Module-II

Effect of Parameters

Effects of Temperature, strain rate, friction and lubrication, hydrostatic pressure in metalworking, Deformation zone geometry, workability of materials, Residual stresses in wrought products..

Forging

Classification of forging processes. Forging machines equipment. Expressions for forging pressures & load in open die forging and closed die forging by slab analysis, concepts of friction hill and factors affecting it. Die-design parameters. Material flow lines in forging, forging defects, residual stresses in forging. Simple problems.

Effect of Parameters

Introduction:

Metal forming includes a wide variety of processes in which the workpiece is plastically deformed to obtain the desired shape and size. In order to plastically deform the metal, a force is applied that will exceed the yield strength of the work material. The deformation characteristics depend on several factors like temperature, friction, strain rate, lubrication, etc.. which need to be controlled or monitored suitably during the forming process, so that a product with good quality can be manufactured economically with ease. The present chapter discusses the effect of various parameters in metal forming process.

TEMPERATURE:

Temperature is an important factor in metal forming operations, because the properties of a metal change with an increase in its temperature. Therefore the metal will react differently to the same manufacturing operation if it is performed under different temperatures, and also the manufactured part may possess different properties.

At low temperatures, although good surface finish, strength and hardness, and close tolerances can be achieved in forming, the amount of stress required to deform the metal is more. With increasing temperatures, deformation becomes easier, ductility increases, and the grain structure of the metal will be refined resulting in better physical properties. However, the strength of the metal decreases and also the surface finish obtained is not good due to the scale formation resulting from surface oxidation at higher temperatures. Also the life of the working tools reduces at higher temperatures. Hence, selecting the working temperature becomes a crucial factor in determining the quality of the final product.

The temperature of the workpiece metal in metal forming depends on the following factors:

a) The initial temperature of the tools and the work material,
b) Heat generation due to plastic deformation,
c) Heat generated by friction at the die and work interface, and
d) Heat transfer between the deforming material and the dies and surrounding environment.

FRICTION:

Metal forming processes involve larger forces for deformation and hence high pressures exist between the contact surfaces of the tool and the work metal. Since, friction is the resistance to sliding along an interface, the higher the contact pressures, the higher will be the friction resulting in

an increase in the deformation resistance of the work metal. Although a certain amount of friction is required for some forming processes, for example, like rolling, where the workpiece is drawn into the rolls due to the friction between the rolls and the work, however excessive friction is always undesirable due to the effects listed below:

a) Friction increases the amount of force or power required to perform an operation.
b) Friction reduces metal flow, hence induces inhomogeneity in the formed part leading to certain defects.
c) Friction increases heat at the interface resulting in wear of the working tools.
d) Friction between the work and the tool give rise to shearing stresses along the contact surface.

Friction is typically characterized by a coefficient of friction (μ), which is the ratio of the frictional resistance force (shear stress τ) to the normal force (p), which presses the su. faces together.

i.e., $\mu = \frac{\tau}{p}$ In general, $\tau = \mu . p$ (Coulomb's friction law)

The value of the coefficient of friction (μ) depends on the following factors:

a) Work metal being formed
b) Tool material used
c) Surface roughness of the work and the tool
d) Speed of deformation
e) Temperature, and
f) Type of lubricant used.

It is important to note that friction changes from point to point at the interface and hence difficult to measure. It is for this reason, the coefficient of friction (μ) is assigned a constant value.

LUBRICATION:

Metal forming processes involve larger forces for deformation and hence when the tool and the workpiece comes in contact with each other, the heat generated due to friction between the contact surfaces can result in the wear of the forming tool, and also there is a loss in the force transmitted to the work metal. In order to avoid metal-to-metal contact, lubricants are used. Lubricants used in manufacturing industry for metal forming processes include, vegetable and mineral oils, soaps, graphite dispersed in grease, water based solutions, solid polymers, wax, and molten glass. The effects of efficient lubrication are listed below:

a) Lubricants avoid metal-to-metal contact by maintaining a thin film between the sliding surfaces.
b) Minimizes friction and hence the heat generated between the sliding parts.
c) Reduces wear of the forming tool thereby increasing the tool life.
d) Results in greatest possible reduction in cross-section in each pass.
e) Circulating lubricant help to carry dust, dirt, and foreign particles from the deformation zone.

Inspite of the various lubricants available, it is important to note that choosing the right lubricant for a particular process depends on a number of factors listed below:

a) Type of forming process (rolling, forging, sheet metal, etc.)
b) Hot working or cold working
c) Type of work material
d) Chemical reactivity of lubricant with the tool and work materials
e) Ease of lubricant application, and f) Cost of lubricant.

STRAIN RATE:

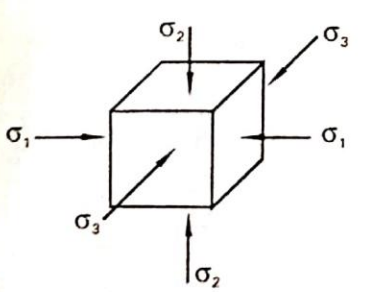
During deformation processes, the speed of the operation is usually measured by strain rate. Strain rate or deformation velocity is defined as the ratio of the deformation speed (v) or speed of ram, to the instantaneous height of the work metal being deformed.

$$\text{i.e., true strain rate } \varepsilon' = \frac{v}{h}$$

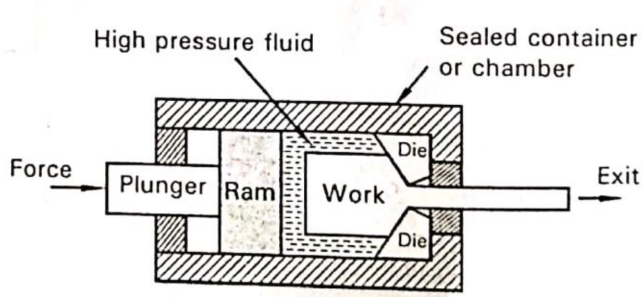
It is clear from the above relation that the strain rate for any particular metal forming process is directly related to the speed at which deformation is taking place. A greater rate of deformation of the work piece would mean a higher strain rate. At higher strain rates, the flow stress* of the material increases, leading to higher loads on the equipment. Along with this beneficial effect, the temperature of the workpiece also increases due to adiabatic heating, and there is also an improved lubrication at the tool-work interface.

HYDROSTATIC PRESSURE IN METAL WORKING:

Hydrostatic pressure is a state of stress characterized by equal principal stresses: compressive stresses or equal tensile stresses in all directions, and no shear stresses on any plane, i.e., $\sigma_1 = \sigma_2 = \sigma_3$ as shown in figure



(a) Unit cube under a state of hydrostatic stress (Compression type)



(b) Hydrostatic extrusion

Hydrostatic pressure is utilized in many metal working operations like wire drawing and extrusion to produce large plastic deformation without fracture, which otherwise would not have been possible. The hydrostatic pressure may arise from the hydrostatic component of the stress state, chiefly by the interaction of the workpiece and the tooling in the presence of a fluid medium as is in the case of extrusion. Figure . (b) shows the various elements of the hydrostatic extrusion process in which th : billet (work metal) is forced through the die by a high hydrostatic fluid pressure resulting from the force of the ram. The high hydrostatic pressure at the deformation zone helps in reducing the tensile stresses below the critical value for cracking, while at the same time the flow stress is unaffected. In addition, deformation carried out under high hydrostatic pressure creates less damage to the material during deformation.

WORKABILITY OF MATERIALS:

Workability refers to the ease with which a material can be shaped by plastic flow without the onset of fracture (without the formation of cracks). This general term includes all other terms like forgeability, rollabilility, extrudability, and formability (the term used for sheet metals). Workability not only depends on the fracture resistance (ductility) of the work material, but also on the specific details of the deformation process like die geometry, lubrication conditions, and workpiece geometry.

The *temperature* and stress state imposed by the processing conditions will strongly influence workability. Most metals have higher workability at higher temperatures. Workability is usually higher under compressive state of stress when compared to tensile stress state. Although a number of mechanical standard tests (tension, compression, torsion, etc.) are available to assess the workability of a metal or alloy, it is very difficult to measure workability in terms of the actual process with all the parameters like temperature, friction, material shape and size, etc., being involved in the process. However, upsetting (compressing work) a cylindrical specimen under controlled strain rate conditions has been found to be a satisfactory test and comes closest to the standard acceptable test.

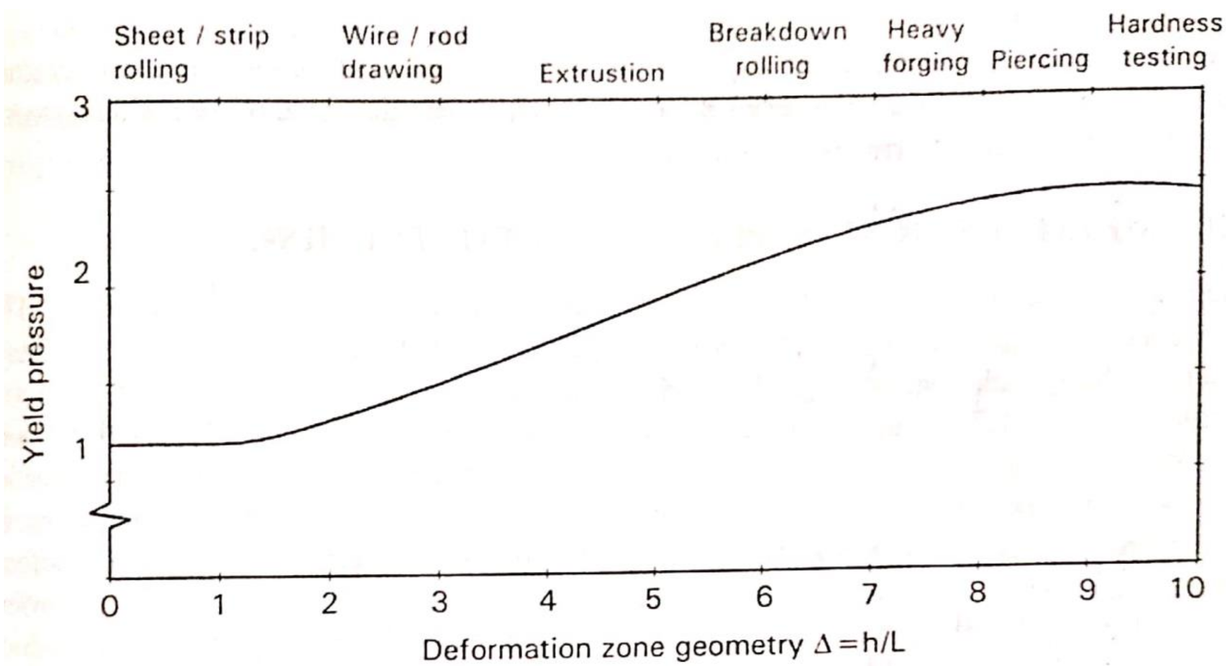
DEFORMATION ZONE GEOMETRY:

Deformation zone refers to the area or region where the deformation of the work metal takes place when the forming tool comes in contact with it. In most of the metal forming processes, the work metal is made to flow through either a narrow or convergent channel; the shape of the deformation zone thus referred as *deformation zone geometry* has a strong influence on the redundant work, frictional work, and the forming forces. The homogeneity, the tendency to crack, the pattern of residual stresses, and the porosity are all affected by the deformation-zone geometry. The deformation zone geometry also influences the properties of the formed material.

