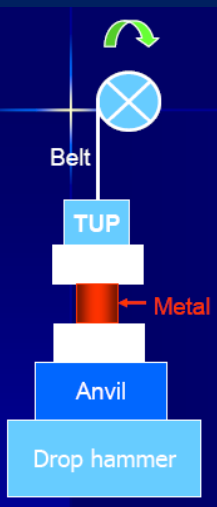


- The upper die and ram are raised by ***friction rolls*** gripping the board.
- After releasing the board, the ram falls under gravity to produce the ***blow energy***.
- The hammer can strike between ***60-150 blows*** per minute depending on size and capacity.
- The board hammer is an energy-restricted machine. The blow energy supplied equal the ***potential energy*** due to the weight and the height of the fall.

Potential energy = *mgh* *…Eq 1*

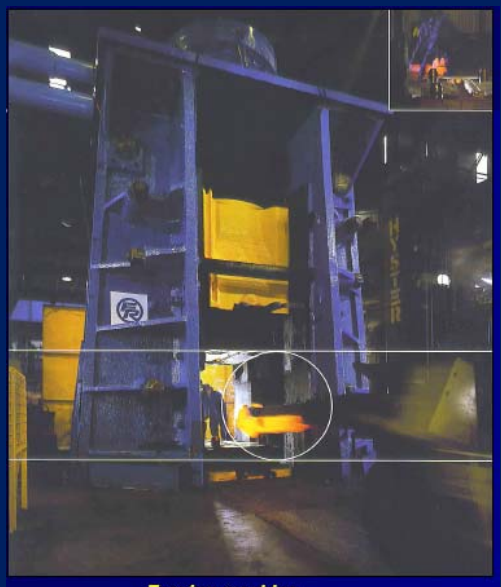
- This energy will be delivered to the metal workpiece to produce ***plastic deformation***.

Forging hammer or drop hammer



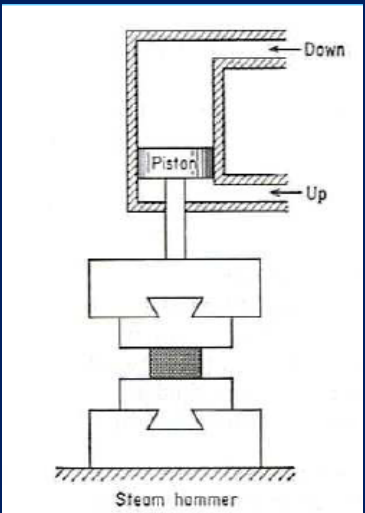
- Provide rapid impact blows to the surface of the metal.
- Dies are in two halves
  - *Lower : fixed to anvil*
  - *Upper : moves up and down with the TUP.*
- Energy (from a gravity drop) is adsorbed onto the metal, in which the maximum impact is on the metal surface.
- Dies are expensive being accurately machined from special alloys (susceptible to thermal shock).
- ***Drop forging*** is good for mass production of complex shapes.

- Example of forging hammer or drop hammer
- The energy supplied by the blow is equal to the potential energy due to the weight of the ram and the height of the fall



Forging machine

Power hammer



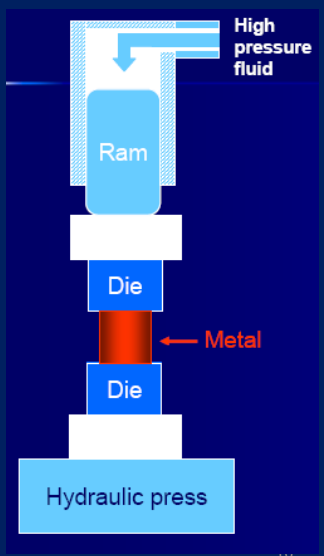
- ***Power hammer*** provides greater capacity, in which the ***ram is accelerated*** on the downstroke by steam or air pressure in addition to gravity.
- Steam or air pressure is also used to raise the ram on the upstroke.
- *The **total energy** supplied to the blow in a power drop hammer is given by*

