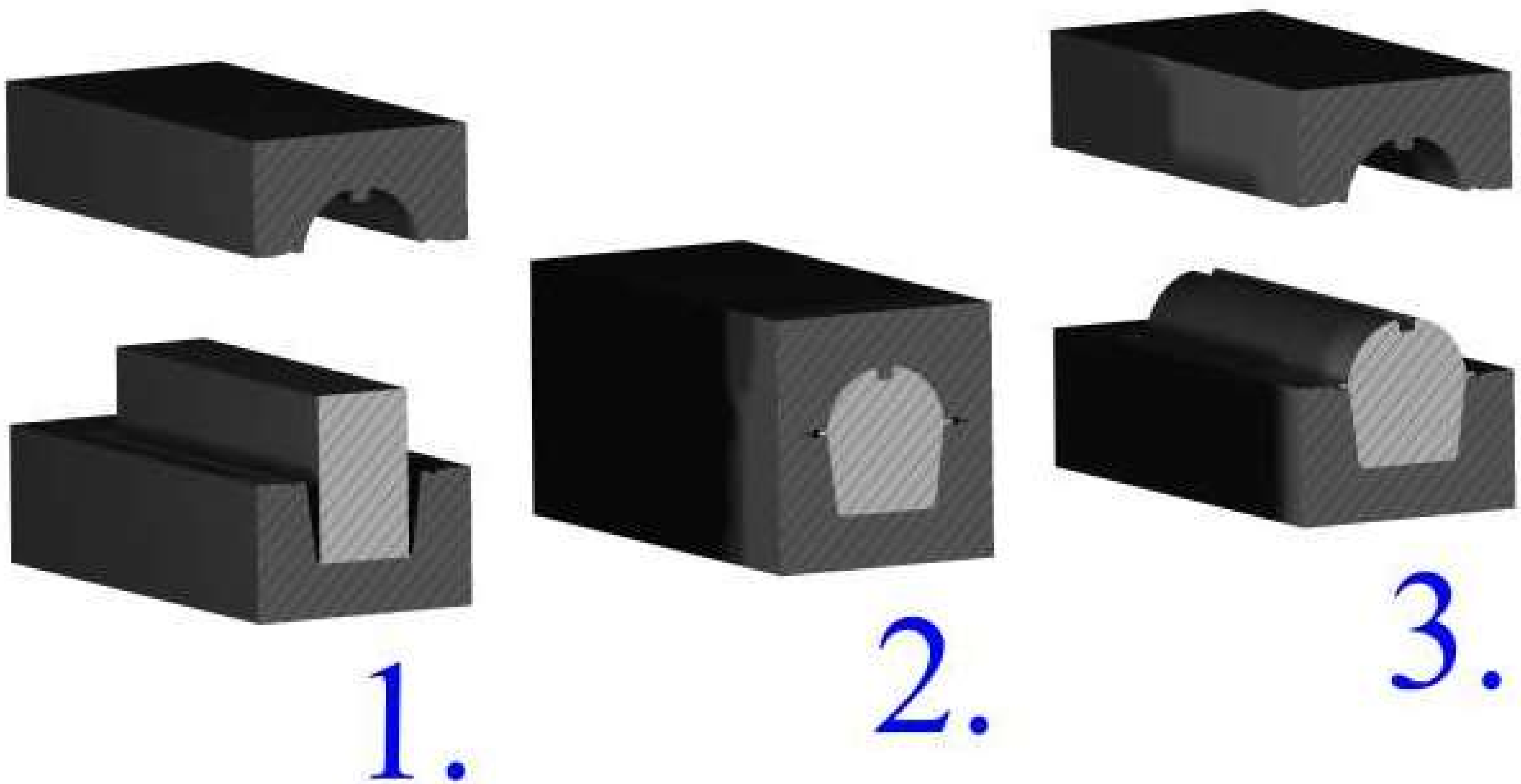
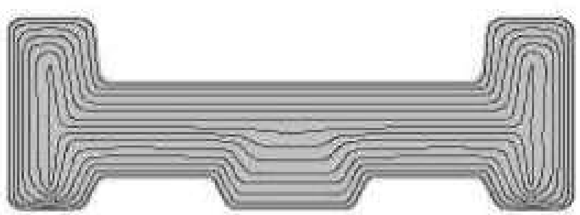
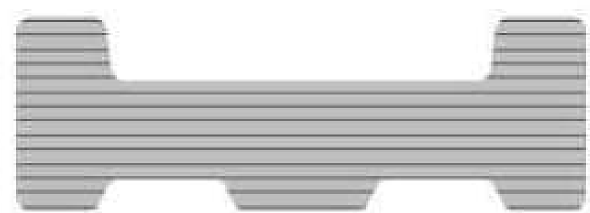
Forging Processes



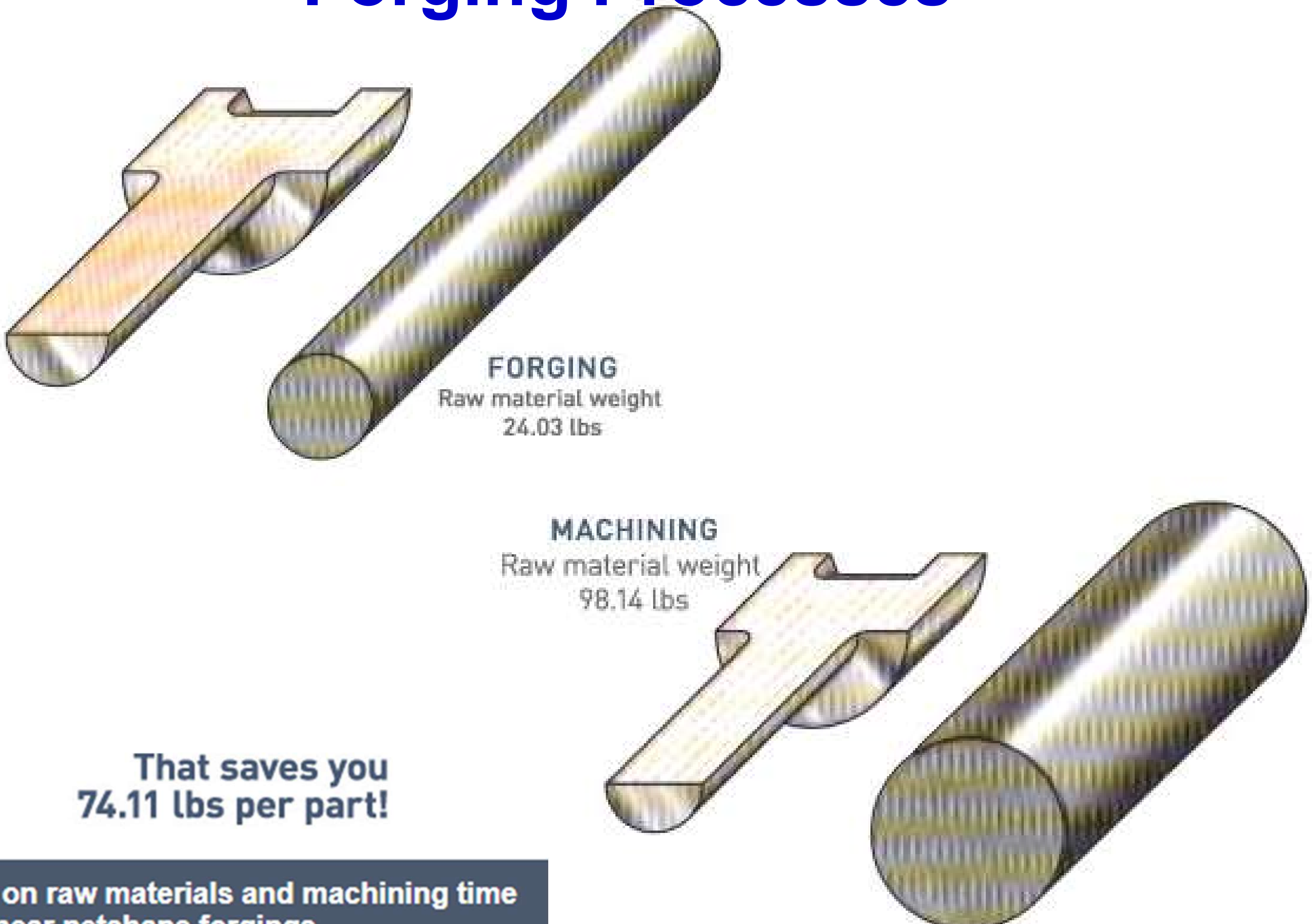


PART PRODUCED BY FORGING



SAME PART PRODUCED BY MACHINING

Forging Processes



That saves you
74.11 lbs per part!

Save on raw materials and machining time
with near netshape forgings

Forging Processes

Forging is the working of metal into useful shape by hammering or pressing.

Forging is a deformation processing of materials through compressive stress

In ancient times, people employed forging for making coins, jewelry, weapons

Typical applications of forging include bolts, disks, gears, turbine disk, crank shaft, connecting rod, valve bodies, small components for hydraulic circuits etc.

Forging Processes

Forging is carried out either hot or cold.

Hot forging is done at temperatures above recrystallization temperatures, typically 0.6 Tm, or above, where Tm is melting temperature.

Warm forging is done in the temperature range: 0.3 Tm to 0.5 Tm.

Cold forging has advantages such as good surface finish, high strength and greater accuracy. Hot forging requires lower loads, because flow stress gets reduced at higher temperatures. Strain rates in hot working may be high – 0.5 to 500 s-1. Strains in hot forging are also high – true strains of 2 to 4. Are common.

Forging Processes

Hot Forging

Advantages:

- High strain rates and hence easy flow of the metal
- Recrystallization and recovery are possible
- Forces required are less

Disadvantages of Hot Working:

- Lubrication is difficult at high temperatures
- Oxidation and scaling occur on the work
- Poor surface finish
- Dies must withstand high working temperature

Forging Processes

Cold Forging

Advantages:

- Less friction between die surface and work piece
- Lubrication is easy
- No oxidation or scaling on the work
- Good surface finish

Disadvantages of Hot Working:

- Low strain rates, hence less reduction per pass.
- Recrystallization and recovery do not occur.
- Hence, annealing is required for further deformation in subsequent cycles.
- Forces required are high

Classification of Forging Processes

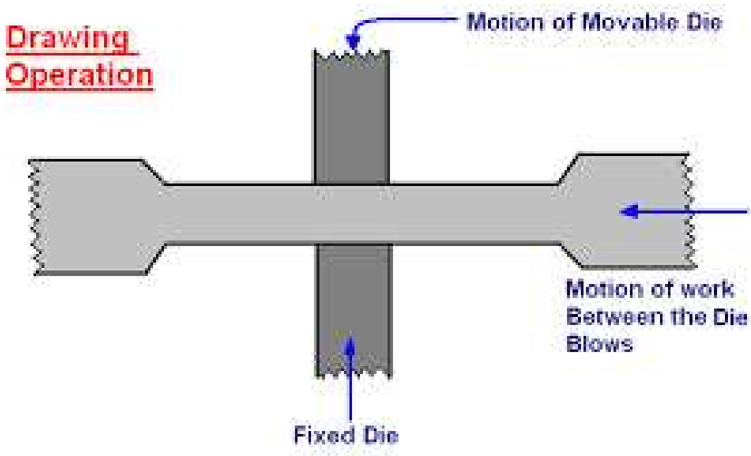
Based on the type of loading,

I. Hammer forging → involves impact load
II. Press forging→ involves gradual loads

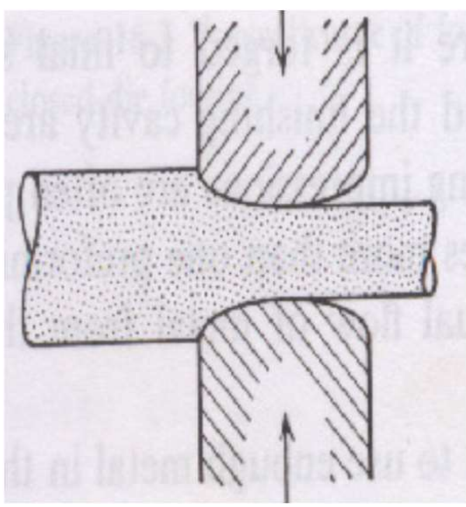
Based on the nature of material flow and constraint on flow by the die/punch,

I. Open die forging,
II. Impression die forging / Closed Die Forging
III. Flashless forging

Forging Operations



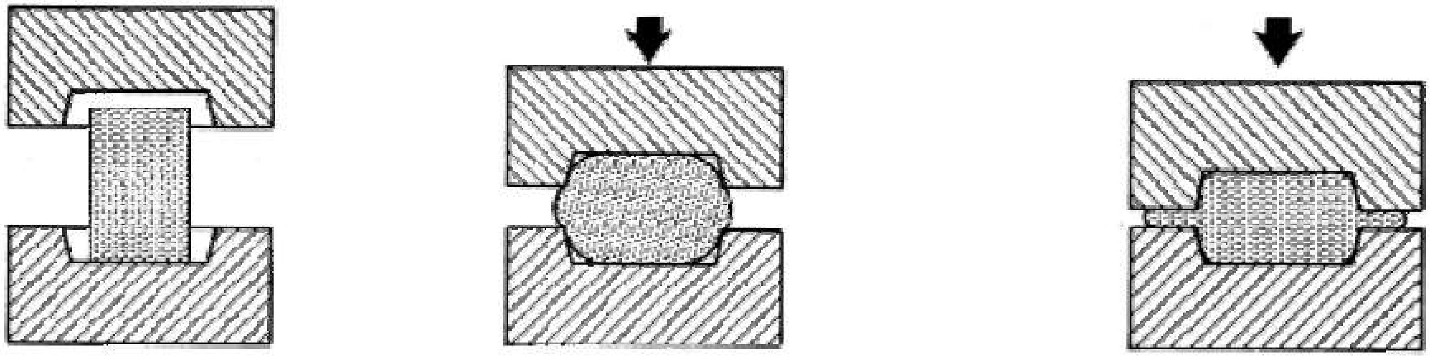
Drawing Operating



This is the operation in which metal gets elongated with a reduction in the cross sedation area.