Deformation zone geometry is characterized by a parameter, Δ (delta), defined as the ratio of thickness or diameter (h) of the work to the contact length (L) between the workpiece and the die.

$$\text{i.e., } \Delta = \frac{h}{L}$$

The exact value of the parameter Δ depends on the shape of the dies, and is hence different for different forming processes. For example, in wire drawing process, if the die angle increases, the length of contact between the work and the die is less, thereby causing an increase in the value of Δ. As the value of Δ increases, the yield pressure required for deformation increases as illustrated in figure . The increase in yield pressure with increasing deformation zone geometry is attributed to the increase in redundant work in the deformation process. For large values of Δ, internal cracks may develop in the work material as a result of secondary tensile stresses.



RESIDUAL STRESSES IN WROUGHT PRODUCT:

Residual stresses are locked-up stresses existing within a body in the absence of external loading or thermal gradients. Residual stresses can occur through a variety of mechanisms including inelastic (plastic) deformations, temperature gradients (during thermal cycle), or structural changes (phase transformation) resulting in desirable or undesirable effects on the formed component. For example, brittle materials can be toughened by including compressive residual stress by shot peening or surface rolling operation. A material having compressive residual stress helps to prevent brittle fracture because the initial crack is formed under compressive (negative tensile) stress. To cause brittle fracture by crack propagation of the initial crack, the external tensile stress must overcome the compressive residual stress before the crack tip experience sufficient tensile stress to propagate. On the other hand, residual stress in a designed structure may cause it to fail prematurely.

Effect of Residual Stresses:

Residual stresses can be sufficient to cause a metal part to suddenly split into two or more pieces even under the absence of external load. Residual stresses can result in visible distortion of a

component and can deform a component while it is being machined or worked. In summary, residual stresses reduces the ductility, increases the hardness thereby reducing the formability of the metal part. They can even cause distortion and warping of the worked part after the deformation process is completed.

Relieving residual stresses

Residual stresses can be relieved by heating (heat treatment process) the metal to a temperature where the yield strength of the material is the same or less than the value of the residual stress. Thus the material can deform and release the stress.

FORGING

INTRODUCTION TO FORGING:

Forging is a type of manufacturing process, wherein a metal is heated to its plastic state (above recrystallization temperature) and then deformed to the desired shape and size by the application of compressive forces through a hammer, press, or rolls. If the compressive force is applied manually by using specific tools, it is called *Hand Forging*, and if the compressive force is applied using machines, it is called *Power Forging*.

Most forging operations are carried out *hot*, although certain metals may be *cold* forged, i.e., forging is performed with metal at or near room temperature (below recrystallization temperature). Typical parts made by forging in modern industry include aircraft components like landing gear, shafts for jet engines and turbines; automobile and railroad components like crankshafts, levers, gears, connecting rods; hand tools like chisels, rivets, screws, and bolts, and a wide variety of components for other applications. The present chapter discusses the various forging processes, equipments, design parameters, and characteristics that are essential in understanding the mechanics of power forging.

CLASSIFICATION OF FORGING PROCESS:

Forging process can be classified into three broad categories as follows:

(1) Open die forging (2) Impression die forging, and (3) Closed die forging (Flashless forging)

OPEN DIE FORGING:

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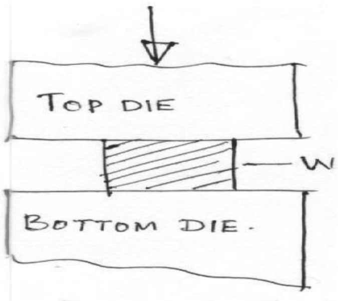
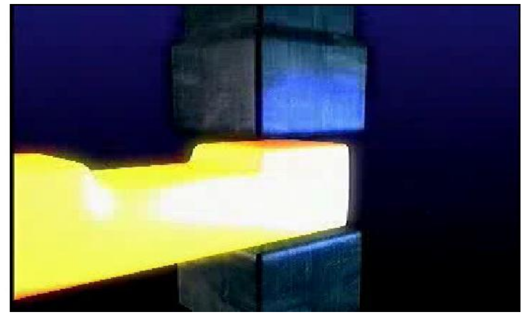
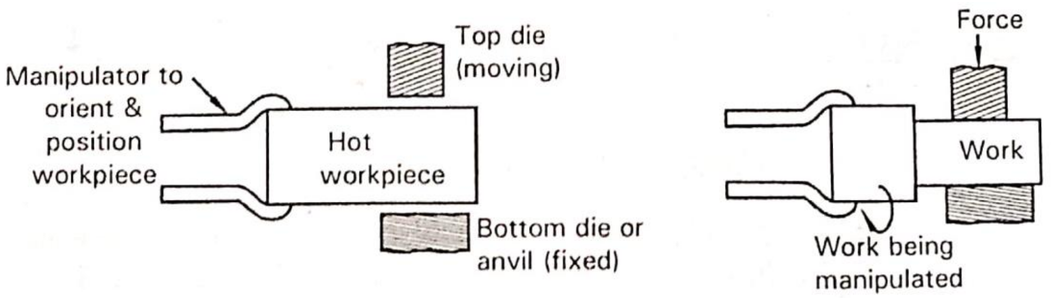
Open die forging, also called as *Smith's forging or flat die forging* is carried out between flat dies that do not enclose the workpiece as shown in figure . The dies are usually flat in shape, but some have simple contoured shapes like round, concave, or convex surface for specialized operations. The heated workpiece metal is placed on a bottom die, which may be a anvil or press bed, while the top die attached to a reciprocating ram strikes repeatedly to deform the workpiece.







(a) Starting stock held by manipulator (b) Open die forging

The operator needs to orient and position the workpiece before each stroke of the ram in order to get the desired shape and size. Secondary operations like machining may be carried out suitably in order to obtain the desired shape, size and finish.

Advantages of open die forging

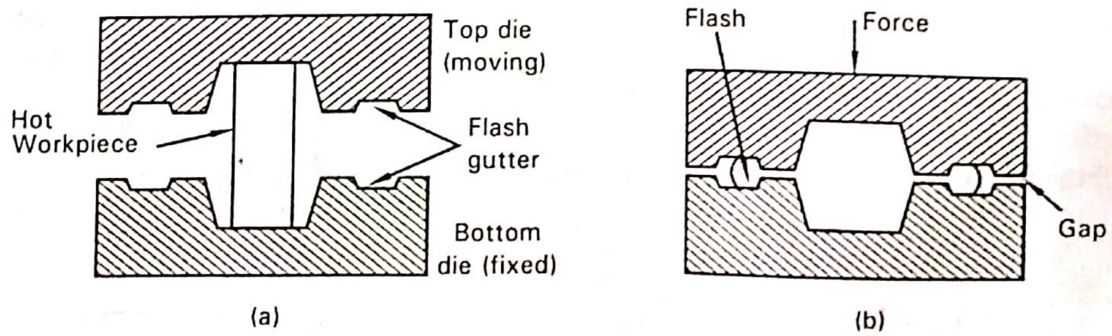
a) Process is relatively simple.
b) Makes use of simple, inexpensive dies.
c) Forged components exhibit good strength characteristics.
d) Suitable for large sized components that cannot be accommodated in closed dies.
e) Preferred when the number of components required is too small to justify the cost of closed dies.

Disadvantages of open die forging

a) Process is limited to simple shapes.
b) Skilled operator is required for proper manipulation of the workpiece during forging.
c) Difficult to maintain close tolerances.
d) Low production rate.
e) Machining to final shape is necessary.

IMPRESSION DIE FORGING:

Impression die forging makes use of matched dies with contoured impression in each die. When the two die halves close, the impressions form a cavity whose shape is similar to that of the desired product. The two die halves do not fully close with each other, instead designed with a small gap between them.



In impression die forging, the hot workpiece metal is placed in the bottom die, which is attached to the anvil or press bed. The top die is attached to a reciprocating ram of the machine. The ram falls down causing the top die to force the heated metal to fill the contours of the die blocks. The ram may impact the workpiece several times to ensure all of the contours are filled. When the two dies come together for the finishing step, any excess metal present is squeezed out of the die cavities as a thin ribbon of metal called *flash*. When the forging is completed, the flash is trimmed off suitably.

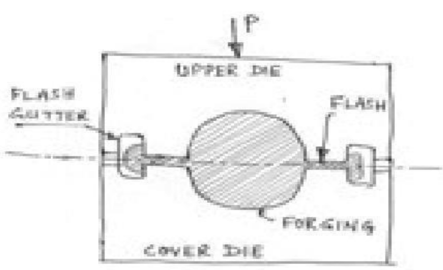
Advantages of Impression die forging

a) Suitable for small and medium sized components and in large quantities.
b) Produces dimensionally accurate forgings.
c) Good surface finish can be obtained.
d) Excess metal is forced out of the die cavity as *flash*, thereby eliminating pressure build-up in the die cavity. This also improves the life of the dies.

Disadvantages of Impression die forging

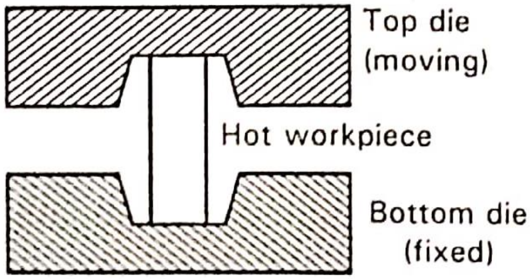
a) Not suitable for large sized components.
b) Initial die costs make the process suitable for mass production only.