$$W = \frac{1}{2}mv^2 + pAH = (mg + pA)H \quad \text{...Eq 2}$$

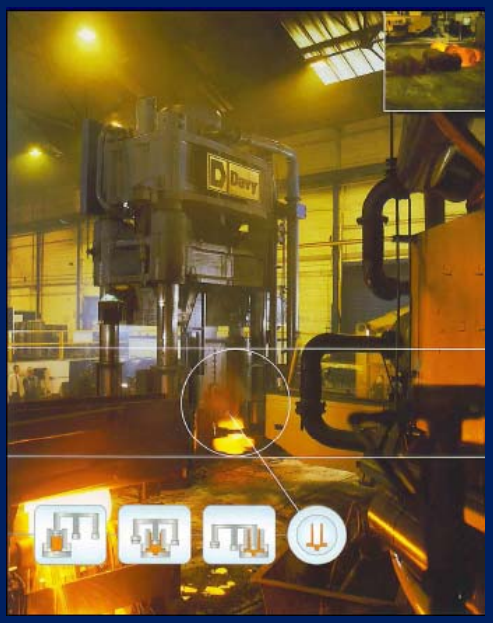
Where
- ***m*** = mass
- ***v*** = velocity of ram at start of deformation
- ***g*** = acceleration of gravity
- ***p*** = air or steam pressure acting on ram cylinder on downstroke
- ***A*** = area of ram cylinder
- ***H*** = height of the ram drop

Hydraulic press forging

- Using a hydraulic press or mechanical press to forge the metal, therefore, gives continuous forming at a slower rate.
- Provides deeper penetration
- Better properties (more homogeneous)
- Equipment is expensive

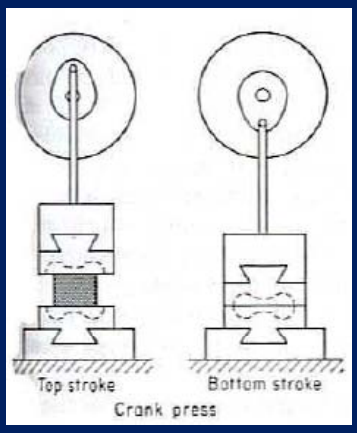


- ***Hydraulic presses*** are load-restricted machines in which hydraulic pressure moves a piston in a cylinder.
- The full press load is available at any point during the full stroke of the ram. Therefore, hydraulic presses are ideally suited for ***extrusion-type forging operation***.
- Due to slow speed, ***contact time is longer*** at the die-metal interface, which causes problems such as heat lost from workpiece and die deterioration.
- Also provide close-tolerance forging.
- Hydraulic presses are ***more expensive*** than mechanical presses and hammers.



A general view of a 445 MN (50,000 ton) hydraulic press. *Source*: Wyman-Gordon Company.

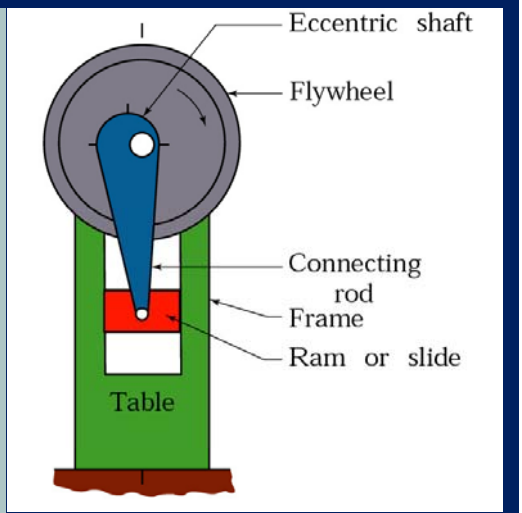
Mechanical press machine



- Crank press translates rotary motion into reciprocating linear motion of the press slide.
- The ram stroke is shorter than in a hammer or hydraulic press.
- Presses are rated on the basis of the force developed at the end of the stroke.
- The ***blow press*** is more like ***squeeze*** than like the impact of the hammer, therefore, dies can be less massive and die life is longer than with a hammer.
- The ***total energy*** supplied during the stroke of a press is given by