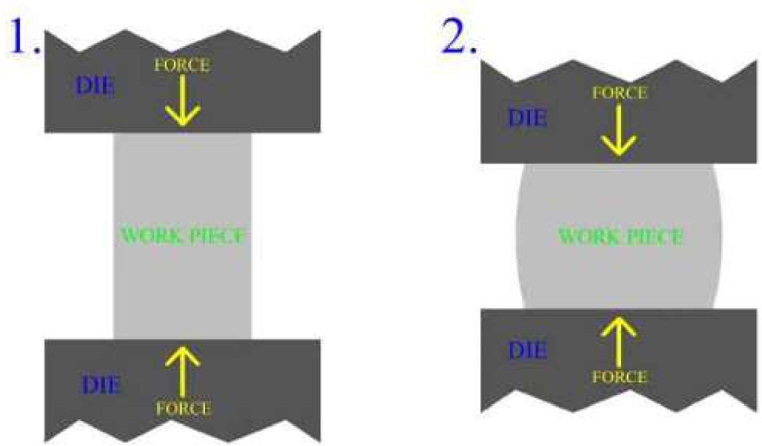
For this, a force is to be applied in a direction perpendicular to the length axis.

Forging Operations



Steps: (i) (ii) (iii) Final

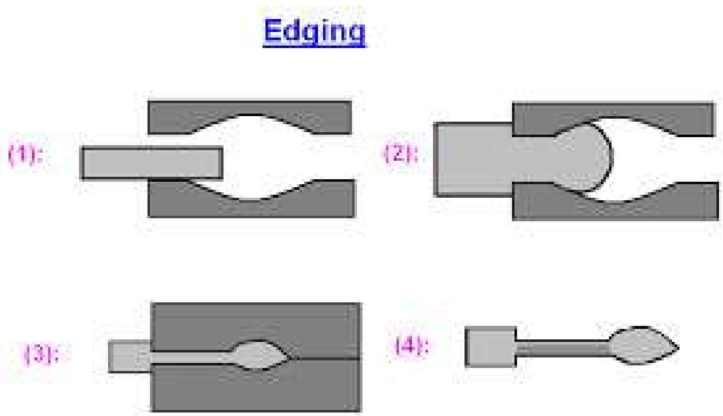
Upsetting Operating



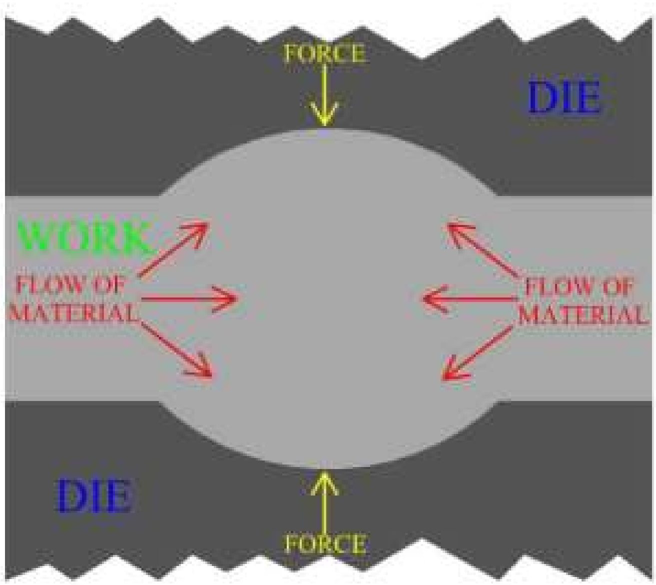
This is applied to increase the cross sectional area of the stock at the expanse of the length.

To achieve the length of upsetting force is applied in a direction parallel to the length axis, For example forming of a bolt head.

Forging Operations



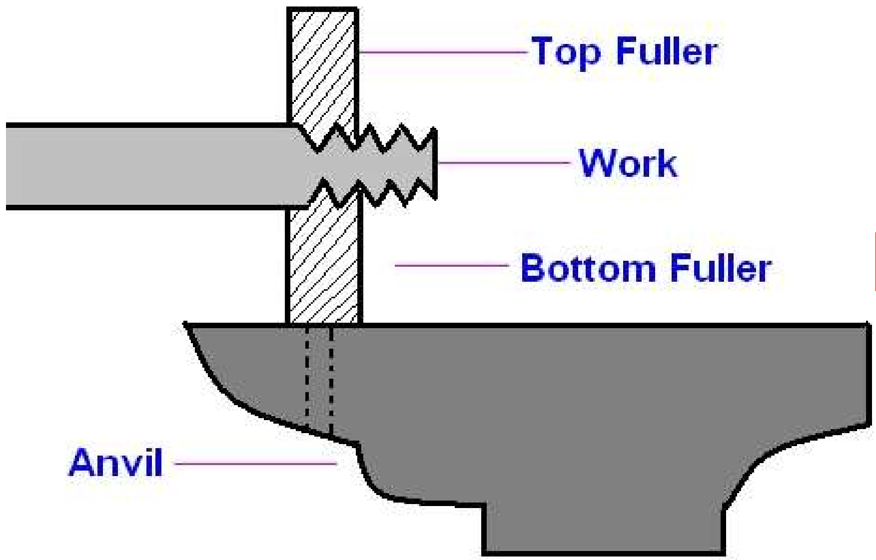
Edging



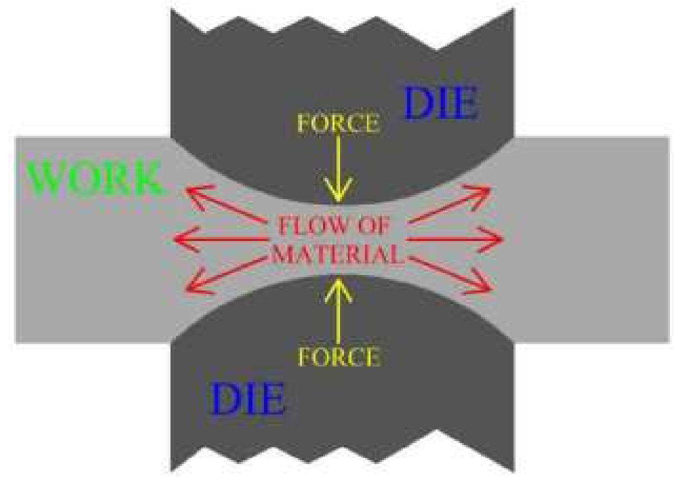
The ends of the bar are shaped to requirement using edging dies.

Edging is frequently as primary drop forging operation

Forging Operations



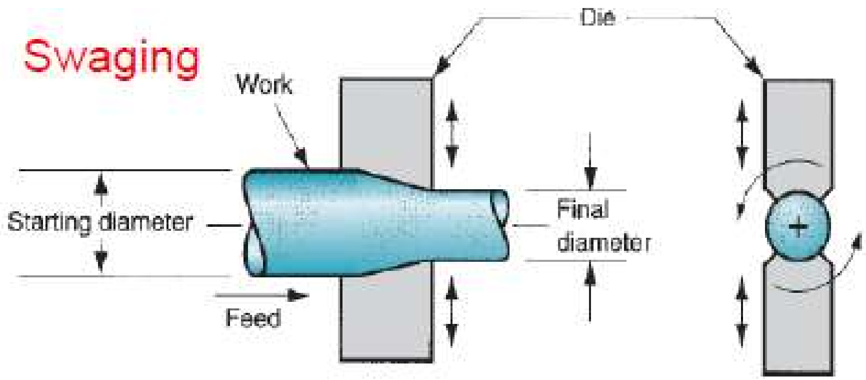
Fullering



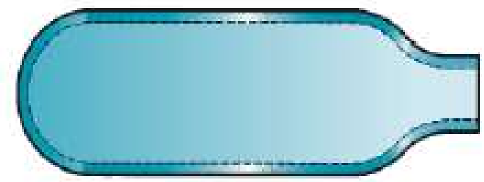
The cross sectional area of the work reduces as metal flows outward, away from center.

The fuller is a forging tool, used to spread the metal. The fuller is placed against the metal stock, and then either the fuller (for an upper fuller) or the stock (for a lower fuller) is struck with a hammer

Forging Operations



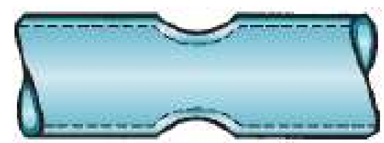
Swaging



Swaging the edge of a cylinder

Diameter reduction of solid work

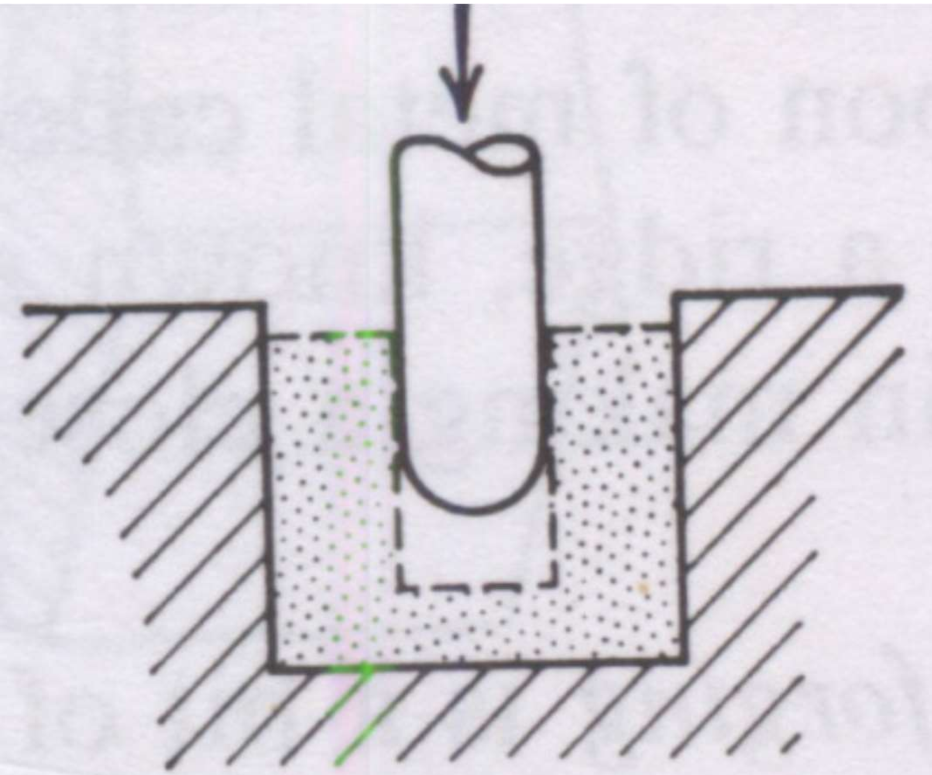
Tube tapering



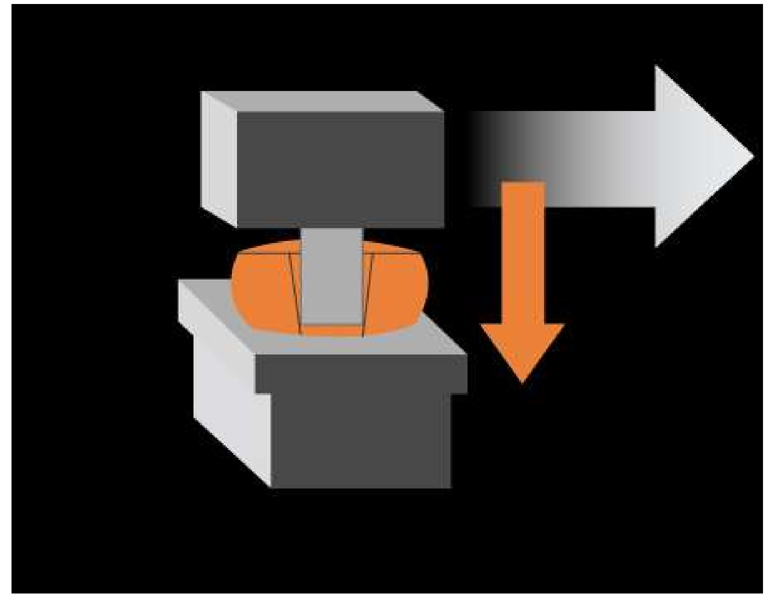
Swaging to form a groove on the tube

Swaging is used to reduce the diameter of a tube or a rod at the end of the work piece to create a tapered section.