CLOSED DIE FORGING:

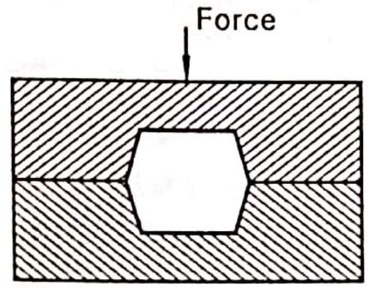


CLOSED DIE FORGING.

Closed die forging is a precision forging in which the entire volume of the work material is enclosed within the die and no material is allowed to escape from the mould during the forging process. As a result, no flash is formed and for this reason, the process is also called *flashless forging*.



(a)



(b)

In closed die forging, the workpiece is deformed between two die halves which carry the impressions of the desired shape of the product. Refer figure The top die is attached to a reciprocating ram of the machine, while the bottom die is attached to the anvil or press bed of the machine. The heated workpiece is placed in the bottom die, the ram falls down causing the top die to force the heated metal to fill the contours of the die blocks. The ram may impact the workpeice several times to ensure all of the contours are filled.

Advantages of closed die forging

a) Suitable for small and medium sized components and in large quantities.
b) Close dimensional tolerances can be achieved.
c) Good surface finish can be obtained.

Disadvantages of closed die forging

a) Not suitable for large sized components.
b) Initial die costs make it suitable for mass production only.
c) Demands rigorous process control, particularly in the amount of starting work material to be used. For example, too little work material results in incomplete filling of die cavity, and too much material will cause a dangerous build up of forces causing the dies to fail prematurely.

FORGING MACHINES AND EQUIPMENTS:

There are different types of machines used to perform a forging operation. These machines are classified under two major categories as listed below:

Forging machines

Hammer (Power Hammer)

- Gravity drop hammer
- Power drop hammer (Air or steam hammer)
- Pneumatic hammer
- Spring hammer
- Counter blow hammer

Presses (Power Press)

- Mechanical press
- Hydraulic press
- Screw press

POWER HAMMERS:

Power hammers, also referred as *Forging Hammers* derive their power from the kinetic energy of a ram (hammer) and the top portion of the die when put into motion. The ram is raised to a predetermined height, where it stores potential energy and when allowed to drop, the potential energy is converted to kinetic energy. The ram and the upper die travel in a linear path towards the lower die which is supported on an anvil. The work is placed in the lower die. At the point of collision when the two dies meet, the kinetic energy is transferred to the hot work causing it to flow and fill the contours of the die blocks. The ram is raised again to provide the next blow and the process repeats till forging is completed.

GRAVITY DROP HAMMER:

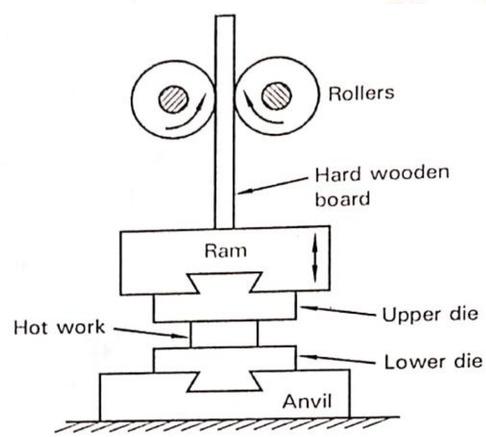
In gravity drop hammers, the ram is raised to a definite height and then allowed to drop freely under its own weight (gravity). Based on the arrangement of ram movement, gravity drop hammers are classified into three types: (1) Board drop hammer (2) Belt drop hammer (3) Chain drop hammer

The features of the most commonly used *board drop hammer* are explained below.

Board Drop Hammer

Figure shows the simplified diagram of a board drop hammer. In a board drop hammer, the upper die is attached to the ram, while the lower die to the anvil as shown in the figure. The ram is attached to a hard wooden board, which lies between a set of mechanically driven rollers. When foot pressure is applied and maintained on a pedal (not shown in figure), the rollers squeeze against the board and revolve in opposite directions. The rollers can thus raise the board and the ram due to the frictional forces between the board and the rollers. Once the ram reaches the highest point of the stroke, the rollers separate thereby loosening the grip on the wooden board. When the board is released, the ram falls under gravity to produce the blow energy on the workpiece.

When the top die comes in contact with the workpiece, immediately the board is lifted upwards and again released to provide the next blow. The hammer continues to operate as long as the pressure on the pedal is maintained. Board drop hammer is preferred for open die forging process only, as the blow energy from the ram cannot be controlled. The mass of the ram and the height of fall remain fixed.



POWER DROP HAMMER:

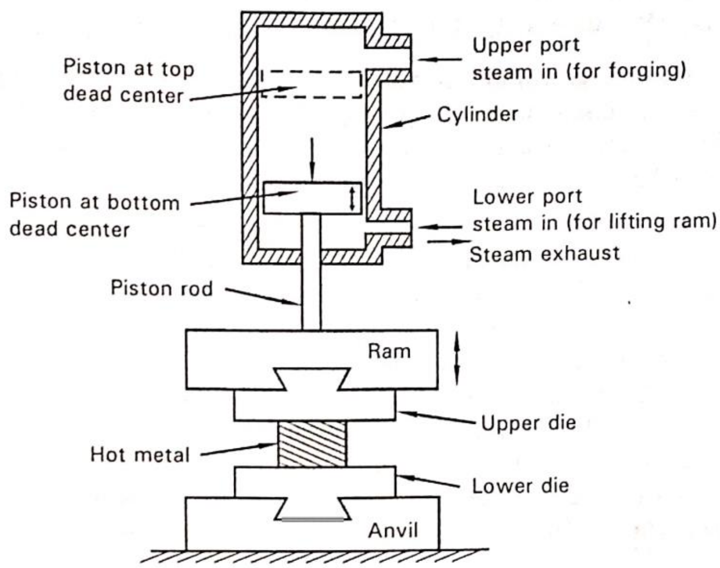
Power drop hammers incorporate the piston-cylinder arrangement and are operated by using either steam or compressed air as the working substance. High pressure compressed air or steam is supplied by means of an external compressor to raise the ram and to accelerate it downward to strike the workpiece.

Steam Hammer

Figure shows the features of a steam hammer in its simplest form. It consists of a cylinder with two ports, reciprocating piston connected to a long piston rod, ram, ands an anvil. The upper die is attached to the ram, while the lower die to the anvil as shown in the figure.

In working, initially the piston will be at the top dead center as shown by dashed lines in figure . The downward stroke of the ram is obtained by exhausting the steam from beneath the piston and admitting pressurized steam from above the piston, i.e., through the upper port. The ram is accelerated by the steam pressure in addition to its own weight (gravity). The heated workpiece which is placed on the lower die, gets compressed between the die blocks. Pressurized steam now enters through the bottom port and acts on the lower side of the piston causing it to move upwards. The ram is then raised to the desired height and the process repeats till forging is completed. Steam pressure ranges from 6 to 85 kgf/cm^2, and is usually delivered by a steam generating unit.

Steam or air hammer is suitable for both open die and closed die forging process, as the intensity of blows can be varied by admitting steam through the lower port while the piston is descending.



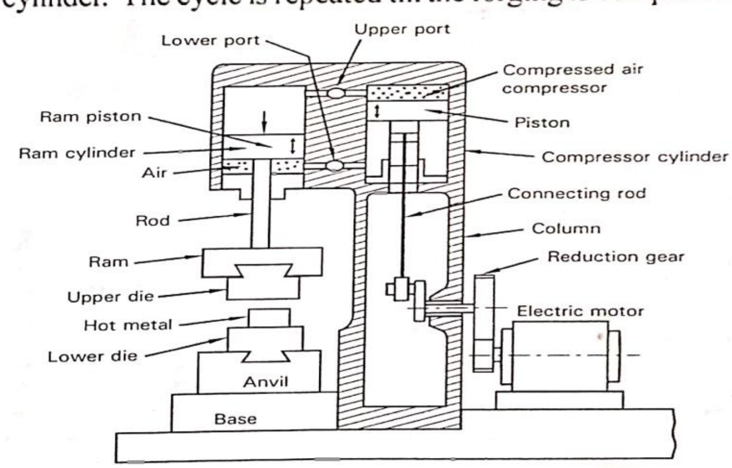
COMPARISSION BETWEEN BOARD AND STEAM HAMMER:

Sl. No.	Board hammer	Steam/Air hammer
1.	Ram movement is by frictional rollers.	Pressurized steam or air is used.
2.	Blow energy (striking energy) to the workpiece is equal to the potential energy of the ram. i.e., blow energy = mgh where m = mass or ram h = height of fall, and g = acceleration due to gravity	Blow energy supplied is due to the steam/air pressure in addition to gravity. i.e., blow energy = pAH + mgh where p = air/steam pressure acting on ram in downward stroke A = area of cylinder, and H = height of ram drop
3.	Blow energy cannot be controlled. The mass and height of fall remain fixed.	Blow energy can be controlled by admitting steam below the piston while it is descending.
4.	Suitable for open die forging only.	Suitable for open and closed die forging.
5.	Less problems due to shock, noise and vibrations.	Greater forging capacity results in comparatively more noise and vibrations.

PNEUMATIC HAMMER OR AIR-LIFT HAMMER:

A pneumatic hammer operates by means of compressed air and is used for forging of small parts. Whereas an air hammer requires external compressor for the supply of compressed air; a pneumatic hammer has a built-in compressor to provide compressed air for raising or lowering the ram. Figure shows the features of a pneumatic hammer.

The equipment consists of two cylinders: *ram cylinder* and *compressor cylinder*. The piston in the compressor cylinder is reciprocated by means of a crank drive, which is powered from a electric motor through a reducing gear. The piston of the compressor cylinder compresses the air and delivers it to the ram cylinder through the upper port so that the piston in the ram cylinder gets actuated. This result in the downward movement of the piston in the ram cylinder causing the ram to accelerate and strike the hot metal placed in the lower die. Now the piston in the compressor cylinder moves downwards compressing and pushing the air into the ram cylinder through the lower port. This results in lifting the piston up in the ram cylinder causing the ram and upper die to move upwards. Note that the air is compressed in both upward and downward stroke of the piston in the compressor cylinder. The cycle is repeated till the forging is completed.



POWER PRESS(PRESSES):

Presses are different from hammers in that instead of delivering energy to a work through impact or collision, the energy is delivered through a single continuous squeezing action. The continuous

squeezing action results in uniform deformation throughout the work. Forging presses are of two types: *Mechanical press*, and *Hydraulic press*. The detailed classification is listed below.