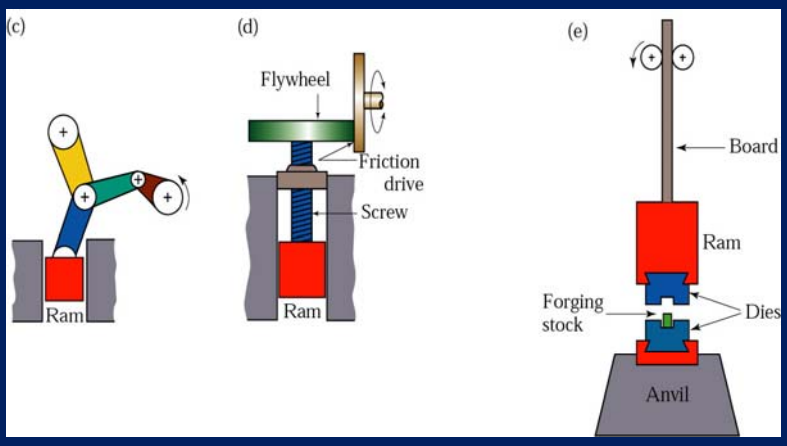
$$W = \frac{1}{2} I\left[\omega_o^2 - \omega_f^2\right] \qquad \text{...Eq 3}$$

Where I is moment of inertia of the flywheel
ω is angular velocity, ω_o-original, ω_f-after deformation, rad.s^{-1}



Mechanical press with an eccentric drive; the eccentric shaft can be replaced by a crankshaft to give the up-and-down motion to the ram

Principles of Various Forging Machines (cont.)



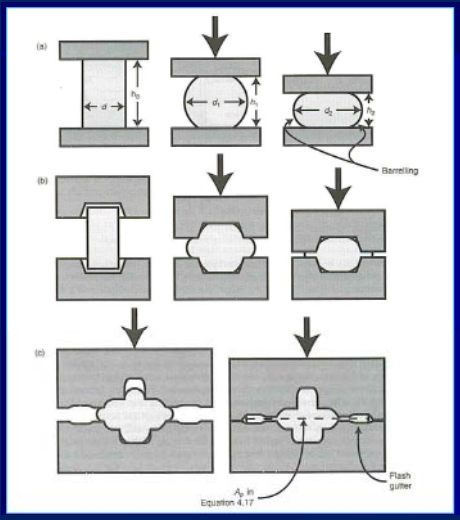
Schematic illustration of the principles of various forging machines. (c) Knuckle-joint press. (d) Screw press. (e) Gravity drop hammer.

Typical values of velocity for various forging machines

Forging machine	Velocity range, ms^{-1}
Gravity drop hammer	3.6-4.8
Power drop hammer	3.0-9.0
HERF machine	6.0-24.0
Mechanical press	0.06-1.5
Hydraulic press	0.06-0.30

Remark: HERF – High Energy Rate Forging

4. Closed and open die forging processes



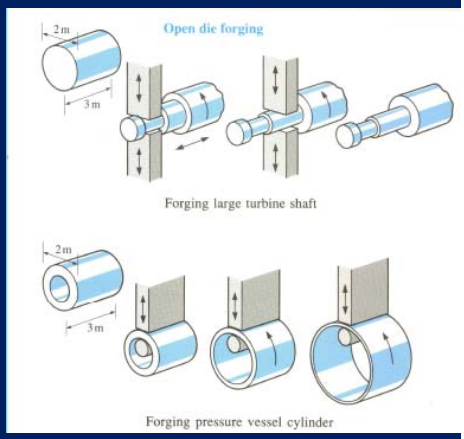
Open-die forging

Closed-die forging

Impression-die forging

Open die forging

- Open die forging is carried out between flat dies or dies of very simple shapes
- The process is used for mostly large objects or when the number of parts produced is small
- Open die forging is often used to pre-form the workpiece for closed die forging