Forging Operations

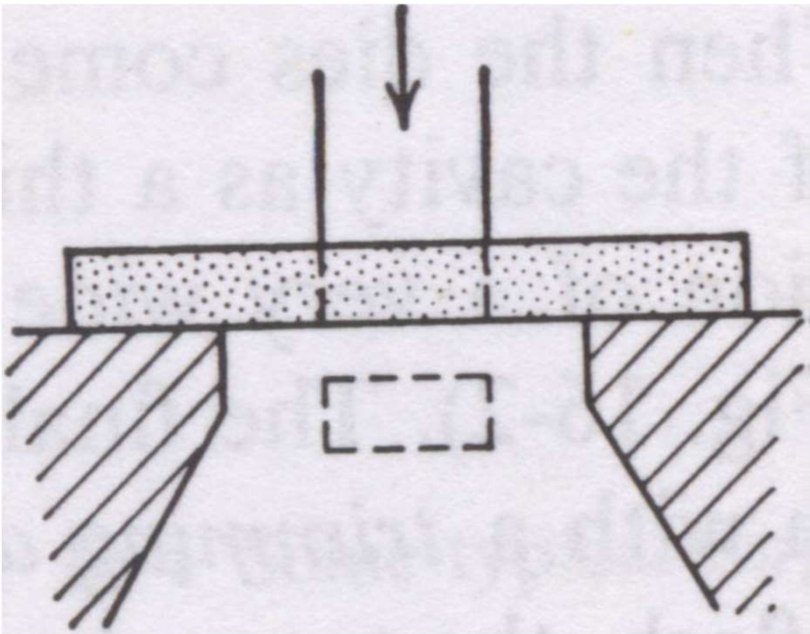


Piercing

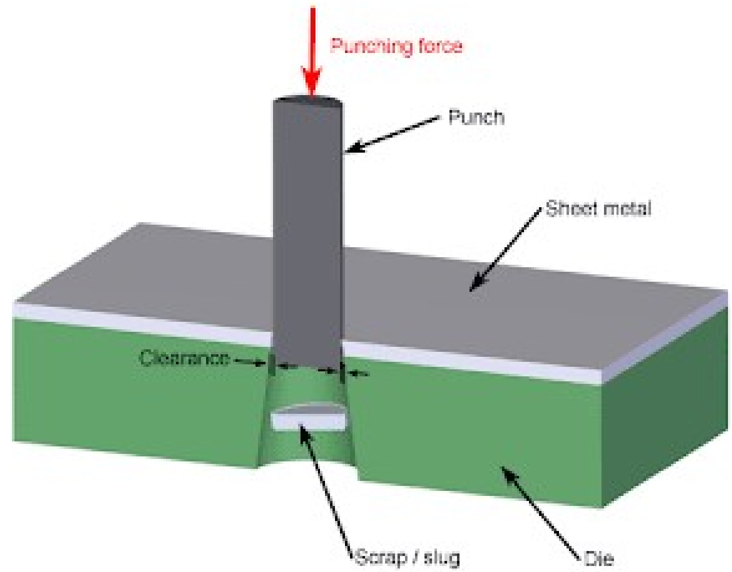


The metal flows around the die cavity as a moving die pierces the metal

Forging Operations



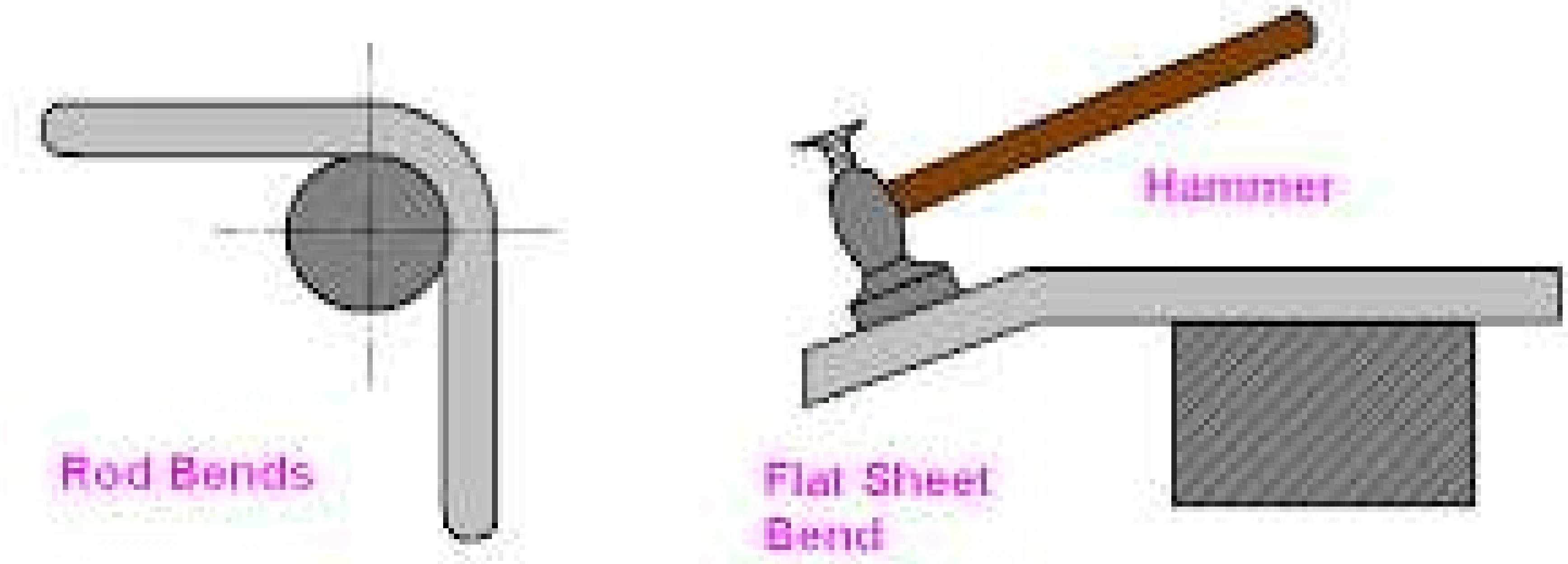
Punching



It is a cutting operation in which a required hole is produced using a punching die