Presses

Mechanical press

- Crank press
- Screw press
- Rack and Pinion press
- Knuckle press

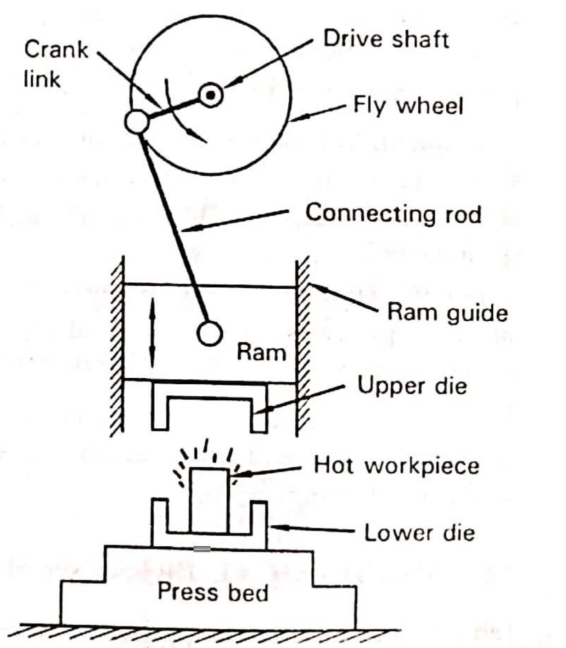
Hydraulic press

MECHANICAL PRESS:

The source of energy in a mechanical press comes from a large flywheel powered by an electric motor. Mechanical presses transform the rotational force of a motor into a translational force vector. In this way, the ram, and hence the upper die connected to the ram obtains its linear motion and power to compress the hot workpiece into the die blocks. The most common types of mechanical presses, viz., crank press and screw press have been discussed in the present chapter.

Crank Press

Figure shows the principle of operation of a crank press. The crank press uses a crank link attached to a drive shaft on which a large flywheel is also mounted. The crank is connected to the connecting rod, which in turn is attached to a ram by a rotational joint. The ram operates in a guide as shown in the figure and travels linearly while moving up and down. The upper die is attached to the ram, while the lower die to the press bed of the machine. The power from an electric motor causes the drive shaft and the flywheel to rotate at suitable speeds. The crank link rotates with the drive shaft and this action causes the connecting rod to convert the rotary motion of the crank into reciprocating (linear) motion of the ram. When the ram and hence the upper die moves downwards, the energy in them is used to close the mould, forming the part within. The work is forged over a single long stroke instead of a series of blows as with a forging hammer. The large flywheel used serves the purpose in this case.



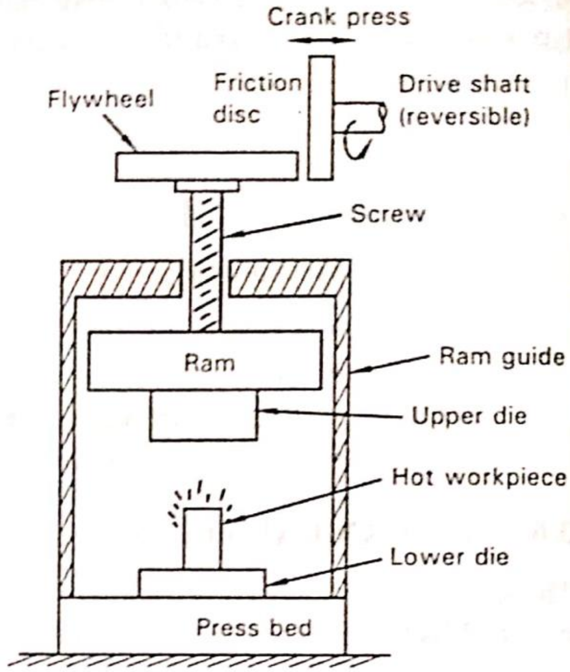
Crank press

Screw Press

Forging screw presses uses the rotational energy of a motor to turn a large screw, which in turn cause the ram and hence the upper die connected to it to move up and down. Figure shows a simple sketch of a screw press.

The screw press consists of a screw, its head connected to a large flywheel, while the tail end of the screw connected to the ram as shown in the figure. Typically a friction disc is used to translate the force from the drive shaft to the screw head. When the flywheel is driven the rotating disc, the screw rotates and pushes the ram with great mechanical advantage. The ram & hence the upper die connected to it moves downwards compressing the hot workpiece against the lower die.

Screw presses are used for bending & straightening operations, & also for upsetting bolt heads.



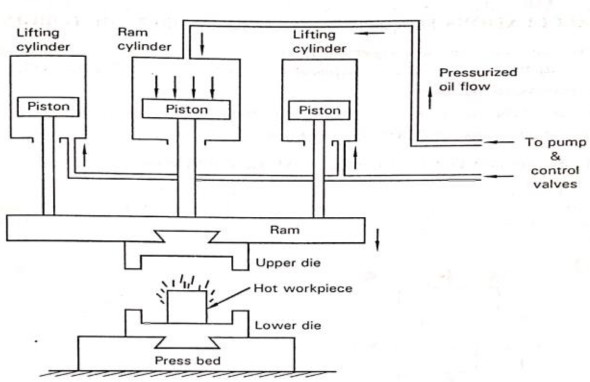
Screw press

HYDRAULIC PRESS:

Hydraulic presses derive the energy for forging through hydraulic pressure. The fluid pressure can be increased (or decreased) by means of pumps and valves; the increased pressure is then transmitted to the ram through a piston-cylinder arrangement. Figure shows the features of a hydraulic press in its simplest form.

The equipment consists of a large diameter ram cylinder and two small diameter lifting cylinders with corresponding pistons reciprocating in them. The pistons are connected to a ram, to which the upper die is attached. The lower die is attached to the press bed of the machine. The force required for forging is applied on the piston by a high pressure fluid, usually oil, supplied continuously by pumps. The high pressure acting on the piston causes it to move downwards and hence the ram and the upper die starts advancing rapidly against the workpiece placed on the lower die. The hot workpiece gets squeezed to fill the contours of the die blocks.

The ram is now lifted up by applying the pressure of the oil on the smaller pistons of the lifting cylinders. When the pistons reach the top dead center, the high pressure oil actuates the ram piston for the next forging operation.



Comparission between Hydraulic Press and Mechanical Press :

Sl. No.	Hydraulic Press	Mechanical Press
1.	Hydraulic presses derive the blow energy through hydraulic pressure.	Mechanical presses derive their blow energy by a large flywheel powered by an electric motor.
2.	They are slow speed machines involving longer contact time with the work.	Faster than hydraulic press.
3.	Low production rate.	Comparatively high.
4.	Longer contact time of the die with the work may lead to heat loss from the workpiece, and also die deterioration.	No such problems.
5.	Low squeezing action results in close dimensional tolerances.	Dimensional tolerances obtained are good, however comparatively low.
6.	Initial cost is higher than mechanical presses of equal capacity.	Low initial cost.

CALCULATION FOR FORGING LOAD IN OPEN DIE FORGING:

The calculations for forging load in open die forging process can be divided into three categories based on the friction between the die (platens) and workpiece surfaces. These include:

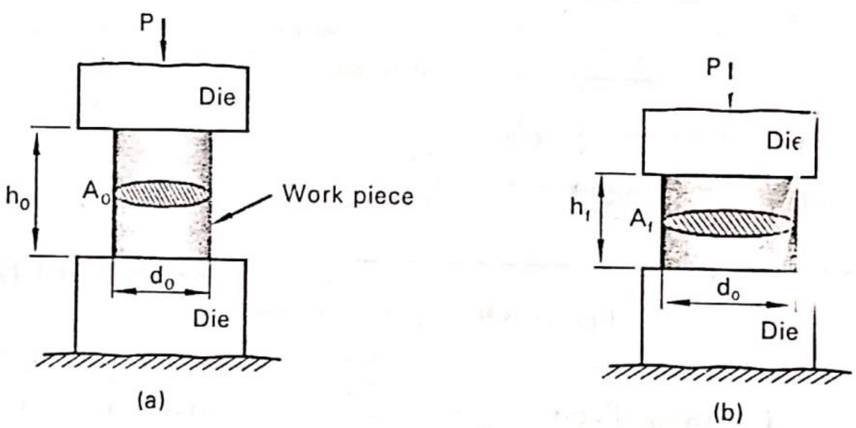
a) In the absence of friction

b) Low friction condition (Lower bound analysis or slab analysis or sliding condition)

c) High friction condition (Sticky friction condition)

Expression for Forging Load in the Absence of Friction:

Consider a round metal bar of diameter d_0 and height (thickness) h_o compressed between two parallel dies as shown in figure. An applied load P is increased until the stress reaches the flow stress* of the material, following which the height of the workpiece will be reduced from initial value of h_o to h_f.



In the absence of friction, the deformation of a workpiece in any forming process tends to be homogeneous and all the work performed by the external loads is used to uniformly deform the work material. That is, any height reduction causes a uniform increase in diameter of the workpiece. The forging load or press capacity is thus obtained as follows:

Forging load F = forging pressure (P) × Area at the end of forging

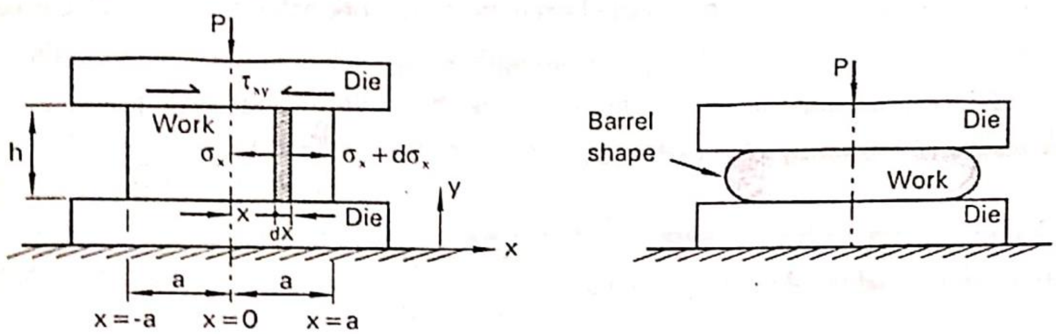
$$= \sigma_o A_f \quad \text{where } \sigma_o = \text{yield strength of the metal and } A_f = \text{final area} = \frac{\pi}{4} d_f^2$$

In practice friction between the die and workpiece cannot be avoided and hence the workpiece develops a barrel shape due to the applied load. This is called *inhomogenous* deformation and changes the load estimation of the forging process, which will be discussed in the following section.