Upsetting

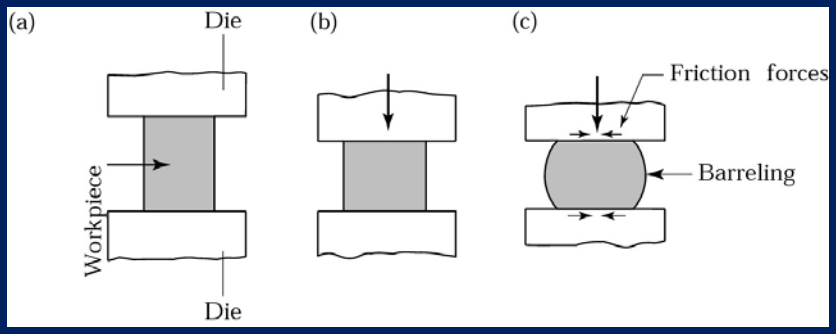


Figure 14.4 (a) Solid cylindrical billet upset between two flat dies. (b) Uniform deformation of the billet without friction. (c) Deformation with friction. Note barreling of the billet caused by friction forces at the billet-die interfaces.

Cogging

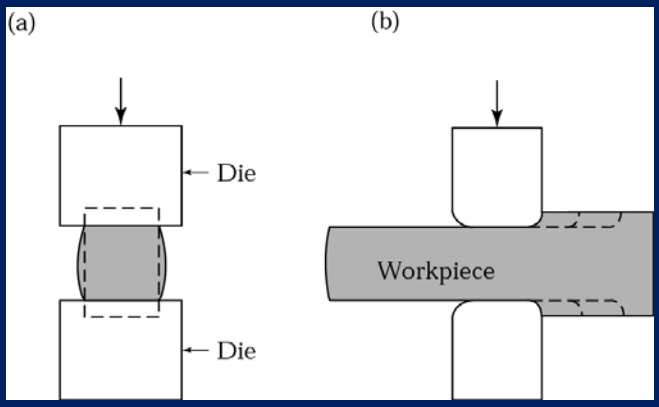


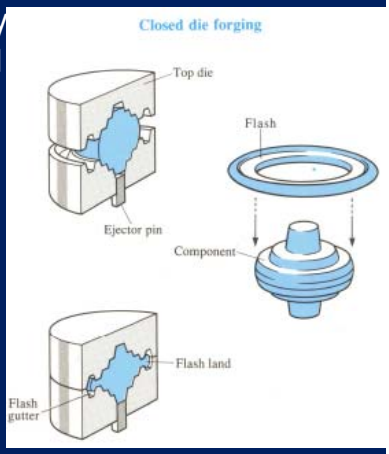
Figure 14.5 Two views of a cogging operation on a rectangular bar. Blacksmiths use this process to reduce the thickness of bars by hammering the part on an anvil. Note the barreling of the workpiece.

Impression-Die & Closed-Die Forging

- Fullering & edging are used to distribute the material
  - Fullering – material is distributed away from an area
  - Edging – material is gathered into an area
- Blocking – rough shaping of the part
- Impression dies – give the part its final shape

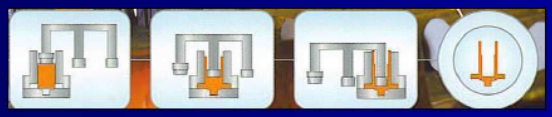
Closed die forging (impression die forging)

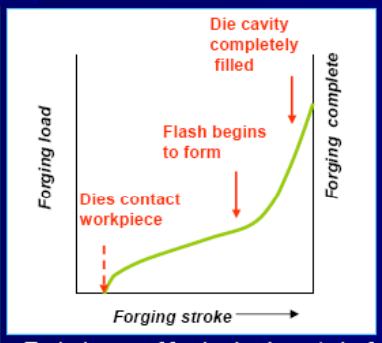
- The workpiece is deformed between two die halves which carry the **impressions** of the desired final shape.
- The workpiece is deformed under high pressure in a closed cavity
- Normally used for smaller components
- The process provide precision forging with close dimensional tolerance
- Closed dies are expensive