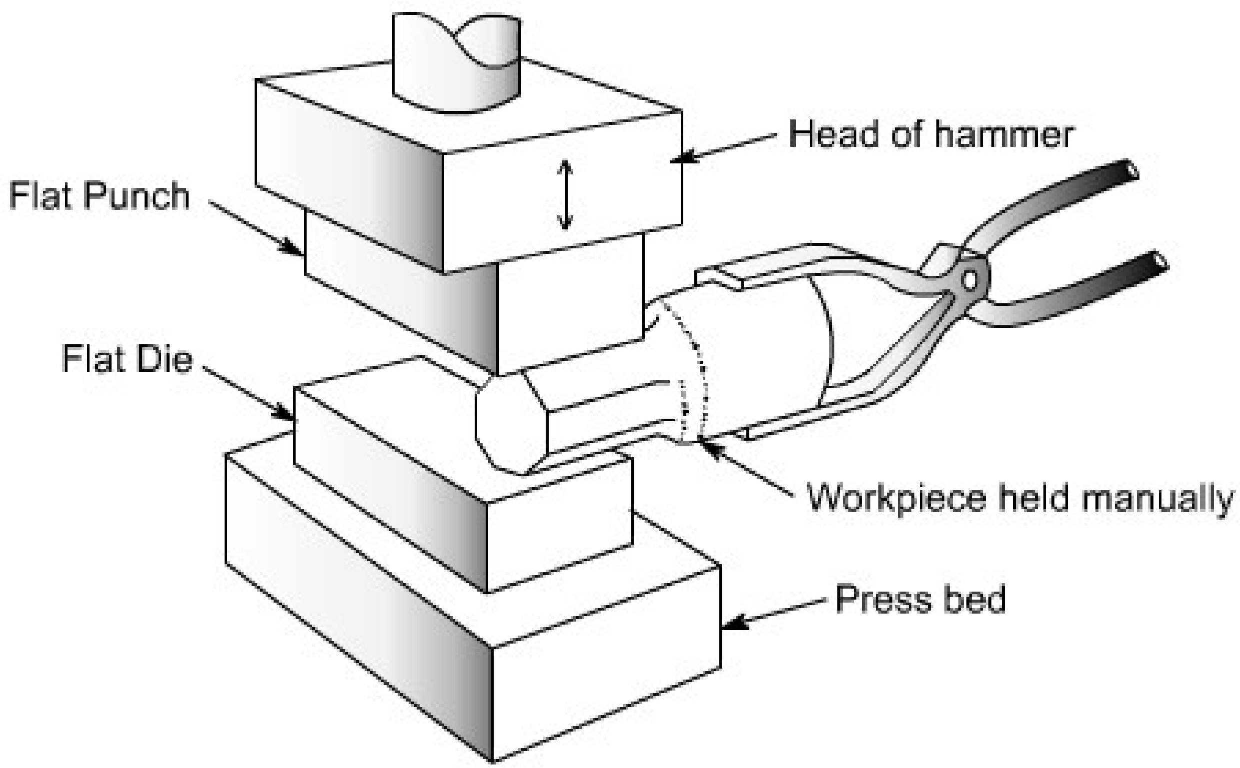
Forging Operations

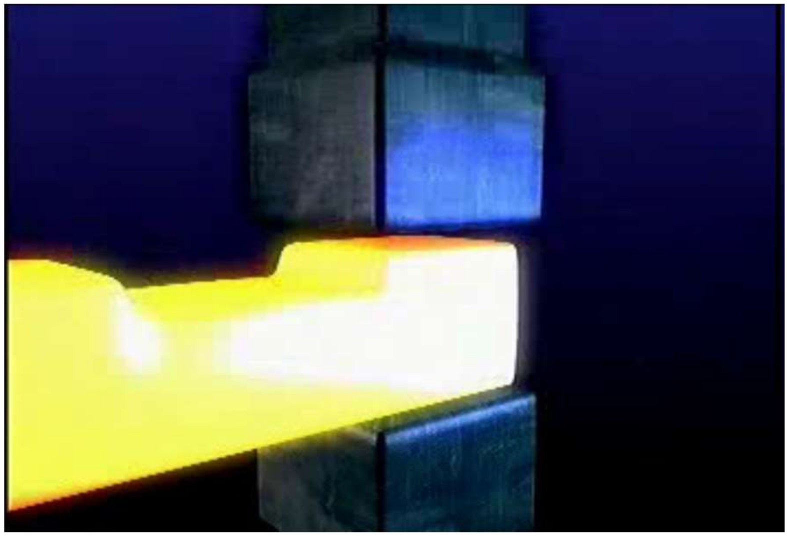
Bending



The metal is bent around a die/anvil

Open Die Forging



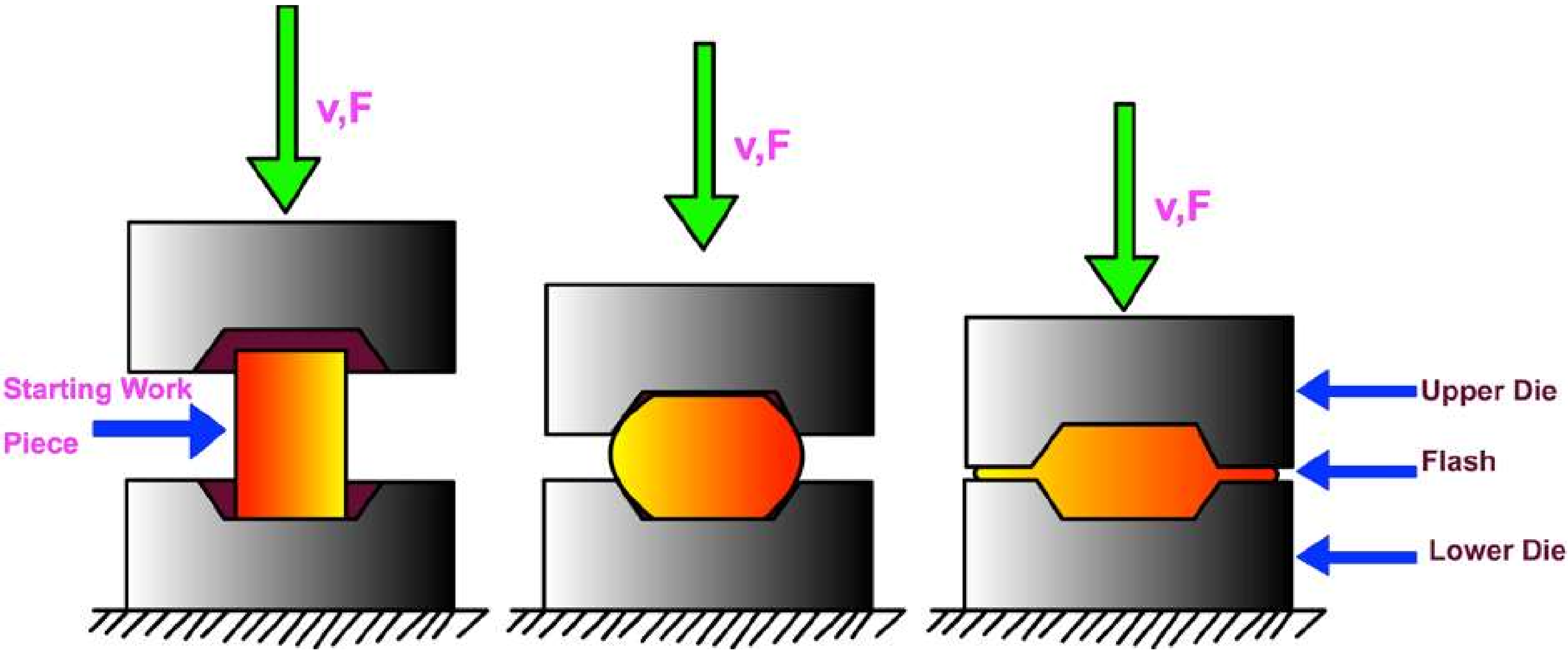


Open Die Forging

Features of open die forging:

- Repeated impact blows are given on the work
- Less dimensional accuracy
- Suitable only for simple shapes of work
- Requires more skill of the operator
- Usually used for a work before subjecting it to closed die forging (to give approximate shape)
- Dies are simple and less expensive
- It can be analyzed much easily
- It is the simplest of all forging operations

Closed Die Forging



Work piece is deformed between two dies with impressions (cavities) of the desired final shape on them.

Closed Die Forging

Closed die forging involves two or more steps:

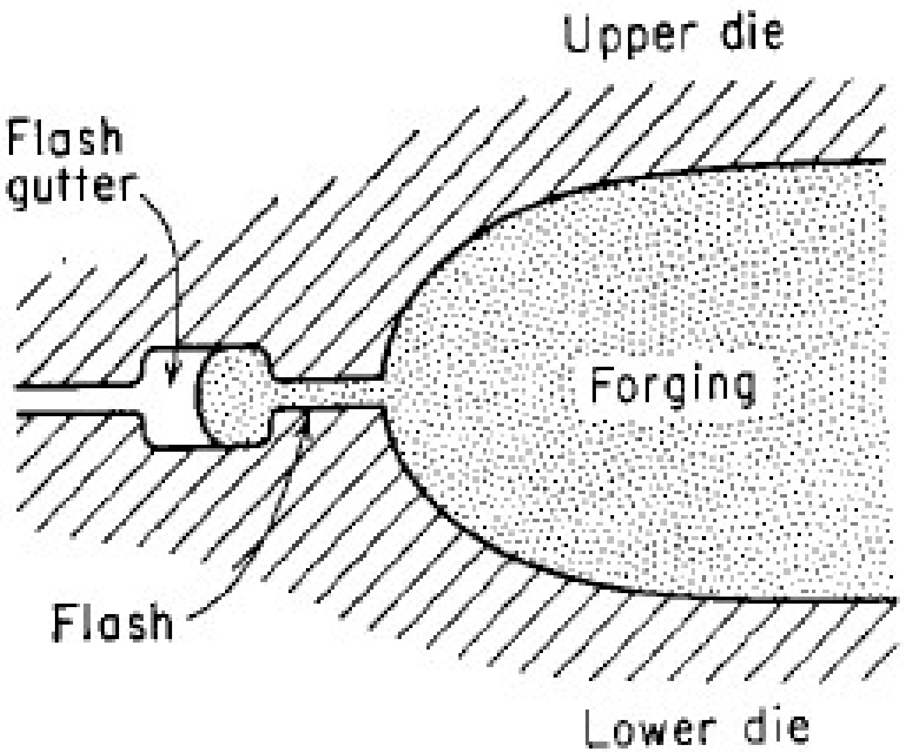
i) Blocking Die: Work is rough forged, close to final shape.

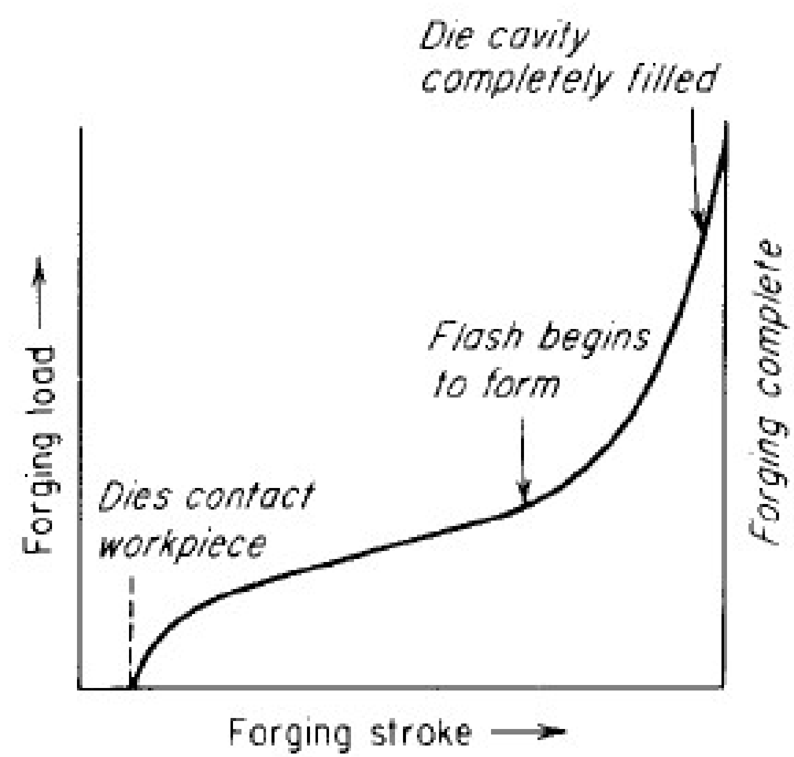
ii) Finishing Die: work is forged to final shape and dimensions.

- Both Blocking Die and Finishing Die are machined into the same die block.
- More number of dies are required depending on the complexity of the job.
- Two die halves close-in & work is deformed under high pressure.
- High dimensional accuracy / close control on tolerances.
- Suitable for complex shapes.
- Dies are complex and more expensive.
- Large production rates are necessary to justify high costs.

Closed Die Forging

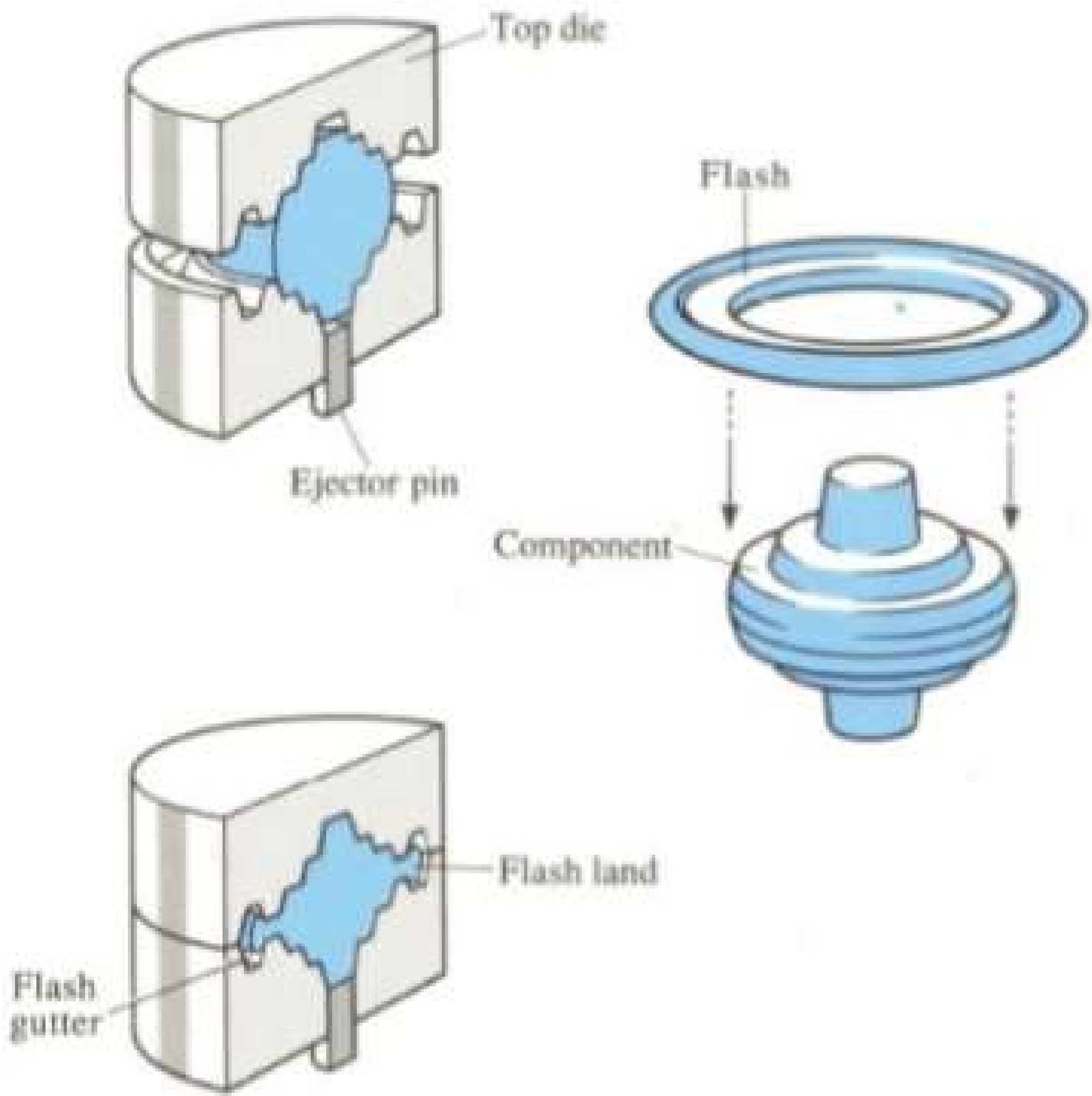
Significance of Flash in Closed Die Forging:





Closed Die Forging

Significance of Flash in Closed Die Forging:



Closed Die Forging

Purposes of Flash

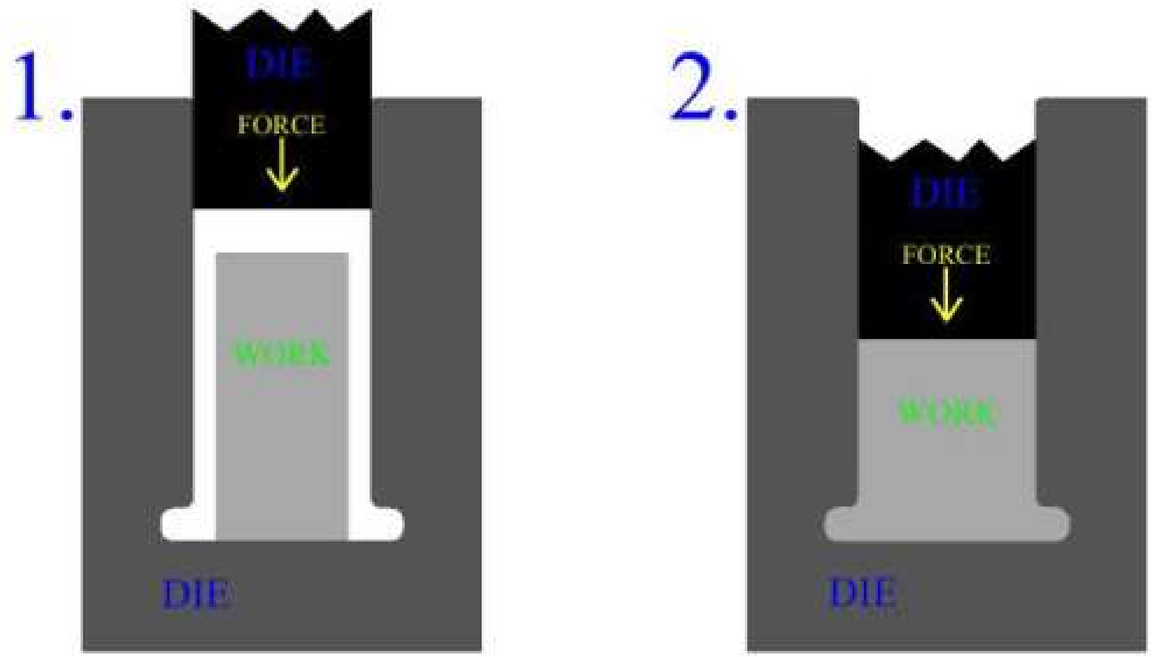
- Flash regulates the escape of metal and thus thin flash increases the flow resistance of the system so that the pressure builds up to high values to ensure that metal fills all recesses of the die cavity.
- Flash acts as a 'safety valve' for excess metal in the closed die cavity.