Expression for Forging Load in the Sliding Friction:

Consider the forging of a rectangular workpiece of width $2a$, thickness (height) h, and length L as shown in figure (a). In the presence of friction, the workpiece develops a *barrel* shape due to the applied load as shown in figure (b). In order to calculate the forging load, it is necessary to determine the local stresses needed to deform each element of the workpiece.

Consider a small element dx of the workpiece of unit length and at a distance x from the center line as shown in figure (a).



(a) Before forging (b) After forging

The following assumptions have been made to simplify the analysis:

1) The forging force (F) attains its maximum value at the end of the operation.
2) The length of the element (dx) is much more than the other two dimensions so that a condition of plane strain* exists.
3) The workpiece material behaves like a ideal plastic material and the operation is taking place in the plastic range.
4) The coefficient of friction (μ) between the workpiece and the die is constant.
5) The forged material follows Von-Mises failure criteria.

Considering the equilibrium of the forces in x-direction, i.e., $\Sigma F_x = 0$, we have

$(\sigma_x + d\sigma_x).h - (\sigma_x)\, h - (2\tau_{xy}).dx = 0$ or $d\sigma_x.h = 2\tau_{xy}.dx$

$$\therefore \quad \frac{d\sigma_x}{dx} = \frac{2\tau_{xy}}{h} \qquad \text{-----(1)}$$

If the friction is assumed to obey Coulomb's law, then. $\tau = \mu p$, where μ is the coefficient of friction between the workpiece and the die, and P is the forging pressure.

$$\therefore \text{ equation (1) reduces to,} \quad \frac{d\sigma_x}{dx} = \frac{2\mu P}{h} \qquad \text{-----(2)}$$

From Von-Mises yield criteria for plane strain condition, we have

$$\sigma_1 - \sigma_3 = \frac{2}{\sqrt{3}}\sigma_0 = \sigma'_0 \text{ (say)} = 2\tau = 2k$$

Take $\sigma_1 - \sigma_3 = \sigma'_0$ -----(3)

where σ_1 = algebriacally largest principal stress

σ_3 = algebriacally smallest principal stress

σ_0 = yield strength of the workmaterial in uniaxial tension

σ'_0 = yield strength of the work material in plane strain

In the present analysis, $\sigma_1 = \sigma_x$(tensile) and $\sigma_3 = -P$ ($-^{ve}$ due to compressive)

Now equation (3) becomes $\sigma_x - (-P) = \sigma'_0$

or $\sigma_x + P = \sigma'_0$ -----(4)

Differentiating equation (4) w.r.t x, we have $\frac{d\sigma_x}{dx} = -\frac{dP}{dx}$ -----(5)

substituting equation (2) in (5), we get $\frac{2\mu P}{h} = -\frac{dP}{dx}$

$$\text{or } \frac{dP}{P} = -\frac{2\mu\, dx}{h}$$

On integration, we have $\int \frac{dp}{p} = -\frac{2\mu}{h}\int dx$

$$\ln P = -\frac{2\mu x}{h} + C \qquad \text{-----(6)}$$

The constant C can be evalutated by using boundary condition, i.e., from the stress condition at the edge of the workpiece element.

i.e., at $x = a$, lateral stress $\sigma_x = 0$

∴ Equation (4) becomes, $0 + P = \sigma'_0$

Thus $P = \sigma'_0$ at $x = a$

Now equation (6) becomes, $\ln(\sigma'_0) = -\frac{2\mu a}{h} + C$

$$\text{or } C = \ln(\sigma'_0) + \frac{2\mu a}{h} \qquad \text{-----(7)}$$

Substituting equation (7) in (6), we have $\ln P = -\frac{2\mu x}{h} + \left[\ln(\sigma'_0) + \frac{2\mu a}{h}\right]$

$$\ln P - \ln \sigma'_0 = \frac{2\mu}{h}(a - x)$$

$$\ln\left(\frac{P}{\sigma'_0}\right) = \frac{2\mu}{h}(a - x)$$

$$\text{or} \quad \frac{P}{\sigma'_0} = e^{\frac{2\mu(a-x)}{h}}$$

$$\therefore \text{ Forging pressure } P = \sigma'_0 \, e^{\frac{2\mu(a-x)}{h}} \qquad \text{-----(8)}$$

It is clear from the above expression that the forging pressure (P) varies exponentially with the width ($2a$) of the workpiece.

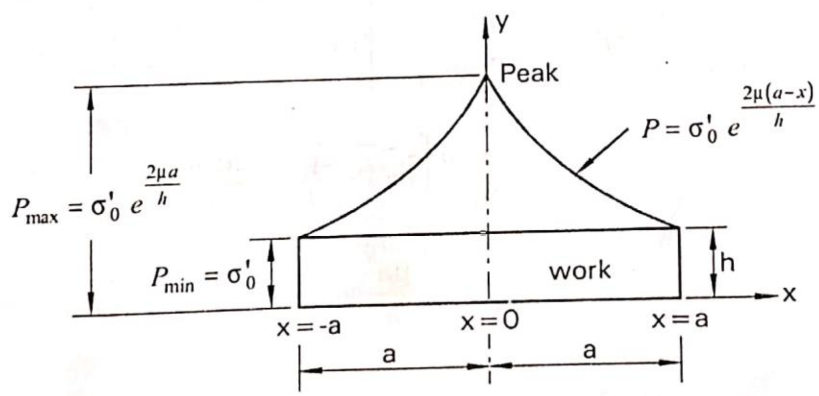
At $x = 0$, i.e., at the center line of the workpiece, the pressure (P) will be maximum, and hence equation (8) reduces to.

$$P = P_{max} = \sigma'_0 \, e^{\frac{2\mu a}{h}}$$

At $x = a$, i.e., at the edge of the workpiece, the pressure (P) will be minimum, and hence equation (8) reduces to

$$P = P_{min} = \sigma'_0$$

A plot of the pressure (P) for different values of distance (x) is shown in figure A peak exists at the center of the work resembling a "hill". Hence this plot is called *Friction Hill*.



Friction hill for sliding friction condition

Expression for Forging Load or Force (F)

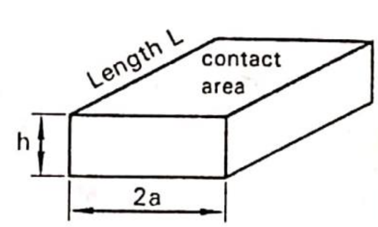
The forging load (F) can be obtained by knowing the average forging pressure acting over the interface between the dies and the workpiece.

$$\text{i.e., Forging load} = F = (\text{Average forging pressure})(\text{Area})$$

$$= (P_{avg})(2a.L) \qquad \text{-----(9)}$$

$$\text{i.e., area } A = 2a.\,L$$

To find P_{avg}



$$\text{w.k.t. Average pressure} \quad P_{avg} = \int_0^a \frac{P}{a}.dx$$

$$= \int_0^a \frac{\sigma'_0}{a} e^{\frac{2\mu(a-x)}{h}}.dx = \frac{\sigma'_0}{a} \int_0^a e^{\frac{2\mu(a-x)}{h}}.dx$$

On integrating, we get $P_{avg} = \frac{\sigma'_0}{a}\left[\frac{e^{\frac{2\mu(a-x)}{h}}}{\frac{-2\mu}{h}}\right]_0^a$

$$P_{avg} = \frac{-\sigma'_0 h}{2\mu a}[1 - e^{\frac{2\mu a}{h}}] \qquad \text{-----(10)}$$

Assuming $\frac{2\mu a}{h}$ to be small, and expanding as a series using $e^y = 1 + y + \frac{y^2}{2!} + - - -$, we get

$$P_{avg} = \frac{-\sigma'_0 h}{2\mu a}\left\{1 - \left[1 + \frac{2\mu a}{h} + \left(\frac{2\mu a}{h}\right)^2 . \frac{1}{2} + - - -\right]\right\}$$

$$P_{avg} = \frac{-\sigma'_0 h}{2\mu a}\left[1 - 1 - \frac{2\mu a}{h} - \frac{2\mu^2 a^2}{h^2}\right]$$

$$= \sigma'_0 + \sigma'_0 \frac{\mu a}{h}$$

$$\text{or } P_{avg} = \sigma'_0\left[1 + \frac{\mu a}{h}\right] \qquad \text{-----(11)}$$

Equation (11) gives the mean or average forging pressure. Now, substituting equation (11) in (9), we get,

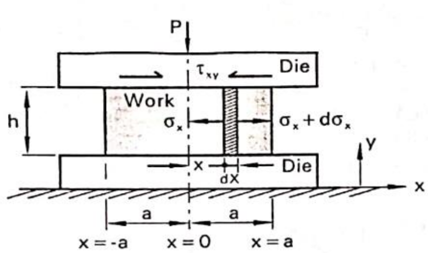
$$\text{Forging load } F = \sigma'_0\left[1 + \frac{\mu a}{h}\right](2a.L) \qquad \text{-----(12)}$$

EXPRESSION FOR FORGING LOAD IN THE STICKING FRICTION:

In hot forging of steel and other alloys, the coefficient of friction between the work and the die is high and also little or no lubricant is used. In such conditions, a layer of workpiece metal coming in contact with the die surface may stick on to the die and flow may take place just under the surface layer. This condition of friction is called sticking friction.

Consider the forging of a rectangular workpiece of width $2a$, thickness (or height) h, and length L as shown in figure . In order to calculate the forging load, it is necessary to determine the local stresses needed to deform each element of the workpiece.

Consider a small element dx of the workpiece of unit length and at a distance x from the center line as shown in figure .



The following assumptions have been made to simplify the analysis:

1) The forging force (F) attains its maximum value at the end of the operation.
2) The length of the element (dx) is much more than the other two dimensions so that a condition of plane strain exists.
3) The workpiece material behaves like a ideal plastic material and the operation is taking place in the plastic range.
4) The coefficient of friction (μ) between the workpiece and the die is constant.
5) The forged material follows Von-Mises failure criteria.

