srivenkateshwaraa College of Engineering & Technology
(Approved by AICTE, New Delhi & Affiliated to Pondicherry University, Puducherry)
13-A, Pondy - Villupuram Main Road, Ariyur, Puducherry - 605 102.
ASPIRE TO EXCEL

DEPARTMENT OF MECHANICAL ENGINEERING

SUBJECT NOTES

SUB NAME: METAL FORMING PROCESS

SUBCODE : MET74 **YEAR & SEM :** IV/VII

PREPARED BY,

Mr. S.Ravindran., M.Tech.,(Ph.D)

ASSISTANT PROFESSOR

SVCET

Metal forming processes
Unit-I

Introduction

Metal forming is a very important manufacturing operation. It enjoys industrial importance among various production operations due to its advantages such as cost effectiveness, enhanced mechanical properties, flexible operations, higher productivity, considerable material saving.

Definition:

Materials are converted into finished products though different manufacturing processes. Manufacturing processes are classified into shaping [casting], forming, joining, and coating, dividing, machining and modifying material property.

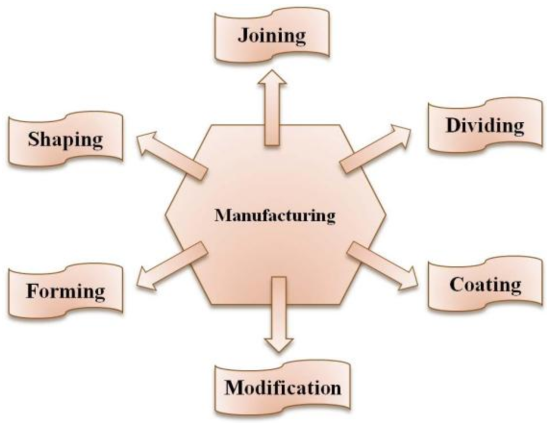


Fig 1.1 various manufacturing operations on materials

Classification of forming processes:

Typically, metal forming processes can be classified into two broad groups. One is bulk forming and the other is sheet metal forming. Bulk deformation refers to the use of raw materials for forming which have low surface area to volume ratio. Rolling, forging, extrusion and drawing are bulk forming processes. In bulk deformation processing methods, the nature of force applied may be compressive, compressive and tensile, shear or a combination of these forces.

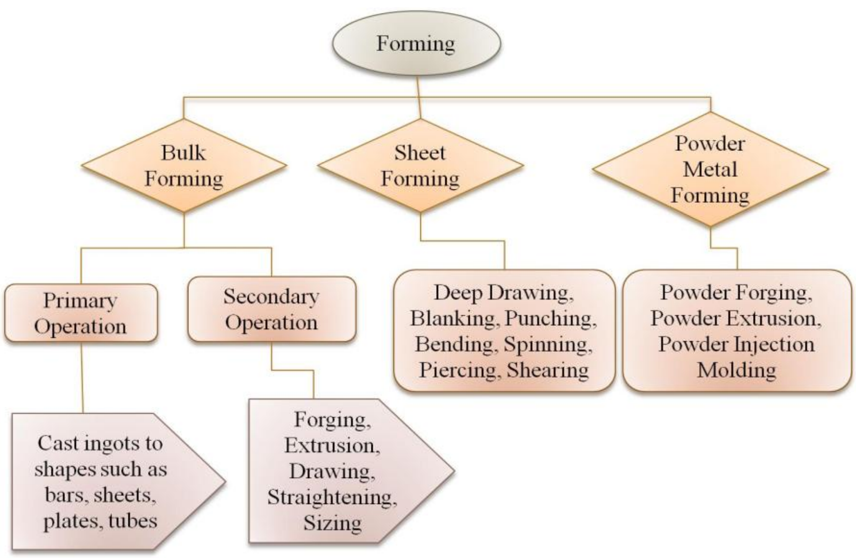


Fig 1.2.Classification of forming processes

Classification of basic bulk forming processes

Bulk forming:

It is a severe deformation process resulting in massive shape change. The surface area-to-volume of the work is relatively small. Mostly done in hot working conditions.

Rolling:

In this process, the work piece in the form of slab or plate is compressed between two rotating rolls in the thickness direction, so that the thickness is reduced. The rotating rolls draw the slab into the gap and compresses it. The final product is in the form of sheet.

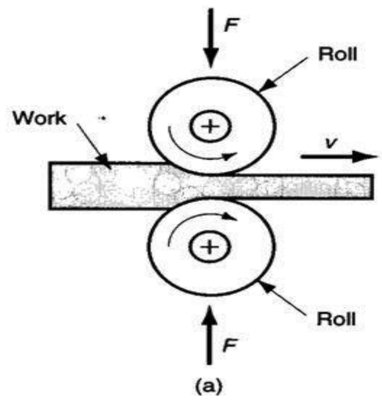


Fig.1.3 Rolling process

Forging:

The work piece is compressed between two dies containing shaped contours. The die shapes are imparted into the final part.