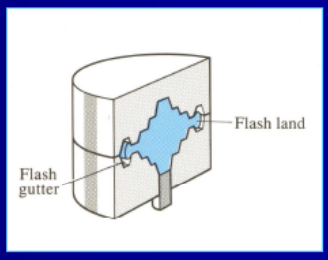
Closed-die forging operation

billet → Preshaped → Rough-forge → Finishing die → Trimming die → Final product



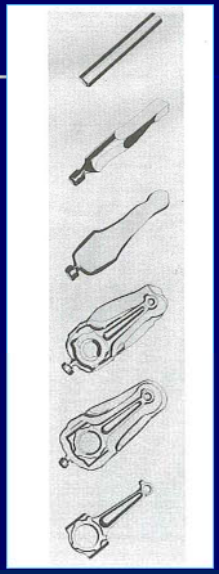


Typical curve of forging load vs. stroke for closed-die forging.



Flash is the excess metal, which squirts out of the cavity as a thick ribbon of metal.

Example: Die set and forging steps for the manufacturing of an automobile engine connecting rod



- ***Preforming*** of a round piece in an open die arrangement.
- Rough shape is formed using a block die.
- The finishing die is used to bring the part to final tolerances and surface finish.
- Removal of flash (excess metal).

Steering knuckle

Rail

Flange

http://www.hirschvogel.de/en/produktionsverfahren/warmumformung.php

See simulation

Die materials

www.nitrex.com

Forging die

Required properties

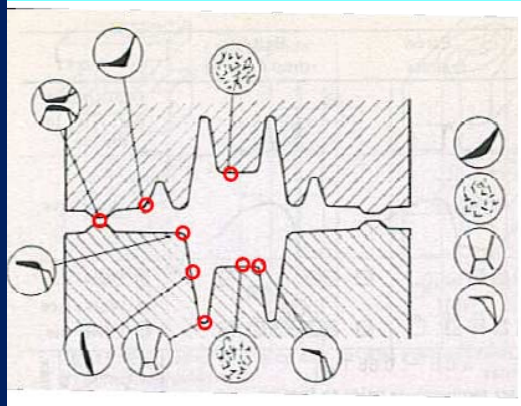
- Thermal shock resistance
- Thermal fatigue resistance
- High temperature strength
- High wear resistance
- Hgh toughness and ductility
- High hardenability
- High dimensional stability during hardening
- High machinability

Die materials: alloyed steels (with ***Cr, Mo, W, V***), tool steels, cast steels or cast iron. (Heat treatments such are nitriding or chromium plating are required to improve die life)

1) ***Carbon steels*** *with 0.7-0.85% C are appropriate for small tools and flat impressions.*
2) ***Medium-alloyed tool steels*** *for hammer dies.*
3) ***Highly alloyed steels*** *for high temperature resistant dies used in presses and horizontal forging machines.*

Die failures

Different types of die failure



Wear (abrasion)