Considering the equilibrium of the forces in x-direction, i.e., $\Sigma F_x = 0$, we have

$$(\sigma_x + d\sigma_x).h - (\sigma_x)\,h - (2\tau_{xy}).dx = 0$$

$$d\sigma_x.h = 2\tau_{xy}.dx$$

$$\text{or} \quad \frac{d\sigma_x}{dx} = \frac{2\tau_{xy}}{h} \qquad \text{-----(1)}$$

In case of sticking friction, the frictional stress on the die and the workpiece interface is equal to k – the yield strength of the metal in shear.

$$\text{i.e.,} \quad \tau_{xy} = k$$

$$\therefore \text{ equation (1) becomes,} \quad \frac{d\sigma_x}{dx} = \frac{2k}{h} \qquad \text{-----(2)}$$

From Von-Miss criteria for plane strain condition, we have

$$\sigma_1 - \sigma_3 = \frac{2}{\sqrt{3}}\sigma_0 = \sigma'_0\,(\text{say}) = 2\tau = 2k \qquad \text{-----(3)}$$

$$\text{Take} \quad \sigma_1 - \sigma_3 = \sigma'_0 \qquad \text{-----(4)}$$

where σ_1 = algebriacally largest principal stress

σ_3 = algebriacally smallest principal stress

σ'_0 = Yield strength of work material in plane strain

In the present analysis, $\sigma_1 = \sigma_x$ (tensile) and

$\sigma_3 = -P$ ($-^{ve}$ due to compressive)

Now equation (4) vbecomes $\sigma_x - (-P) = \sigma'_0$

$$\text{or} \quad \sigma_x + P = \sigma'_0 \qquad \text{-----(5)}$$

$$\text{Differentiating equation (4) w.r.t to 'x' we get} \quad \frac{d\sigma_x}{dx} = -\frac{dP}{dx} \qquad \text{-----(6)}$$

$$\text{substituting equation (2) in (6) we get} \quad \frac{2k}{h} = -\frac{dP}{dx}$$

$$\text{or} \quad dP = -\frac{2k}{h}.dx$$

$$\text{On integrating, we get} \quad P = -\frac{2kx}{h} + C \qquad \text{-----(7)}$$

where C is a constant that can be evaluated by using boundary condition, i.e., at $x = a$, $\sigma_x = 0$

$\therefore$ equation (5) becomes, $0 + P = \sigma'_0$

Thus $P = \sigma'_0$ at $x = a$

Now equation (7) becomes, $\sigma'_0 = -\dfrac{2ka}{h} + C$

$$\text{or } C = \sigma'_0 + \frac{2ka}{h} \quad \text{-----(8)}$$

Substituting equation (8) in (7), we get $P = -\dfrac{2kx}{h} + \left[\sigma'_0 + \dfrac{2ka}{h}\right]$

$$P = \sigma'_0 + \frac{2k}{h}(a - x)$$

But from equation (3), we have $2k = \sigma'_0$

$$\therefore\ P = \sigma'_0 + \frac{\sigma'_0}{h}(a - x)$$

$$\text{or } P = \sigma'_0\left[1 + \frac{(a - x)}{h}\right] \quad \text{-----(9)}$$

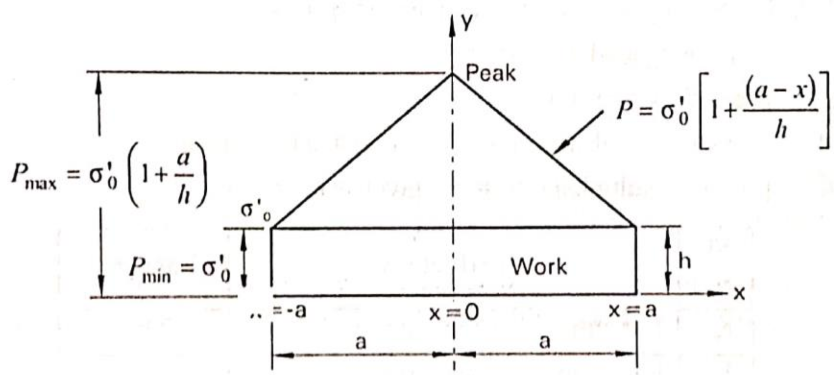
At $x = 0$, i.e., at the center of the workpiece, the pressure (P) will be maximum, and hence equation (9) reduces to:

$$P = P_{max} = \sigma'_0\left[1 + \frac{a}{h}\right] \quad \text{-----(10)}$$

At $x = a$, i.e., at the edge of the workpiece, the pressure (P) will be minimum and hence equation (9) reduces to:

$$P = P_{min} = \sigma'_0 \quad \text{-----(11)}$$

A plot of the pressure (P) for different values of distance 'x' is shown in figure   A peak exists at the center of the work resembling a "hill", Hence this plot is called *Friction Hill*.



Expression for Forging load or Force (F)

The forging load (F) can be obtained by knowing the average forging pressure acting over the interface between the die and the workpiece.

i.e., Forging load $= F$ = (average forging pressure) (Contact area)

$$= (P_{avg})(2a.L) \quad \text{-----(12)}$$

To find P_{avg}

w.k.t. average pressure $P_{avg} = \int_0^a \frac{P}{a} dx$

$$= \int_0^a \frac{\sigma'_0}{a}\left[1+\frac{(a-x)}{h}\right]dx = \int_0^a \frac{\sigma'_0}{a} dx + \int_0^a \frac{\sigma'_0}{a}\frac{(a-x)}{h} dx$$

$$= \int_0^a \frac{\sigma'_0}{a} dx + \int_0^a \frac{\sigma'_0}{h} dx - \int_0^a \frac{\sigma'_0 x}{a h} dx$$

On integrating & further simplification, we get $P_{avg} = \sigma'_0\left[1+\frac{a}{2h}\right]$ -----(13)

Equation (13) gives the average or mean forging pressure. Substituting equation (13) in (12), we get:

Forging load $= \sigma'_0\left[1+\frac{a}{2h}\right](2a.\ L)$ -----(14)

FORGING LOAD IN CLOSED DIE FORGING:

In case of closed die forging, it is quite difficult to estimate the load required to forge a component. The complexity arises due to the pre-forging operations carried out on the component before it is forged in closed dies. To calculate the forces, certain pressure-multiplying factors have been recommended. The forging load is calculated using the formula:

Forging load $F = \sigma_f A.k$

where σ_f = mean flow stress

A = cross-sectional area of the component at the parting line including the flash.

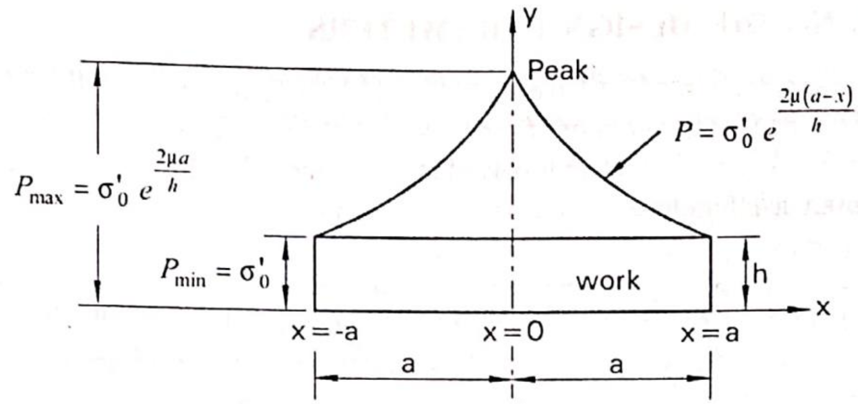
K = pressure multiplying factor as given in table

Sl. No.	Particulars	Factor k
1.	For simple shapes without flash	3 – 5
2.	For simple shapes with flash	5 – 8
3.	Complex shapes with flash	8 –12

CONCEPT OF FRICTION HILL:

The distribution of pressure with respect to distance ($2a$) on the workpiece (or forging die) is called friction hill. In forging, friction increases the pressure and forces between the dies and the workpiece, and may limit the attainable reduction.

Figure illustrates the pressure distribution during compression with sliding friction condition. It can be seen that the pressure is minimum at the edges of the workpiece and reaches to a maximum at the center of the work. Since a peak exists at the center of the work resembling a hill, this plot is called as friction hill.

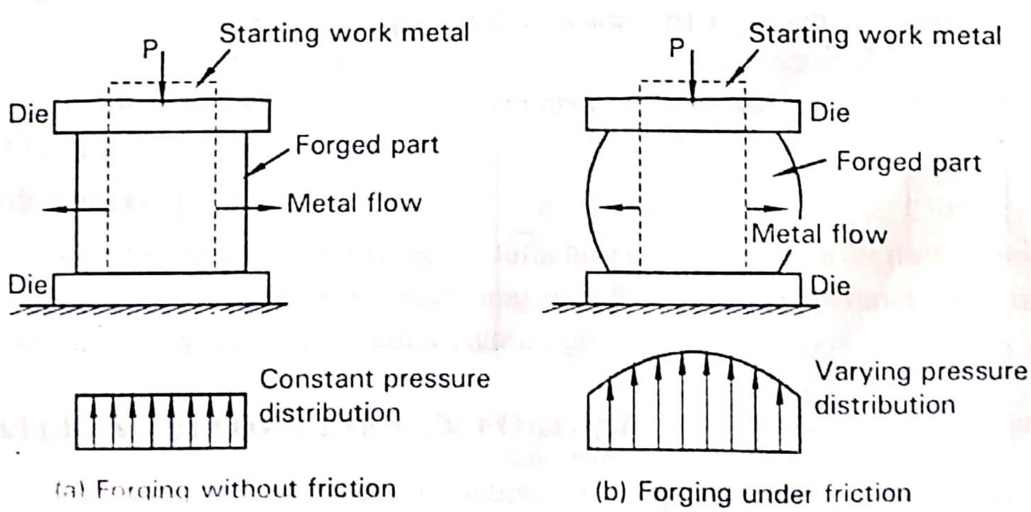


Friction hill for sliding condition

The effects of friction can be visualized by considering the axial upsetting of a cylinder shown in figure Theoretically speaking, if there were no friction between the die and the work surface, the cylindrical shaped workpiece would reduce in height and remain cylindrical in shape. The normal pressure would be constant over the contact points as shown in figure However in actual process, friction exists, and in such a case, the outward movement of the work material in contact with the die surface is restricted. hence the cylinder bulges. The pressure distribution is no longer constant as shown in figure instead rises to a maximum due to the frictional effects. In other words, the frictional force opposes the outward flow of the material, meaning that a higher stress must be generated near the centre of the contact zone to move the material outwards. This gives rise to the so called friction hill.

Factor affecting friction hill

The main factor that affects the die pressure is the aspect ratio of the section (a/h). The greater the aspect ratio, the higher the maximum pressure needed to cause yielding. Also, roughness on the die surface adds to friction and hence proper selection of die material to retain its finish is necessary. Smooth die surfaces and better lubrication reduces the frictional effects in forging.