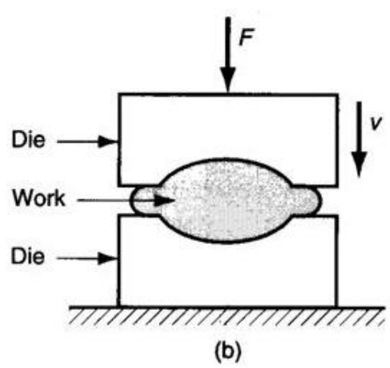


Fig.1.4 Forging process

Extrusion:

In this, the work piece is compressed or pushed into the die opening to take the shape of the die hole as its cross section.

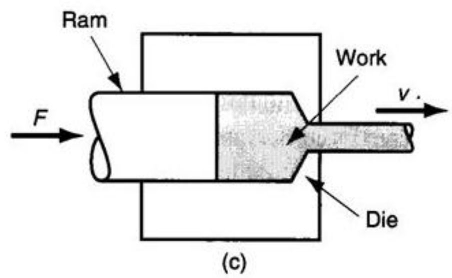


Fig.1.5 Extrusion process

Wire or rod drawing:

Similar to extrusion, except that the work piece is pulled through the die.

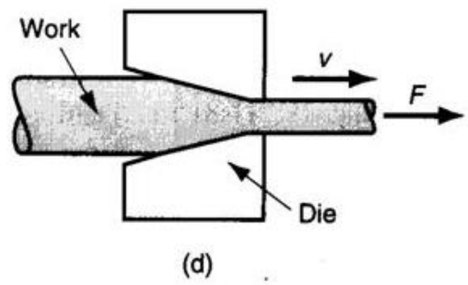


Fig.1.6 Wire or rod drawing

Classification of basic sheet forming processes

Sheet forming:

Sheet metal forming involves forming and cutting operations performed on metal sheets, strips, and coils. The surface area-to-volume ratio of the starting metal is relatively high. Tools include punch, die that are used to deform the sheets.

Bending:

In this, the sheet material is strained by punch to give a bend shape (angle shape) usually in a straight axis.

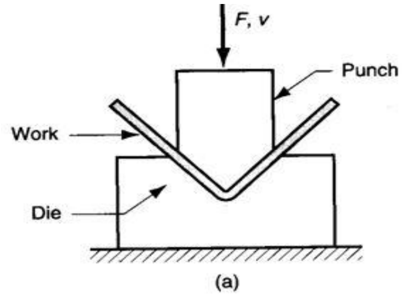


Fig.1.7 Bending process

Deep (or cup) drawing:

In this operation, forming of a flat metal sheet into a hollow or concave shape like a cup is performed by stretching the metal in some regions. A blank-holder is used to clamp the blank on the die, while the punch pushes into the sheet metal. The sheet is drawn into the die hole taking the shape of the cavity.

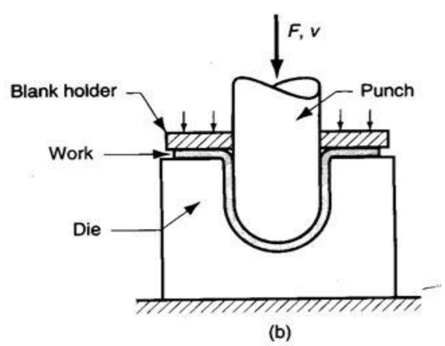


Fig.1.8 Deep (or cup) drawing process

Shearing:

This is nothing but cutting of sheets by shearing action.

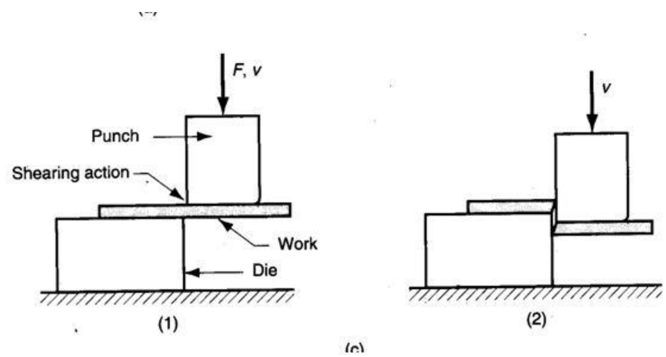


Fig.1.8 Deep (or cup) drawing process

Effect Of Temperature In Metal Forming

Properties of a metal change with an increase in temperature. Therefore, the metal will react differently to the same manufacturing operation if it is performed under different temperatures and the manufactured part may posses different properties. For these reasons, it is very important to understand the materials that we use in our manufacturing process. This involves knowing their behavior at various temperature ranges. In industrial metal forming manufacture, there are three basic temperature ranges at which the metal can be formed, cold working, warm working, and hot working.