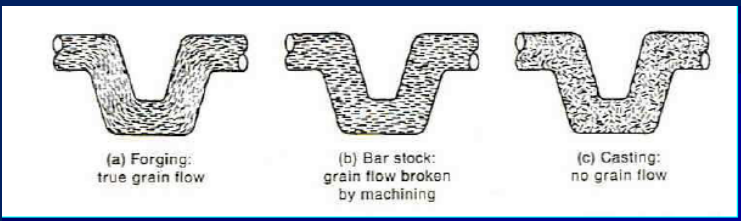
Thermal fatigue

Mechanical fatigue

Permanent deformation

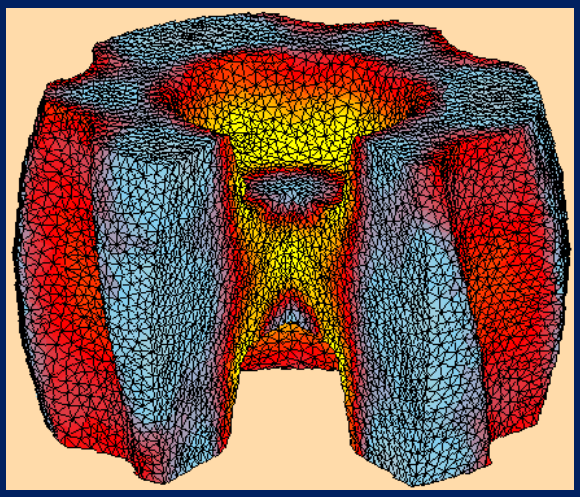
- Different parts of dies are liable to permanent deformation and wear resulting from ***mechanical and thermal fatigue***.
- ***Important factors:*** shape of the forging, die materials, how the workpiece is heated, coating of die surface, the operating temperature (should not exceed the annealing temperature).

5. Effect of forging on microstructure



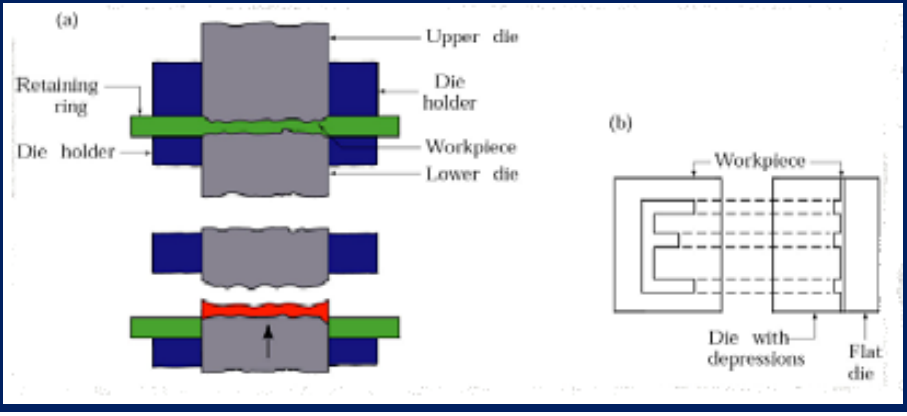
grain structure resulting from (a) forging, (b) machining and (c) casting.

- The formation of a grain structure in forged parts is ***elongated*** in the direction of the deformation.
- The metal flow during forging provides ***fibrous microstructure*** (revealed by etching). This structure gives ***better mechanical properties*** in the plane of maximum strain but (perhaps) lower across the thickness.
- The workpiece often undergo ***recrystallisation***, therefore, provide finer grains compared to the cast dendritic structure resulting in improved mechanical properties.

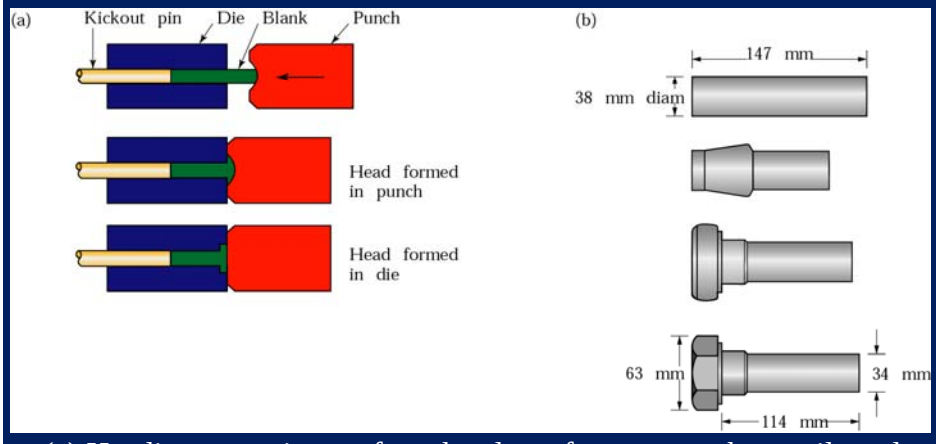


6. Other forging related process – Coining

- Closed-die forging process
- Used for minting coins, medallions, & jewelry
- Lubricants can not be used in coining
- Can be used to improve surface finish