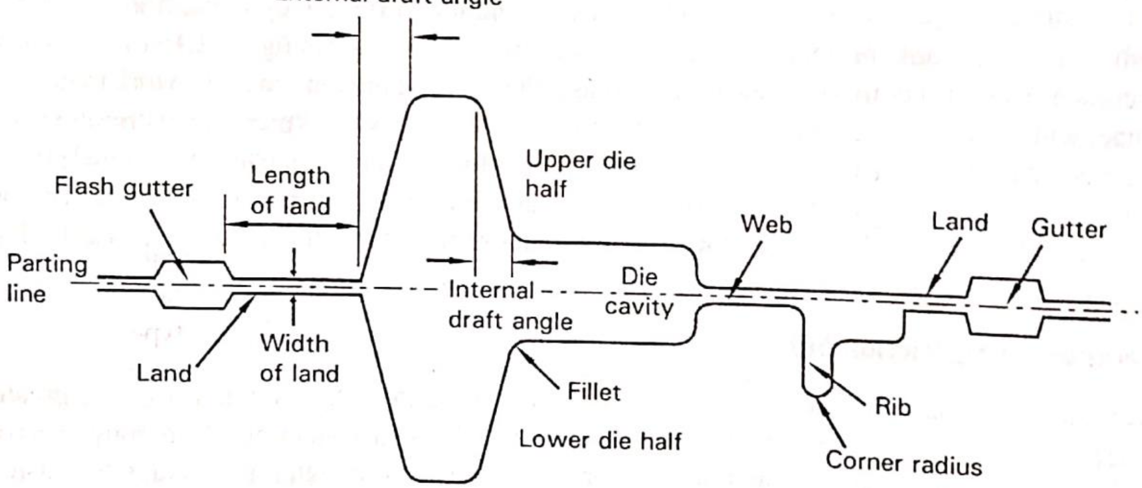
FORGING DIE DESIGN PARAMETERS:

Forging dies into which impressions have been cut need to be designed carefully. Proper die design ensures complete die filling, minimum flash loss, and defect free metal flow leading to a sound forged component. A few parameters involved in designing a forging die are illustrated in figure and discussed briefly below.

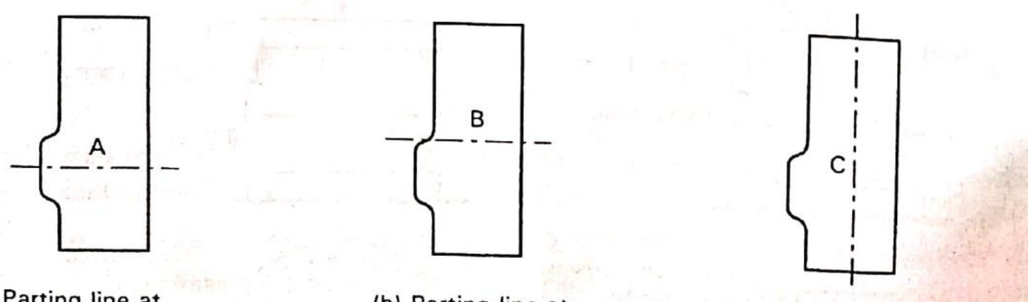
a) Parting line

Parting line is the line where the two die halves meet. It determines the metal flow through the mould during the forge compression. The parting line also dictates where flash will be formed and affects the grain structure of the forged part if not properly located.

Figure shows a forging with possible locations of a parting line. The location of the parting line *C* will better facilitate the flow of metal through the mould unlike *A* or *B*. The parting line should be located at the largest cross-section of the part as shown in the figure



Features of forging die design



(a) Parting line at varying section thickness

(b) Parting line at mid-height

(c) Parting line at largest cross-section of the part

Parting line location

b) Flash

In case of impression die forging, the excess material from the workpiece escapes the mould as flash, however in some situations if the excess material does not get a chance to exit the mould, pressure builds up in the mould leading to improper forging and also wear of the dies.

Figure shows the details provided in a die incorporating flash gutter. The excess metal called *flash* travel through a narrow passage called *land* before it opens up into a gutter. As it flows through the land, the friction between the flash and the mating die surfaces resists further flow of material out of the mould, resulting in build-up of pressure in the mould. In addition, the cooling of the flash from the mating die surfaces increases resistance to flow of material out of the mould thereby increasing pressure within the mould. Hence the length of the land and its width need to be designed carefully. The pressure within the die cavity is often controlled by varying the width of the land.

c) Draft

Draft is a taper provided on all sides of the die to facilitate easy removal of the part from the mould after forging is completed. Figure illustrates the draft angle provided in forging a component. Soft materials like aluminum and magnesium require less draft angles than the hard to forge materials like steel, nickel, and titanium alloys. In general, common draft angles used in manufacturing industries are 3, 5, 7, and 10 degrees.

d) Corner & Fillet Radii

During forging, the work metal flows and fills the die cavity; the flow of material will have to change directions depending on the parts geometry. At sharp corners of the part, the material may not follow the path of the corners, thereby resulting in vacancies or cold shut type of defects. Sharp corners will also act as stress raisers in the mould. Hence, good forging die design should provide adequate enough fillet and corner radius to allow for easy metal flow. Refer figure

e) Rib & Web Thickness

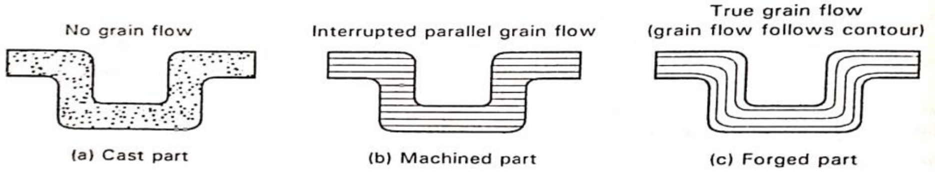
Thin sections like ribs and webs within the die cavity will not allow the work material to flow easily while forging. Refer figure . Long narrow ribs are harder to fill and require more forces, however increasing the width of a long rib will facilitate filling of the material during forging. Web thickness should not be too small as it might cool faster than to rest of the part causing tears or warping of the part.

f) Other allowances

The dimensions of the die cavity in forging manufacture should account for the shrinkage of the part during cooling, and allowances for machining and other finishing operations that may follow the forging process also need to be included accordingly.

MATERIAL FLOW LINES IN FORGING:

During forging, the hot workpiece under the action of the applied force gets plastically deformed and takes the shape of the die in contact with it. It is desirable to have a component with favourable grain orientation throughout the structure of the material. This results in better mechanical properties like strength, toughness, etc. in the component. The grain flow pattern and its effects can be best understood by comparing with the cast and machined component as shown in figure



In a cast part, there is no grain flow, the grains are oriented randomly and hence exhibits uniform properties in all directions. Refer figure (a). In a machined component, the grain flow is in one direction, and is interrupted by the machining as shown in figure (b). The strength and toughness of the part will be greater in the direction of the fibers, but weaker in the direction perpendicular to the fiber orientation. However in a forged part as shown in figure (c), the grain flow is continuous, and follow the contour of the part. The grain size will usually be smaller in forging compared to casting, and the grains will undergo deformation in preferred orientations. This helps to develop maximum mechanical properties for applications where shock and fatigue are encountered.

FORGING DEFECTS:

A few defects that occur normally in a forged part are discussed briefly below.

a) Cold shut

Cold shut is a discontinuity produced when two surfaces of the metal fold against each other without welding properly. This happens mainly due to improper die design and working temperatures.

b) Die shift

Die shift is a defect resulting from wrong alignment of the die halves. The forged part takes the improper shape resulting in a defect.

c) Surface crack

Surface crack is a defect on the work surface of the forged part resulting from excessive working at too low temperatures.

d) Unfilled section

Unfilled section is a defect that occurs when metal does not completely fill the die cavity. Such a defect occurs due to improper die design or wrong use of forging technique.

e) Overheating defects

Overheating defects are caused by improper heating conditions. This leads to surface oxidation and scale formation on the work surface, which need to be removed by certain finishing operations.

f) Flakes

Flakes are internal ruptures caused by improper cooling of large forgings. Rapid cooling of the part causes the exterior surface to cool too fast resulting in internal fractures.

g) Scale pits

Scale pits are irregular depressions on the surface of the forged part. This is mainly caused due to improper cleaning of the starting work material being used.

RESIDUAL STRESSES IN FORGING:

Forging is usually carried out at fairly high temperatures. When the forged component is cooled from the high temperature level, a difference in temperature between the surface and the core (central zone) is developed. The surface cools and contracts rapidly than the hotter central zone of the component, and as a result internal stresses (residual stresses) are induced in the material, Residual stresses remain in the material resulting in reduced strength and ductility of the material. Hence special precautions must be taken during the cooling of large steel forgings from the hot working temperature. Large forgings are subjected to formation of small cracks, or flakes at the center of the cross-section. Such forgings need to be cooled slowly from the working temperature and this may be accomplished by burying the forging in ashes for long durations, or using a controlled cooling furnace.

ADVANTAGES AND DISADVANTAGES OF FORGING

Advantages

a) Forging refines the grain structure and improves physical properties of the metal. The strength of the forged part is better than the cast or machined part.

b) Grain flow can be oriented resulting in parts with maximum impact strength and fatigue resistance.

c) Heavy parts can also be formed easily to the desired shape and size.

d) Forging yields parts that have high strength to weight ratio.

e) Forging minimizes, and in some cases eliminates machining costs.

Disadvantages

a) Forging involves significant capital expenditure for machinery, tooling and facilities.

b) Difficult to forge intricate and non-symmetrical parts.

c) Not suitable for hollow shaped parts.

d) Operating conditions are somewhat dangerous. This is due to high temperatures of the working metal and strong blows from hammers and presses.

Nomenclature

$2a$ = Width of workpiece (where a = half-width).