Closed Die Forging

Significance of Flash in Closed Die Forging:

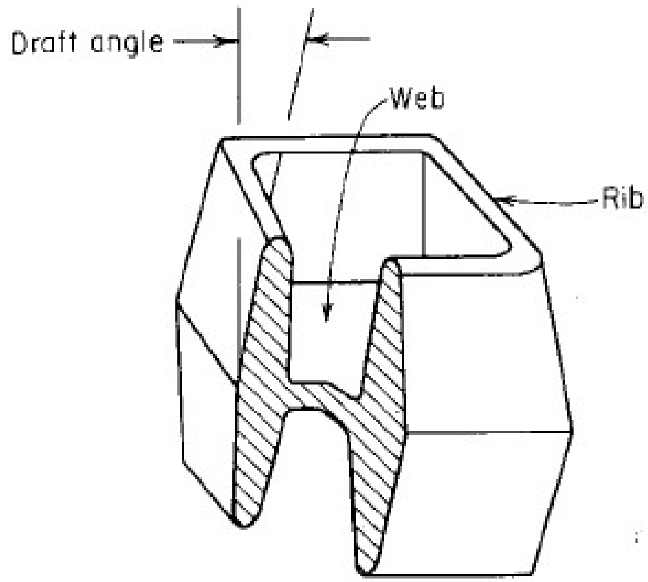
- Excess metal is taken initially to ensure that die is completely filled with metal to avoid any voids.
- Excess metal is squeezed out of the die cavity as a thin strip of metal, called flash.
- A flash gutter is provided to reduce the area of flash.
- Thin flash increases the flow resistance of the system & builds up the pressure to high values which ensures that all intricate shapes of cavity are filled.
- Flash design is very critical and important step in closed die forging.
- Extremely thin flash results in very high pressure build up which may lead to breaking of the dies.

Flashless Forging



Flashless forging is a type of precision forging process in which the entire volume of the work metal is contained within the die and no material is allowed to escape during the operation. Since no material can leave the mold as the part is forged, no flash is formed. Like other precision forging processes, flashless forging has rigorous process control demands, particularly in the amount of material to be used in the work piece. Too little material and the die will not fill completely, too much material will cause a dangerous build up of forces

Typical Forging Nomenclature



The metal flow is greatly influenced by the part geometry. Spherical or blocklike shapes are easiest to forge in impression dies. Shapes with thin and long sections or projections (ribs and webs) are more difficult because they have higher surface area per unit volume, and therefore friction and temperature effects are enhanced. It is particularly difficult to produce parts with sharp fillets, wide thin webs, and high ribs (Fig. 16-4). Moreover, forging dies must be tapered to facilitate removal of the finished piece. This *draft allowance* is approximately 5° for steel forgings.

Typical Forging Nomenclature

Die preheating may be required to prevent the die chilling effect which may increase the flow stress on the periphery of the billet. As a result, incomplete filling or cracking of the preform may occur

Dimensional tolerances in impression die forging may be as close as ±0.5% of the dimensions of the forged part.
In case of hot forging, dimensional accuracy is less.

Some of the factors such as die surface finish, draft allowance, accuracy of die impression dimensions, die wear, lubrication etc control the quality of finished product.

Forging Machine

– Based on principles of operation

Forging Hammers

- ✓ Board Hammers
- ✓ Power Hammers

Force is supplied by falling of weight / ram

Forging Presses

- ✓ Mechanical Presses
- ✓ Hydraulic Presses

Presses deliver energy through a force that acts over a distance or stroke.

Forging Machine

Forging Hammers

✓ Board Hammers

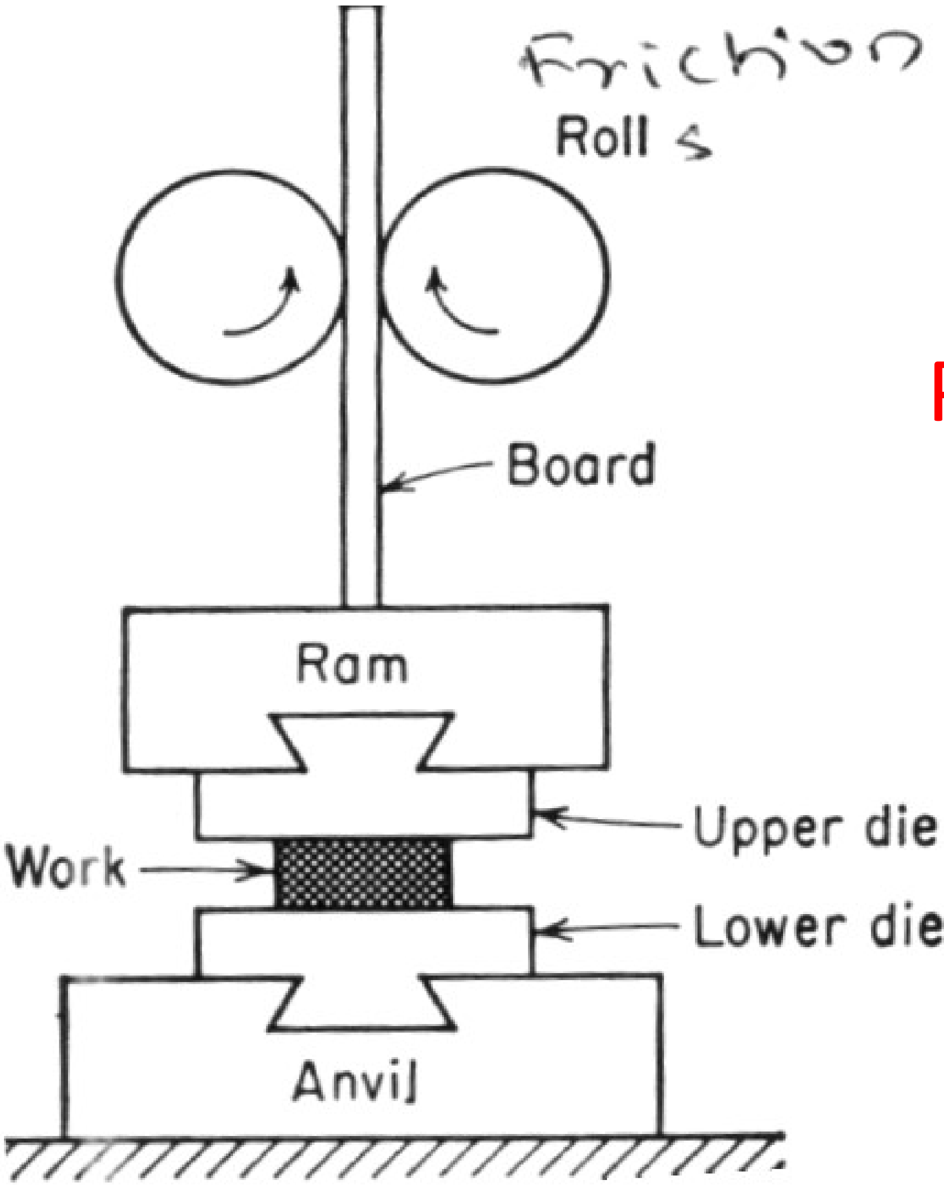
✓ Power Hammers

Force is supplied by falling of weight / ram

Energy restricted machines since the deformation results from dissipating the kinetic energy

Forging Hammers

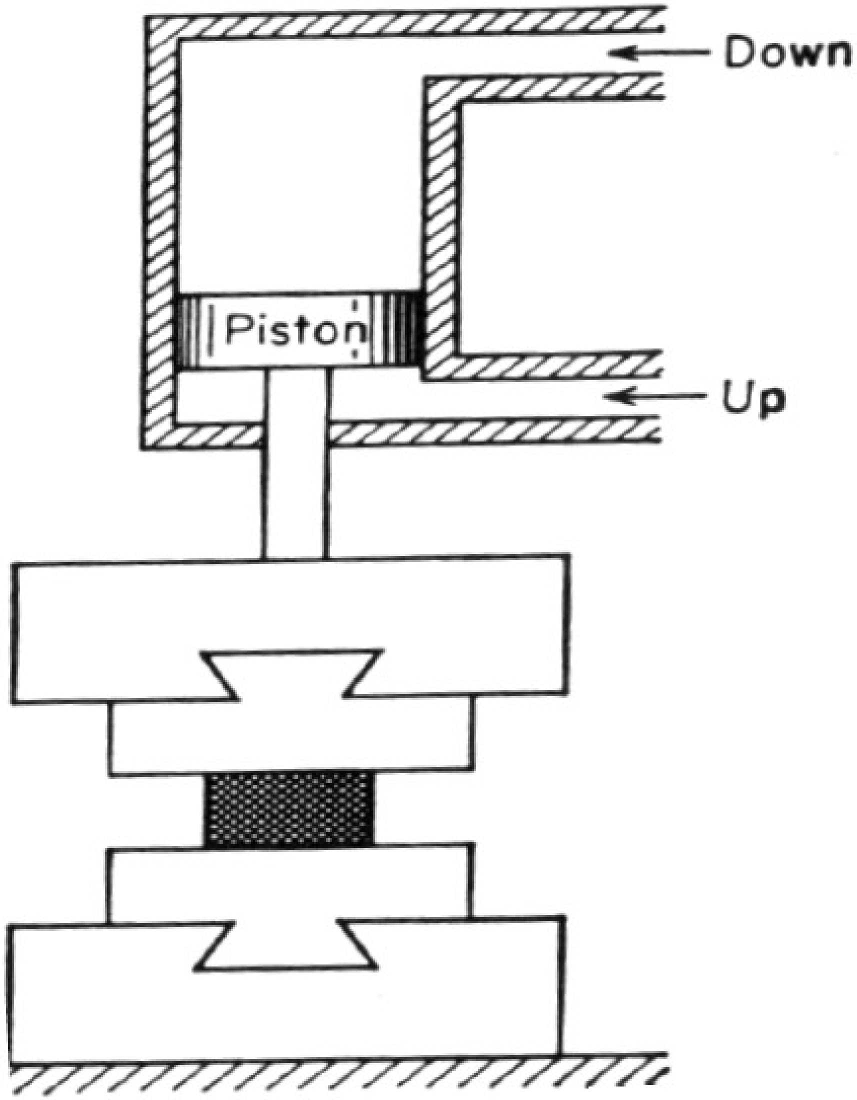
Board Hammers



Potential Energy = mgh

Forging Hammers

Power Hammers



The total energy supplied in a blow:

It is given by : $W = 1/2mv^2 + pAH = (mg + pA)$

Where m= mass of ram

v= velocity of ram at the start of deformation

g= acceleration due to gravity

p= air/ steam pressure on ram on down stroke

A= area of ram cylinder

H= height of ram drop

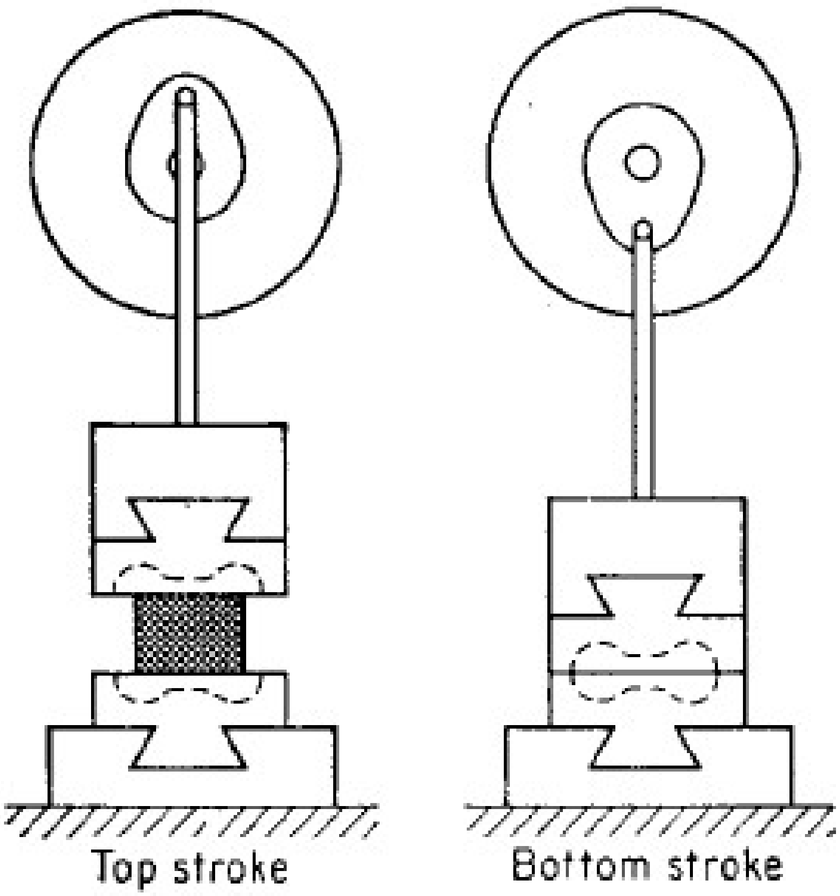
Forging Machine

Mechanical Presses

Stroke restricted machines since length of the press stroke and available load at various positions of the stroke represent the energy

Forging Machine

Mechanical Presses



Crank press

$$W = \frac{1}{2} I(\omega_0^2 - \omega_f^2)$$

where I = moment of inertia of the flywheel

ω = angular velocity, (ω_0 initially; ω_f after deformation) rad s^{-1}

Forging Machine

Hydraulic Presses

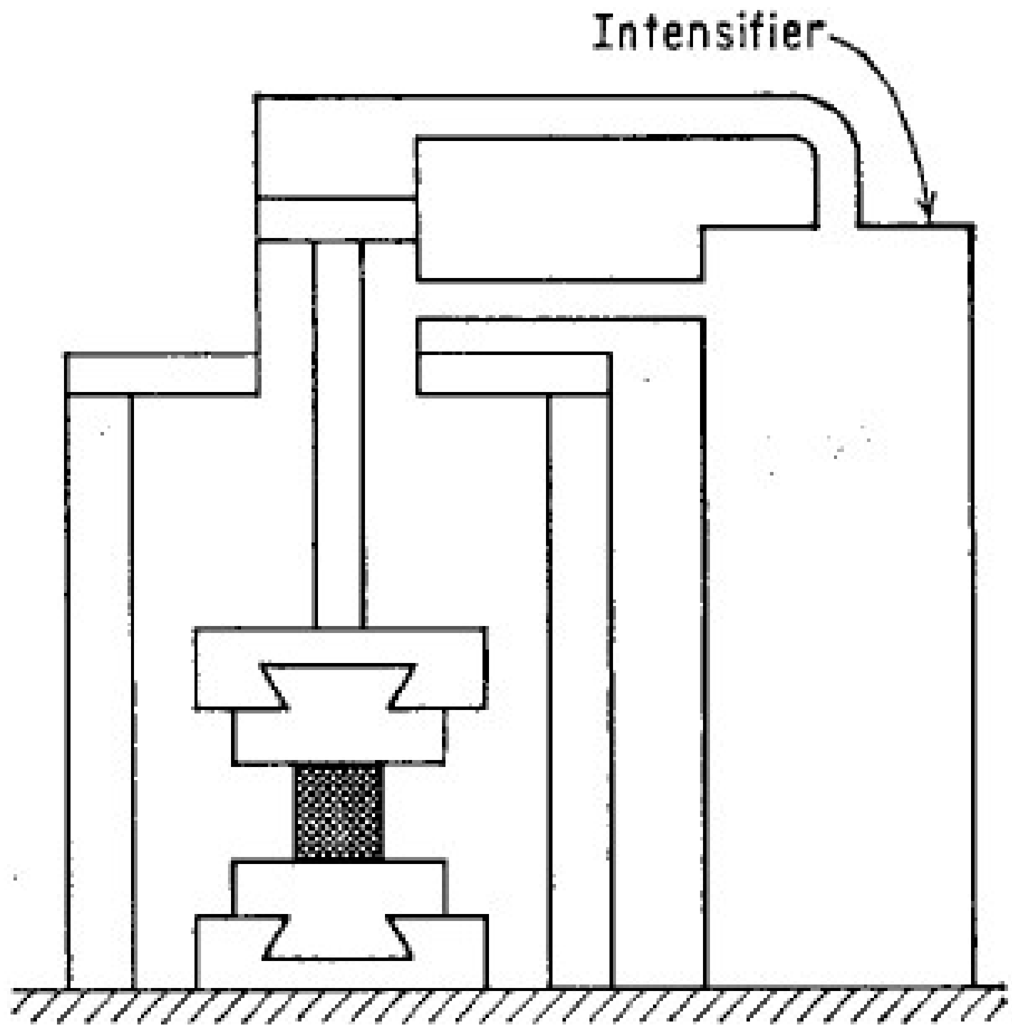
Load restricted machines since their capability for carrying out a forming operation is limited chiefly by maximum load capacity

Forging Machine

Hydraulic Presses

- It has more of squeezing action than hammering

- Hence dies can be smaller and have longer life than with a hammer. than with a hammer. than with a hammer.



Hydraulic press

Calculation of Forging Load

Prediction of forging load and pressure in a closed-die forging operation is quite a difficult calculation.

Three Approaches

(i) Forging load required for a new part from information available form previous forgings of the same materials and similar shape

(ii) Empirical Approach

(iii) Slab Analysis

Calculation of Forging Load

Empirical Approach

Schey[1] has expressed the forging load as

$$P = \bar{\sigma} A_t C_1 \tag{16-23}$$

where A_t = cross-sectional area of the forging at the parting line, including the flash

C_1 = a constraint factor which depends on the complexity of the forging. C_1 has a value of 1.2 to 2.5 for upsetting a cylinder between flat dies. C_1 varies from 3 to 8 for closed-die forging of simple shapes with flash and from 8 to 12 for more complex shapes

$\bar{\sigma}$ significant, or effective, true stress

Forging Defects

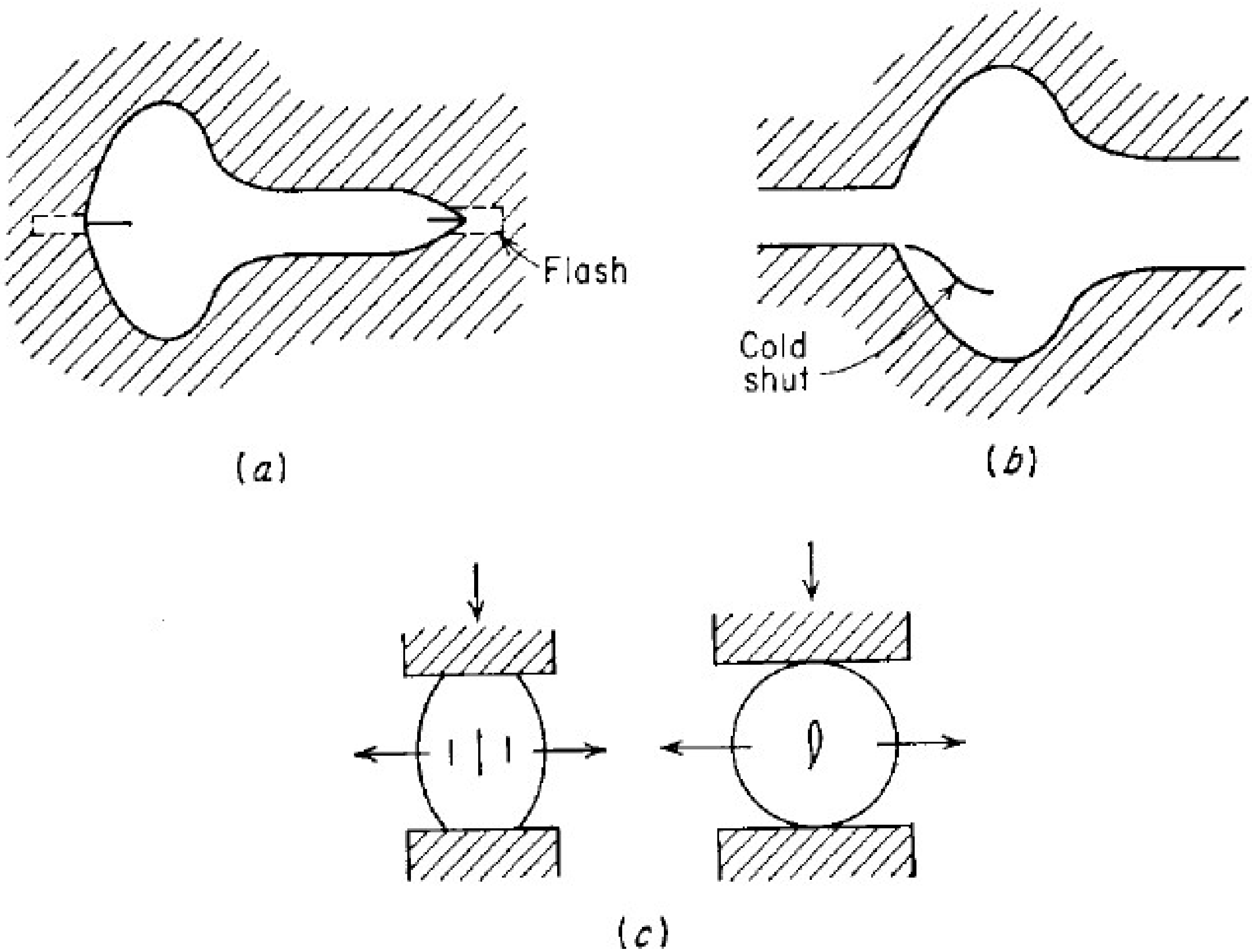


Figure 16-11 Typical forging defects. (*a*) Cracking at the flash; (*b*) cold shut or fold; (*c*) internal cracking due to secondary tensile stresses.

Forging Defects

1) Incomplete forging penetration:

Dendritic ingot structure at the interior of forging is not broken. Actual forging takes place only at the surface.

Cause- Use of light rapid hammer blows

Remedy- To use forging press for full penetration.

2) Surface cracking:

Cause- Excessive working on the surface and too low temperature. Or result of Hot Shortness

Remedy- To increase the work temperature

3) Cracking at the flash:

This crack penetrates into the interior after flash is trimmed off.

Cause- Very thin flash

Remedy- Increasing flash thickness, relocating the flash to a less critical region of the forging, hot trimming and stress relieving.

Forging Defects

4) Cold shut (Fold):

Two surfaces of metal fold against each other without welding completely.

Cause- Sharp corner (less fillet), excessive chilling, high friction

Remedy- Increase fillet radius on the die.

5) Unfilled Section (Unfilling/Underfilling):

Some section of die cavity not completely filled by the flowing metal.

Cause- Improper design of the forging die or using forging techniques, less raw material, poor heating.

Remedy- Proper die design, Proper raw material and Proper heating.

6) Die shift (Mismatch): Misalignment of forging at flash line.

Cause- Misalignment of the die halves.

Remedy- Proper alignment of die halves. Make mistake proofing for proper alignment for eg. provide half notch on upper and lower die so that at the time of alignment notch will match each other. Figure

Forging Defects

7) Scale Pits (Pit marks):

Irregular depurations on the surface of forging.

Cause- Improper cleaning of the stock used for forging. The oxide and scale gets embedded into the finish forging surface.

Remedy- Proper cleaning of the stock prior to forging.

8) Flakes:

These are basically internal ruptures.

Cause- Improper cooling of forging. Rapid cooling causes the exterior to cool quickly causing internal fractures.

Remedy- Follow proper cooling practices.

9) Improper grain flow:

Cause- Improper die design, which makes the metal not flowing in final interred direction.

Remedy- Proper die design.