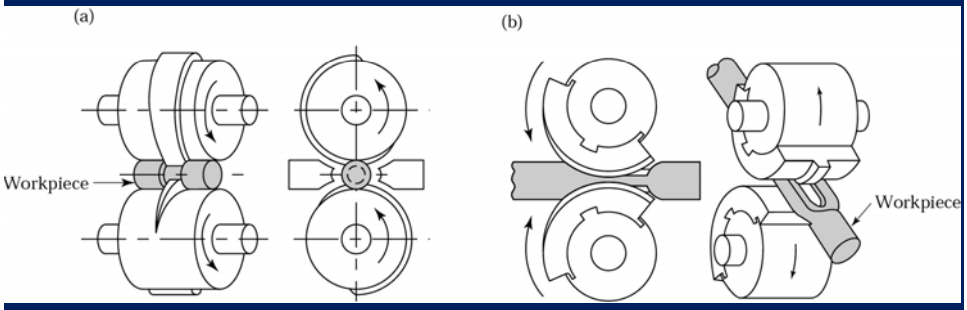


Other forging related process – Heading/Upset Forging



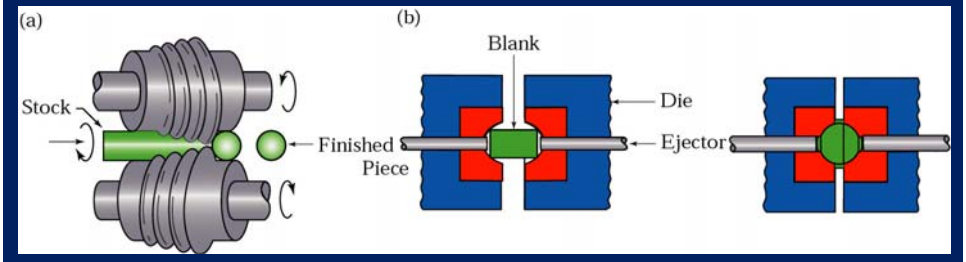
(a) Heading operation, to form heads on fasteners such as nails and rivets. (b) Sequence of operations to produce a bolt head by heading.

Other forging related process – Roll-Forging



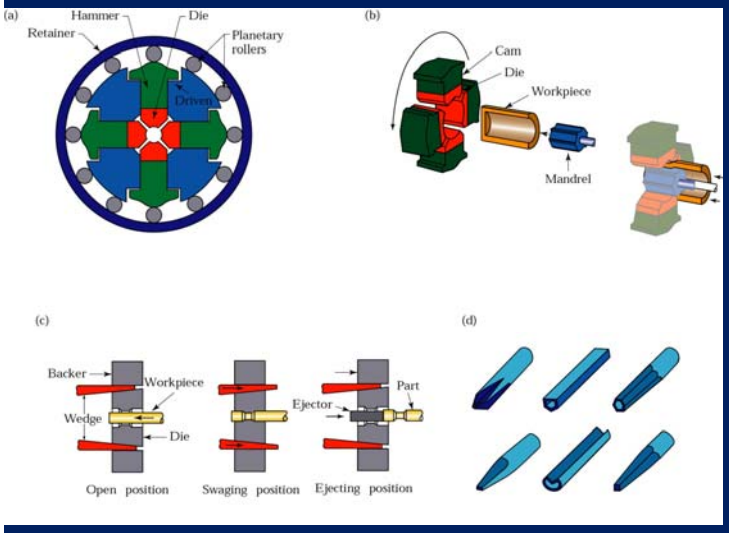
Two examples of the roll-forging operation, also known as *cross-rolling*. Tapered leaf springs and knives can be made by this process..