For cylindrical workpiece, $2a = d$ (where d = diameter) and $a = r$ (radius)

h = height (thickness) of workpiece

L = length of workpiece

μ = Coefficient of friction between work and die surface

σ_0 = Average yield stress of the work material in tension/compression

σ_0' = Yield strength of the work material in plane strain = $\frac{2}{\sqrt{3}}\sigma_0$

P_{min} = Minimum forging pressure

P_{avg} = average forging pressure

P_{max} = maximum forging pressure

F_{min}, F_{avg}, and F_{max} represents minimum forging force, average and maximum forging force respectively.

m = sticking friction factor ($m = 1$ for 100% sticking friction condition)

ε = Compressive strain

Formulas

1. In the absence of friction, forging pressure $P = \sigma_0$
2. Under sliding friction condition
   - Minimum forging pressure $P_{min} = \sigma'_0$
   - Mean or average forging pressure $= P_{avg} = \sigma'_0\left[1+\frac{\mu a}{h}\right]$
   - Maximum forging pressure $= P_{max} = \sigma'_0 e^{\frac{2\mu a}{h}}$

Note In general, $P_{max} = e^{\frac{2\mu(a-x)}{h}}$. Since forging pressure is maximum at the center of workpiece, where $x = 0$, $P_{max} = \sigma'_0 e^{\frac{2\mu a}{h}}$

3. Under sticking friction condition
   - Mean or average forging pressure $P_{avg} = \sigma'_0\left[1+\frac{ma}{2h}\right]$
   - Maximum forging pressure $= P_{max} = \sigma'_0\left[1+\frac{ma}{h}\right]$
4. Forging load or press capacity = (Forging pressure) (Area at the end of forging)
   - Mean or average forging load $F_{avg} = (P_{avg})$ (Area at the end of forging)
   - Maximum forging load $= F_{max} = (P_{max})$ (Area at the end of forging)
5. For **circular discs** under sliding friction condition
   - Average forging pressure $P_{avg} = \frac{\sigma_0}{2}\left(\frac{h}{\mu r}\right)^2\left[e^{\frac{2\mu r}{h}} - \frac{2\mu r}{h} - 1\right]$

     where $r = r_f$ radius of disc after forging (r is replaced by "a" in case of non-circular discs)

     $h = h_f$ height of work after forging

     Note that $\sigma_0 = \sigma'_0$ is the yield stress of the disc material in tension/compression.
   - Maximum forging pressure $= P_{max} = \sigma_0 e^{\frac{2\mu r}{h}}$
6. For circular discs under sticking condition
   - Mean or average forging pressure $P_{avg} = \sigma_0\left[1+\frac{2r}{h\times 3\sqrt{3}}\right]$
   - Maximum forging pressure $= P_{max} = \sigma_0\left[1+\frac{2r}{h\sqrt{3}}\right]$

     (r is replaced by "a" in case of non-circular discs)
7. Compressive strain $\varepsilon = \ln\left(\frac{h_1}{h_2}\right)$ or $\ln\left(\frac{h_0}{h_f}\right)$

Model Question Problems.

Model Question Paper: Problems Module - II

Problem:- A circular disc of 150mm radius & thickness 50mm is forged to half its original thickness by open die forging. Determine the maximum forging force if the co-efficient of friction between the job and the die is 0.25. The average yield stress is 4 N/mm².

Soln:- The present problem involves forging a circular disc.

Step 1 Data

Radius of disc before forging $= r_0 = 150mm$

Thickness (height) of disc before forging $= h_0 = 50mm$

Thickness (height) after forging $= h_f = 25mm$ $\mu = 0.25$ (Sliding friction condition)

Average yield stress of circular disc material $= \sigma_0 = 4\ N/mm^2$

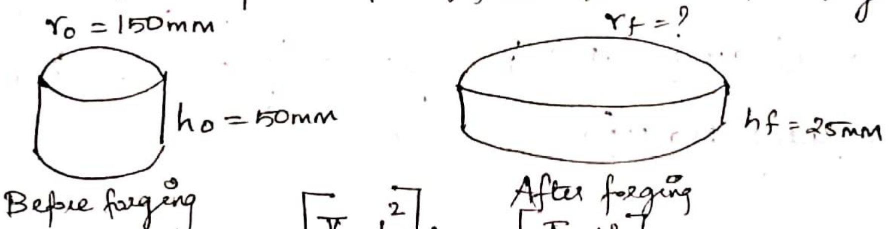
Step 2 To find Maximum forging force (F_{Max})

W.k.T Maximum forging force $F_{Max} = (P_{Max})$ (Area at the end of forging) → ①

To find P_{Max}: For circular disc, $P_{max} = \sigma_0 e^{\frac{2\mu r_f}{h_f}}$

But $r_f = ?$

W.k.T Vol. of Workpiece before forging = Volume after forging



Before forging   After forging

i.e., $\left[\frac{\pi}{4} d_0^2\right] h_0 = \left[\frac{\pi}{4} d_f^2\right] h_f$

$(2 \times 150)^2 (50) = (2 \times r)^2 25$

$4 r_f^2 = 180 \times 10^3$ $\therefore r_f = 212.13mm$

Now equation (2) becomes, $P_{max} = 4 e^{\frac{2(0.25)212.13}{25}} = 278.35\ N/mm^2$

Now, equation (1) becomes

$F_{Max} = (278.35)\left(\frac{\pi}{4} d_f^2\right)$

$= 278.35 \left[\frac{\pi}{4}(2 \times 212.13)^2\right] = 39.35 \times 10^6$

$\therefore F_{Max} = 39.35 \times 10^6 N = \frac{39.35 \times 10^6}{9.81} kg = 4.0112 \times 10^6 kg$

$$= \frac{4.0112 \times 10^6}{1000} = 4011 \text{ TONS}$$

Thus Maximum forging force $F_{max} = 4011$ TONS //.

Problem: 2

A circular bar of 150 mm diameter × 100 mm height is forged at room temperature btwn two flat dies to 25mm height. Determine the yield strength, average die pressure as well as Maximum die pressures at the beginning of plastic deformation & at the end of compression. The yield strength of the material is given as $\sigma = 100.0(0.0085 + \varepsilon)^{0.39}$ N/mm² and $\mu = 0.1$.

Soln:

The present problem involves forging a circular bar (disc)

Step 1 Data

diameter of bar before forging $= d_0 = 150$ mm; $\therefore r_0 = 75$ mm

height of bar before forging $= h_0 = 100$ mm

height of bar after " $= h_f = 25$ mm

Flow stress $= \sigma = 100(0.0085+\varepsilon)^{0.39}$ N/mm²

$\mu = 0.1$ (sliding friction Condition) ⟵ (1)

Note Yield stress (σ_0) is replaced by flow stress (σ) for Work hardening Material.

Step 2

→ To find σ_0, P_{avg} & P_{max} at the beginning of Plastic deformation

→ Let the compressive strain (ε) at the beginning of Plastic deformation be zero ∴ equation (1) becomes

$$\sigma = \sigma_0 = 100(0.0085)^{0.39} = 15.57\,N/mm^2$$

Thus yield strength $\sigma_0 = 15.57\,N/mm^2$ at the beginning of deformation.

For circular disc, under sliding condition, we have

$$P_{avg} = \frac{\sigma_0}{2}\left(\frac{h}{\mu r}\right)^2 \left[e^{\frac{2\mu r}{h}} - \frac{2\mu r}{h} - 1\right]$$

Where $r = r_0$

$h = h_0$

$$\therefore P_{avg} = \frac{15.57}{2}\left[\frac{100}{0.1(75)}\right]^2 \left[e^{\frac{2(0.1)75}{100}} - \frac{2(0.1)(75)}{100} - 1\right]$$

$$P_{avg} = 16.37\,N/mm^2$$

and, w.k.t. $P_{max} = \sigma_0 e^{\frac{2\mu r}{h}}$

$$= 15.57 e^{\frac{2(0.1)(75)}{100}}$$

$$\therefore P_{max} = 18.08\,N/mm^2$$

Step 3. To find σ_0, P_{avg}, P_{max} at the end of Compression

At the end of plastic deformation, we have

$$\text{Compressive strain} = \ln\left[\frac{h_0}{h_f}\right]$$

$$= \ln\left[\frac{100}{25}\right] = 1.386$$

Now equation (1) becomes

$$\sigma = \sigma_0 = 100(0.0085 + 1.386)^{0.39}$$

Yield strength $\sigma_0 = 113.84 \ N/mm^2$ at the end of deformation

For circular disc, Under sliding condition we have

$$P_{avg} = \frac{\sigma_0}{2}\left[\frac{h}{\mu r}\right]^2\left[e^{\frac{2\mu r}{h}} - \frac{2\mu r}{h} - 1\right] \longrightarrow (2)$$

where $r = r_f$ & $h = h_f$

But $r_f = ?$

w.k.t Volume of WBF = Volume after forging

$$\left[\frac{\pi}{4} d_0^2\right] h_0 = \left[\frac{\pi}{4} d_f^2\right] h_f$$

$$(150)^2 \cdot 100 = d_f^2 \cdot 25$$

$\therefore d_f = 300 mm; \ \therefore r = 150 mm$

Now equation (2) becomes,

$$P_{avg} = \frac{113.84}{2}\left[\frac{25}{0.1(150)}\right]^2\left[e^{\frac{2(0.1)(150)}{25}} - \frac{2(0.1)150}{25} - 1\right]$$

$\therefore P_{avg} = 177.1 \ N/mm^2$

& w.k.t $P_{max} = \sigma_0 e^{\frac{2\mu r}{h}}$

where $r = r_f$

& $h = h_f$

$$= (113.84) e^{\frac{2(0.1)150}{25}} \approx 378 \ N/mm^2$$

Thus $P_{max} = 378 \ N/mm^2$

Answers:-

At the beginning of compression :-

$\sigma_0 = 15.57\ N/mm^2$

$P_{avg} = 16.37\ N/mm^2$

$P_{max} = 18.08\ N/mm^2$

At the end of compression :-

$\sigma_0 = 113.84\ N/mm^2$

$P_{avg} = 177.1\ N/mm^2$

$P_{max} = 378\ N/mm^2$

ASSIGNMENT QUESTIONS:

1.Explain the effects of Following Parameters in metal forming process (i) Temperature ,(ii) Strain Rate, (iii) Friction and Lubrication

2. Explain Deformation Zone Geometry

3.Derive an expression for Forging Pressure and load in open die Forging by slab analysis with sliding friction at the interface and also draw the friction hill.

4. Derive an expression for Forging Pressure and load in open die Forging with Sticking friction at the interface and also draw the friction hill.

5.Write short notes on Workability of Materials and Hydrostatic pressure in Metal Working.

6.Mention the Deference between slip and Twinning deformation in Materials.

7.Classify and explain the various forging process, with neat sketches.

8.List and explain Die Design Parameters in Forging.

9.Explain the mode of plastic deformation occurring in metals

10.Comment on : (i)Metallurgical aspect in metal forming and (ii)Residual stresses in wrought products.

11.Explain with sketch the working of (i) ‘ Board-Drop Hammer’,(ii)’Power drop Hammer’.

12.with a neat sketch explain the material flow lines and Defects in forging.

13.With a help of neat sketch explain the ‘Crank Press’.

14. Mention the Deference between Hydraulic and Mechanical Press.