10) Residual stresses in forging:

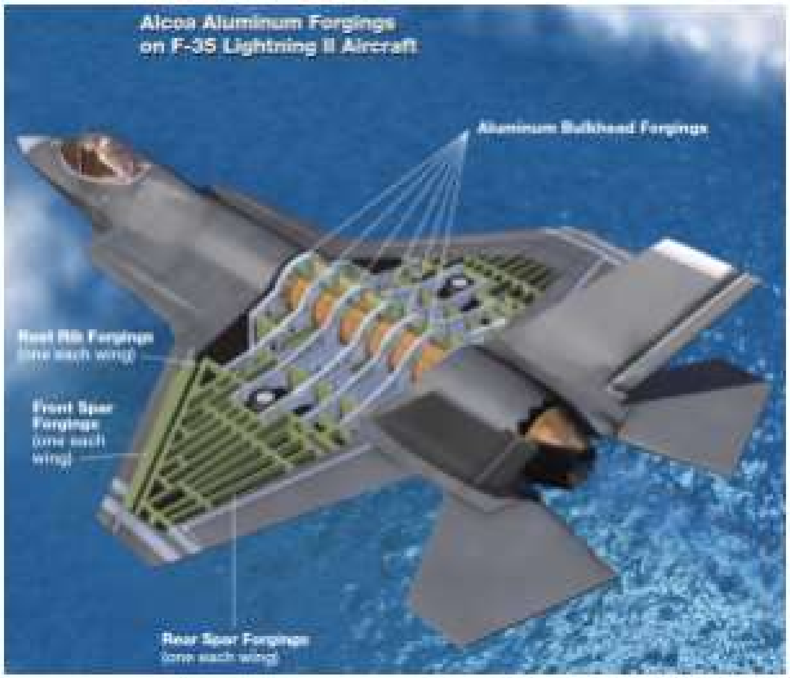
Cause- Inhomogeneous deformation and improper cooling (quenching) of forging.

Remedy- Slow cooling of the forging in a furnace or under ash cover over a period of time.

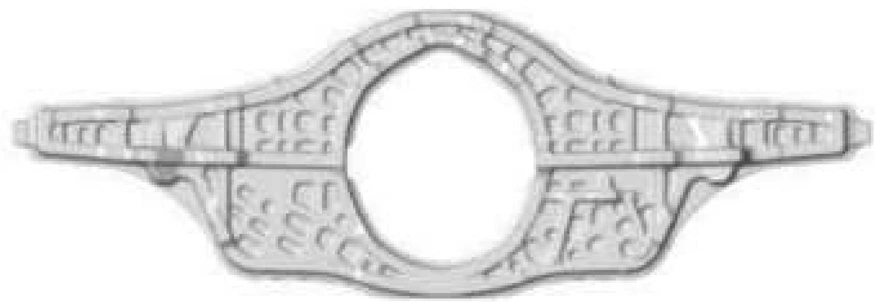
Forging Defects

The deformation produced by forging results in a certain degree of directionality to the microstructure in which second phases and inclusions are oriented parallel to the direction of greatest deformation. When viewed at low magnification, this appears as *flow lines*, or *fiber structure*. The existence of a fiber structure is characteristic of all forgings and is not to be considered as a forging defect. However, as was discussed in Sec. 8-15, the fiber structure results in lower tensile ductility and fatigue properties in the direction normal to it (transverse direction). To achieve an optimum balance between the ductility in the longitudinal and transverse directions of a forging, it is often necessary to limit the amount of deformation to 50 to 70 percent reduction in cross section.

Forging Application



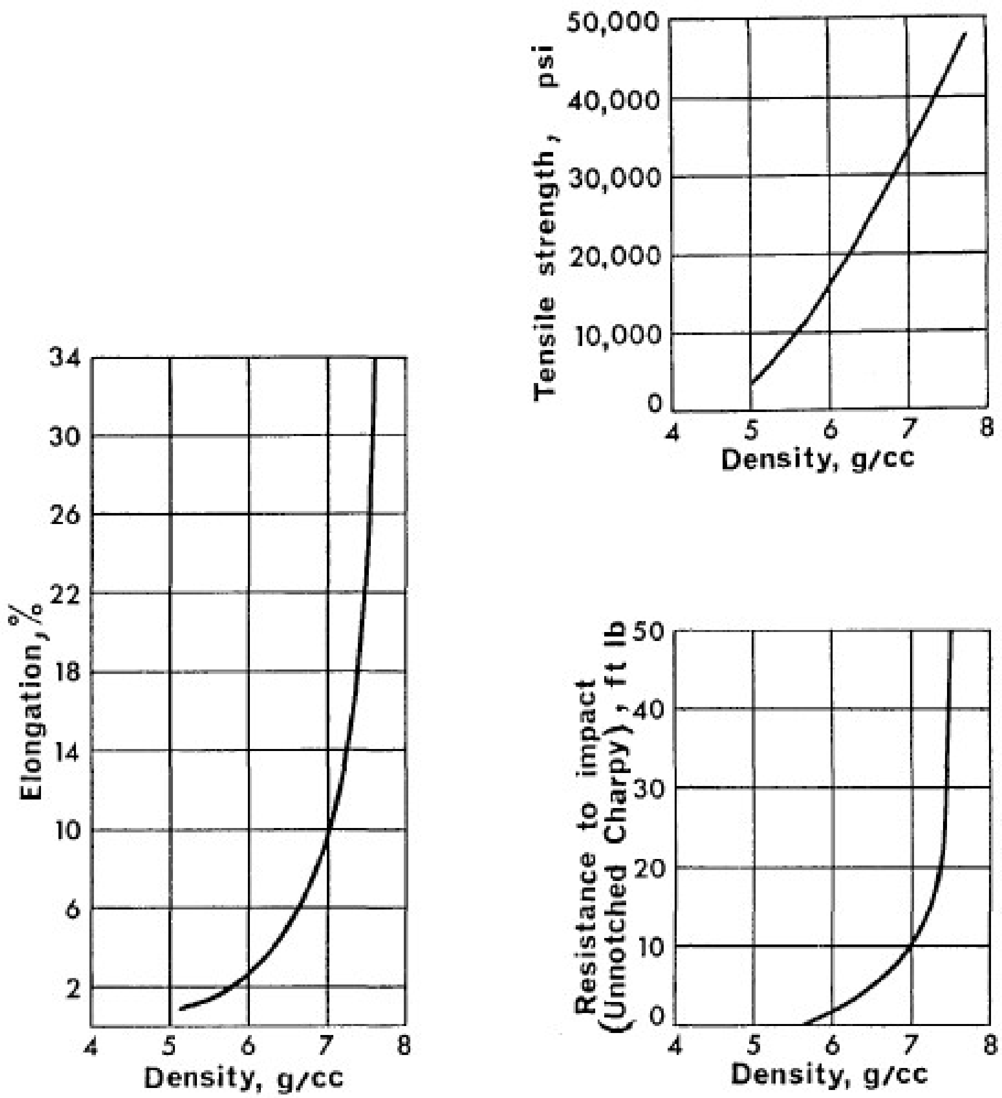
Cut-away of F-35 showing large single-piece bulkheads, frames, and spars made from forgings



STOVL 496 bulkhead, 19.6 x 6.5 ft

Forging for a single piece bulkhead on F-35 variant with short takeoff and vertical landing capability

Powder Metallurgy Forging



[*Courtesy Amer. Inst. Min. Met. Eng.*

Fig. 3. The relationship of properties and sintered density for iron powders. (*After Squire.*[8])

Powder Metallurgy Forging

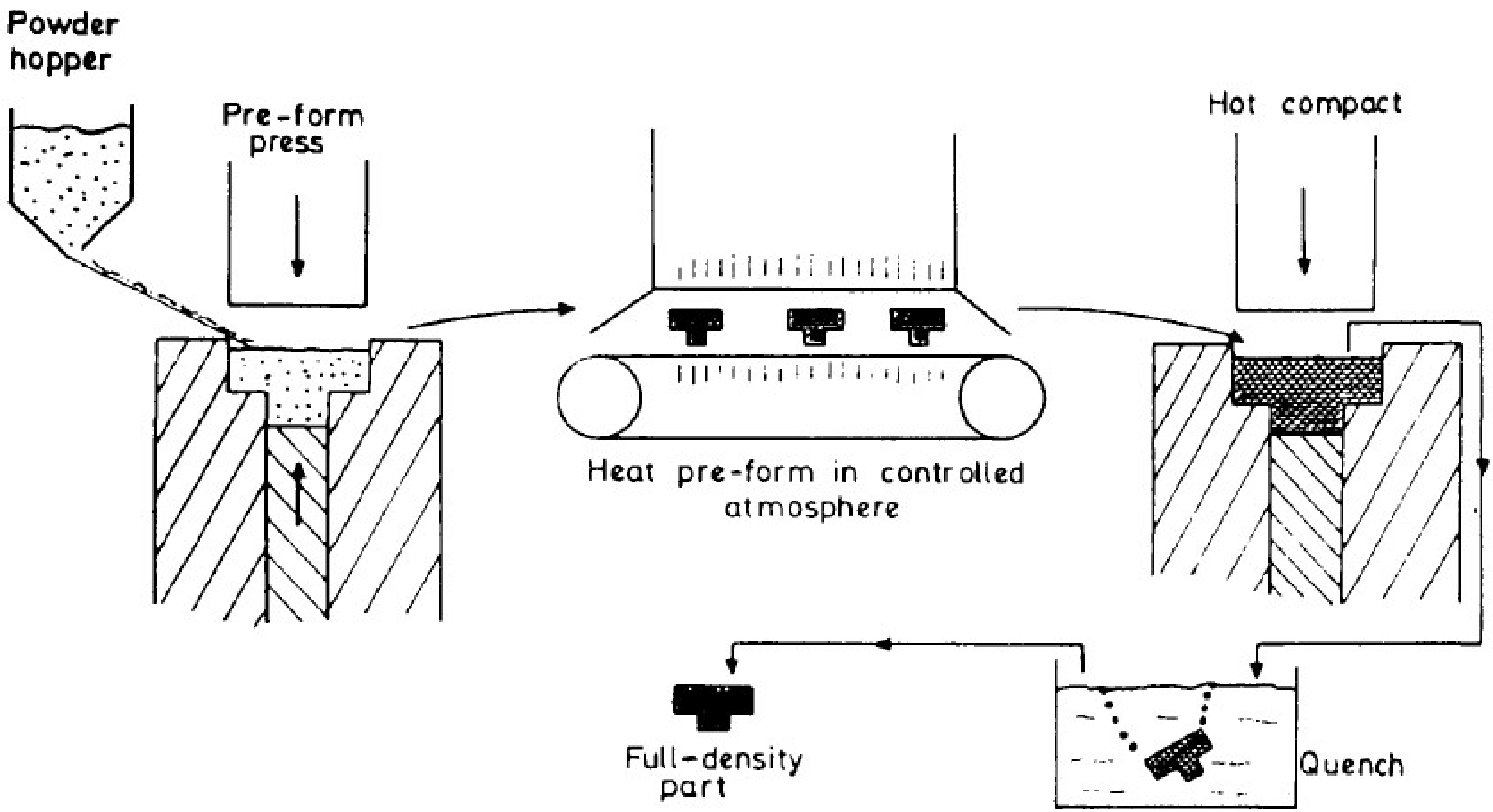


Fig. 4. Schematic route for powder forging.

Powder Metallurgy Forging

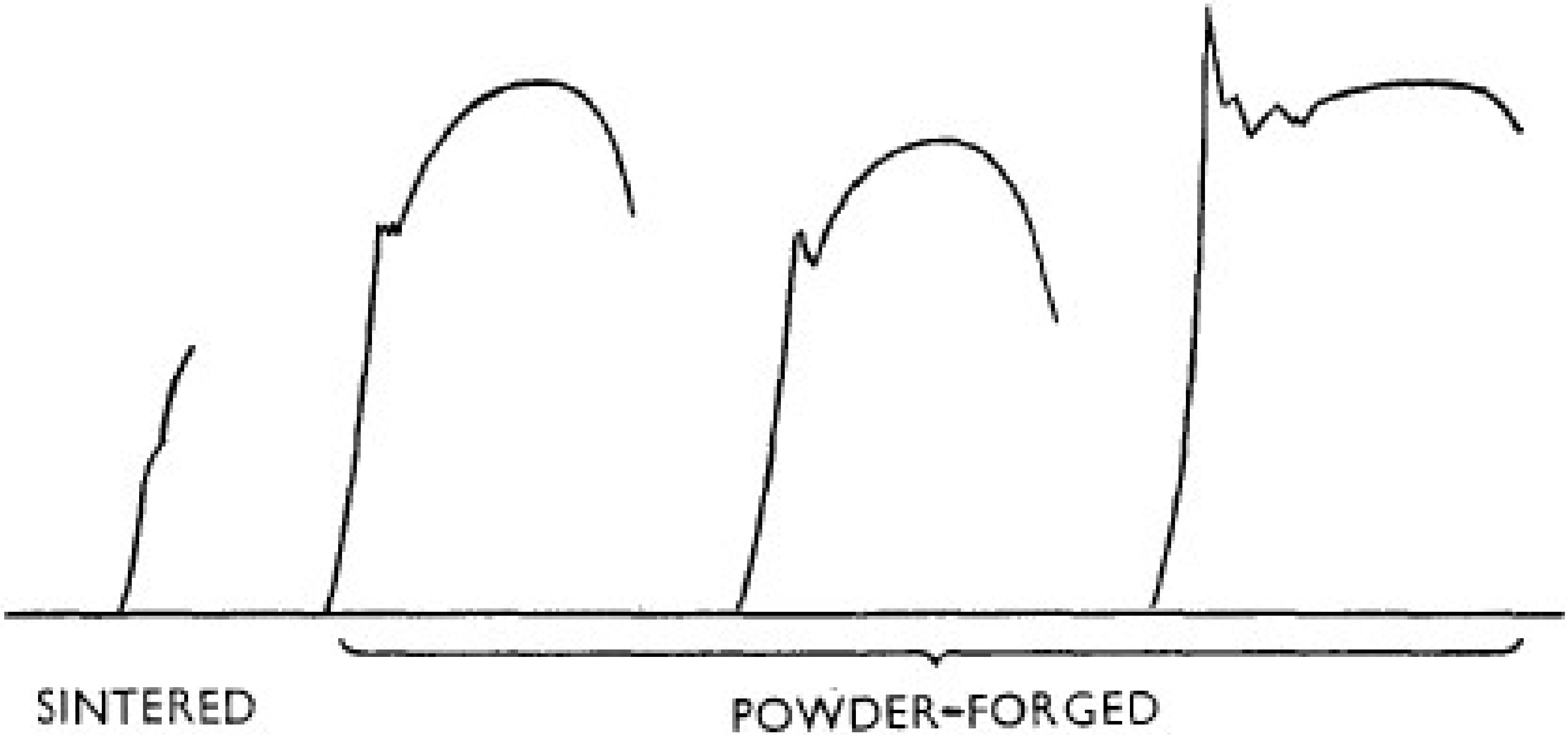


Fig. 5. The stress/strain curves of powder-forged iron samples (3 sources) compared with a sintered sample.