Other forging related process – Production of Bearing Blanks



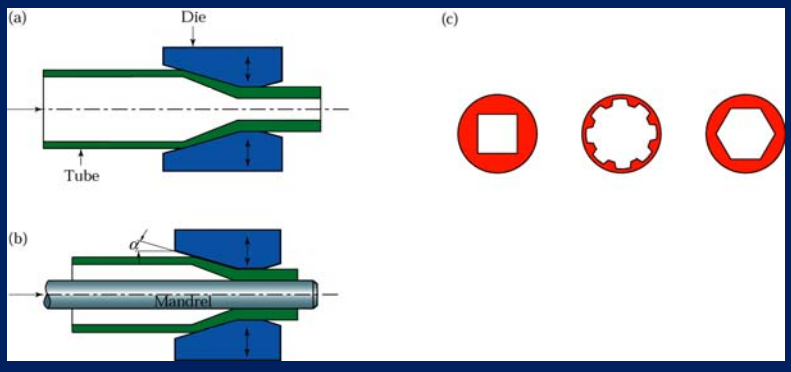
(a) Production of steel balls by the skew-rolling process. (b) Production of steel balls by upsetting a cylindrical blank. Note the formation of flash. The balls made by these processes are subsequently ground and polished for use in ball bearings (see Sections 25.6 and 25.10).

Other forging related process – Swaging



(a) Schematic illustration of the rotary-swaging process. (b) Forming internal profiles on a tubular workpiece by swaging. (c) A die-closing type swaging machine, showing forming of a stepped shaft. (d) Typical parts made by swaging.

Swaging of Tubes With and Without a Mandrel



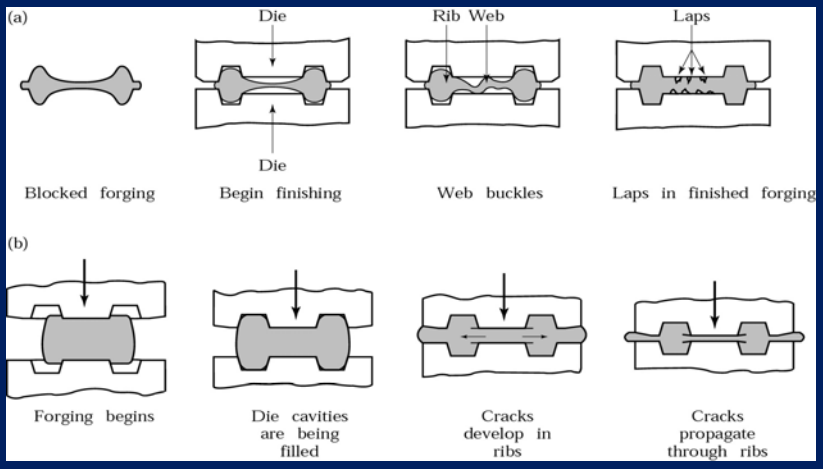
(a) Swaging of tubes without a mandrel; not the increase in wall thickness in the die gap. (b) Swaging with a mandrel; note that the final wall thickness of the tube depends on the mandrel diameter. (c) Examples of cross-sections of tubes produced by swaging on shaped mandrels. Rifling (spiral grooves) in small gun barrels can be made by this process.

Classification of Metals in Decreasing Order of Forgeablilty

TABLE 14.3

Metal or alloy	Approximate range of hot forging temperature (°C)
Aluminum alloys	400–550
Magnesium alloys	250–350
Copper alloys	600–900
Carbon and low–alloy steels	850–1150
Martensitic stainless steels	1100–1250
Austenitic stainless steels	1100–1250
Titanium alloys	700–950
Iron-base superalloys	1050–1180
Cobalt-base superalloys	1180–1250
Tantalum alloys	1050–1350
Molybdenum alloys	1150–1350
Nickel-base superalloys	1050–1200
Tungsten alloys	1200–1300

7. Defects in Forged Parts



Examples of defects in forged parts. (a) Labs 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.

Relative Unit Costs of a Small Connecting Rod

Relative unit costs of a small connecting rod made by various forging and casting processes. Note that, for large quantities, forging is more economical. Sand casting is the more economical process for fewer than about 20,000 pieces.