Powder Metallurgy Forging

Closed die forging from powder metallurgy preforms (conventionally bar stock as workpiece)

Advantages

- ✓ Improved material utilization
- ✓ Elimination of machining
- ✓ Forming the final size in one stroke
- ✓ Uniformity of structure
- ✓ Reduced directionality of properties relative to conventional forged parts

Powder Metallurgy Forging

Closed die forging from powder metallurgy preforms (conventionally bar stock as workpiece)

Advantages

✓ Volume decreases during plastic deformation as the porosity is closed up and eliminated

✓ Presence of voids causes a significant decrease in local ductile which increases the likely wood of fracture during forging (apply forming limit concept to avoid fracture)

✓ Presence of voids increases the surface area over which unfavorable oxidation / contamination reaction can occur

Powder Metallurgy Forging

Plastic Poisson's ratio for sintered porous preforms in terms of preform density and theoretical density is given by the expression:

$$\nu = \frac{1}{2}\left(\frac{\rho}{\rho_{th}}\right)^2$$

Powder Metallurgy Forging

The classical theory of plasticity is based on the assumption of constancy of volume, which leads to the further condition that yielding is unaffected by the hydrostatic component of the stress state. A modification of the von Mises' yield criterion is needed for dealing with porous materials which densify with plastic deformation. Kuhn has shown that a workable yield criterion is

$$\sigma_0(\rho, \varepsilon) = \left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2} + (1 - 2\nu)(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1) \right]^{1/2} \tag{16-30}$$

The first term in Eq. (16-30) is the usual von Mises' criterion, and the second term accounts for the porosity through Poisson's ratio and Eq. (16-24). Several other yield functions for compressible P/M materials have ben proposed.[2]

Powder Metallurgy Forging

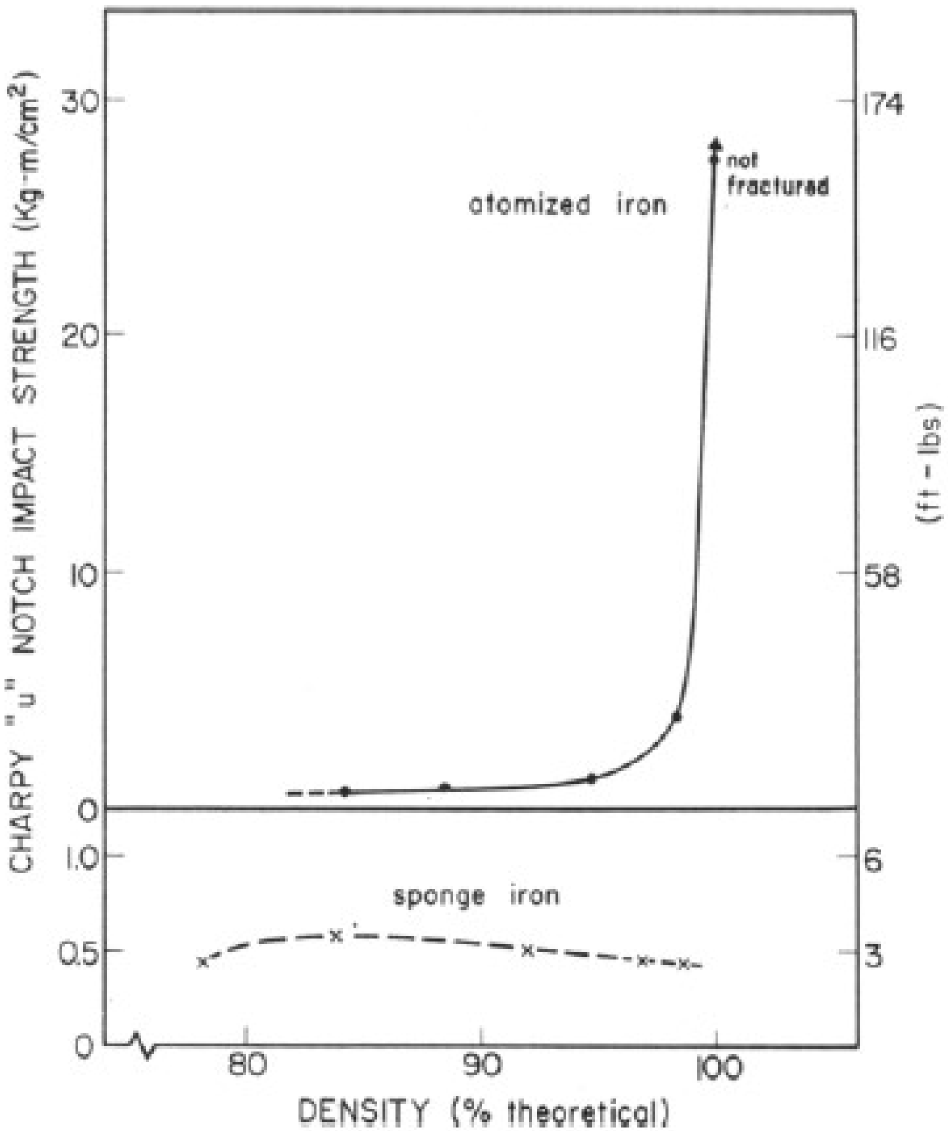


Fig. 1—Dependence of impact strength on density for two different types of iron powder forgings.[2]

Powder Metallurgy Forging

Often it is economical to combine sintering and hot forging in a single step.

First the green compact is heated in a furnace up to sintering temperature for the required duration.

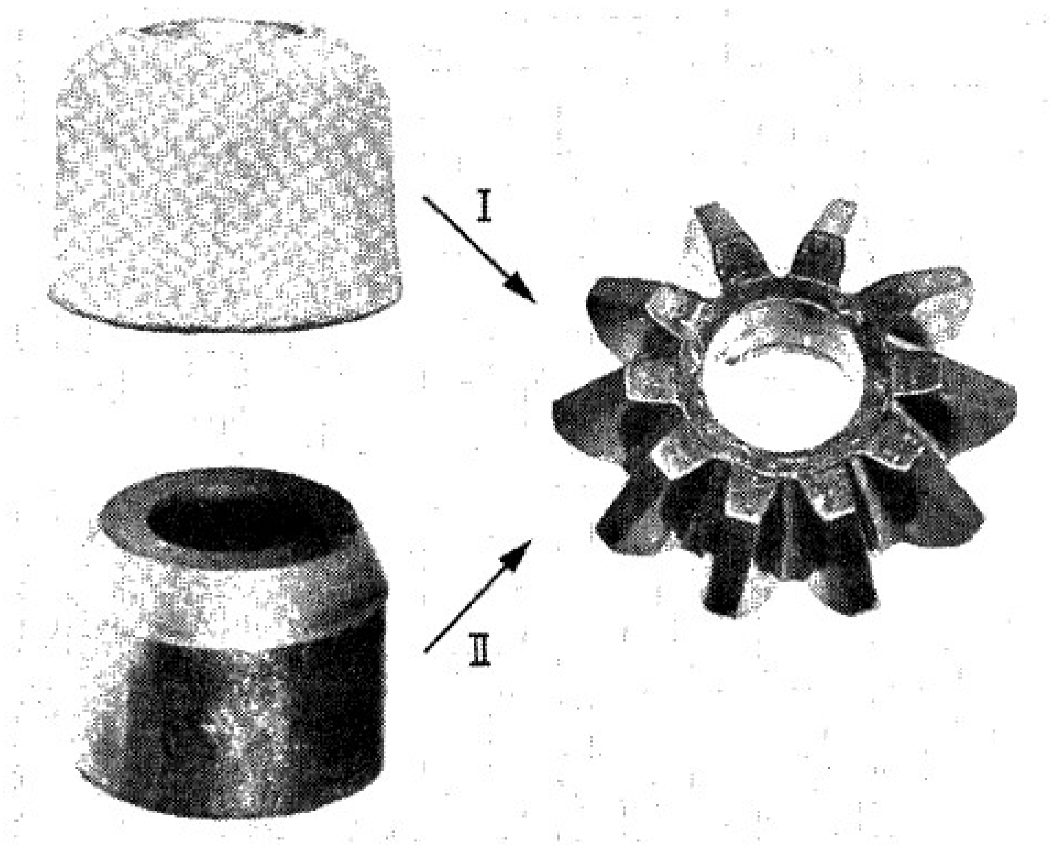
It is immediately followed by hot forging of the sintered preform by transferring it from the furnace to the forging die.

This way considerable saving in energy could be achieved. Cold forged parts have good surface finish and dimensional tolerances. However, hot forging requires lower loads and easy flow of material occurs.

In upset forging, there is always the chance of occurrence of surface cracks due to excess tensile stress.

In closed die forging such surface cracks generally avoided. Further, closed die forging of sintered material does not require flash.

Powder Metallurgy Forging



4 Preform and forged gear (dia. 45 mm): in alternative I an isostatically compacted preform is used; in alternative II a mechanically compacted preform (Photographs of preforms and gear courtesy Dr S. Corso, Fiat, Torino)

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Powder Metallurgy Forging

Fig. 15. A selection of powder-forged components.

Powder Metallurgy Forging

The three principal variables in powder forging are:

I. preform density,
II. temperature of forging, and
III. applied load

Residual Stresses in Forging

Residual stresses are ‘self equilibrating internal stresses existing in a free body which has no external forces or constraints on its boundary’

Residual Stresses in Forging

Continuous bodie[redacted] may experi[redacted]o exte[redacted]
str[redacted]

Th[redacted]larly in the stru[redacted], and they must be a[redacted]ufacturing methods, including for[redacted]

The main mechanism of residual-stress generation is any source of “misfit” in the material, one of which is the non-uniform plastic deformation induced by forging.

Residual Stresses in Forging

Why are residual stresses important?

- ✓ Quenching of closed die forgings which have thin cross sections can cause distortion during the quenching operation, leading to expensive hand finishing.
- ✓ Forgings that are machined after the quenching operation will distort from their intended shape if the internal stress pattern is not relieved.
- ✓ Tensile stresses which are revealed during the machining operation will enhance stress corrosion cracking.
- ✓ The unaccounted for stress pattern may lead to premature failure of forged parts.

Residual Stresses in Forging

The residual stresses produced in forgings as a result of inhomogeneous deformation are generally small because the deformation is usually carried out well into the hot-working region. However, appreciable residual stresses and warping can occur on the quenching of steel forgings in heat treatment.

Special precautions must be observed during the cooling of large steel forgings from the hot-working temperature. Large forgings are subject to the formation of small cracks, or *flakes*, at the center of the cross section. Flaking is associated with the high hydrogen content usually present in steel ingots of large size, coupled with the presence of residual stresses. In order to guard against the development of high thermal or transformation residual stresses, large forgings are very slowly cooled from the working temperature. This may be accomplished by burying the forging in ashes for periods up to several weeks or, in the controlled cooling treatment which is used for hot-rolled railroad rail and certain forgings, by transferring the hot forging to an automatically controlled cooling cycle which brings the forging to a safe temperature in a number of hours. The use of vacuum-degassed steel largely eliminates problems with flaking.