Cold working, warm working, hot working

Cold working:

Generally done at room temperature or slightly above RT.

Advantages compared to hot forming:

(1) closer tolerances can be achieved; (2) good surface finish; (3) because of strain hardening, higher strength and hardness is seen in part; (4) grain flow during deformation provides the opportunity for desirable directional properties; (5) since no heating of the work is involved, furnace, fuel, electricity costs are minimized, (6) Machining requirements are minimum resulting in possibility of near net shaped forming.

Disadvantages:

(1) Higher forces and power are required; (2) strain hardening of the work metal limit the amount of forming that can be done, (3) sometimes cold forming-annealing-cold forming cycle should be followed, (4) the work piece is not ductile enough to be cold worked.

Warm working: In this case, forming is performed at temperatures just above room temperature but below the recrystallization temperature. The working temperature is taken to be 0.3 Tm where Tm is the melting point of the workpiece.

Advantages: (1) enhanced plastic deformation properties, (2) lower forces required, (3) intricate work geometries possible, (4) annealing stages can be reduced.

Hot working: Involves deformation above recrystallization temperature, between 0.5Tm to 0.75Tm.

Advantages: (1) significant plastic deformation can be given to the sample,(2) significant change in work piece shape, (3) lower forces are required, (4) materials with premature failure can be hot formed, (5) absence of strengthening due to work hardening.

Disadvantages: (1) shorter tool life, (2) poor surface finish, (3) lower dimensional accuracy, (4) sample surface oxidation.

Flow stress:

Flow curves and their significance in forming process

Flow stress is the stress required to sustain a certain plastic strain on the material. Flow stress can be determined form simple uniaxial tensile test, homogeneous compression test, plane strain compression test or torsion test.In forming of materials, we are concerned with flow stress of material being formed, as this affects the ability of material to undergo deformation. Factors such as strain rate, temperature, affect the flow stress of materials. A simple power law expression for flow stress of a material which does not show anisotropy can be expressed as:

$\sigma = k\varepsilon^{n}$ where n is known as strain hardening exponent.

Higher strain hardening exponent values enhance the flow stress. Similarly, flow stress is enhanced with increase in strain rate during a plastic deformation process.

Effect of strain rate on flow stress becomes more pronounced at higher temperatures. AT higher temperatures [hot working], strain hardening may not have effect on flow stress. However, during cold working effect of strain on flow stress cannot be neglected. In such cases, average flow stress can be determined between two given strains.

In hot forming, temperatures of working are above recrystallization temperature. Therefore, the grains of the metal get elongated along direction normal to applied force, giving raise to anisotropy. During recovery process, locked up dislocations get released. Residual stresses are reduced. Recrystallisation of new grains can happen when the metal gets heated above recrystallization temperature. Secondary grain growth may follow primary recrystallization. In hot working, metal may get softened after hot deformation process. Recrystallised grain size affects the flow stress of material.

A general expression for flow stress, encompassing temperature, strain, strain rate, recrystallisation has been given in the form:

$$\sigma = \frac{2}{\sqrt{3(1-m)}} K\varepsilon^{n}\dot{\varepsilon}^{m}\exp(-\beta T)$$

n is strain hardening exponent, m is strain rate sensitivity exponent, T is temperature.

Materials are subjected to complex states of stresses during forming. Stress required for forming, yield or flow stress therefore depends on several factors, such as strain, strain rate, temperature etc.

From the uniaxial tensile test, one can understand material behavior considerably. Form the tensile test data, we can determine flow stress, though this method has limitations due to localized deformation called necking.

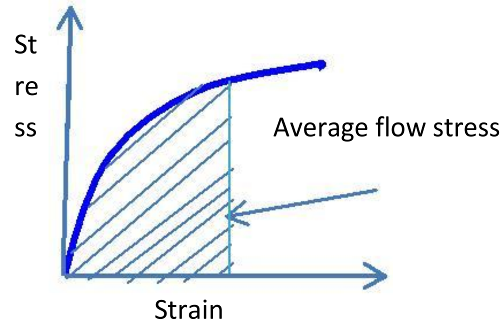
Flow curve is the stress-strain curve for a material in the plastic range. It describes material behavior in metal forming. From flow curve, we can determine the flow stress as

$$\sigma = k\varepsilon^{n}$$

In forming processes, such as forging, the instantaneous flow stress can be found from the flow curve, as the stress required to cause a given strain or deformation.

In extrusion, for example, the flow stress considerably changes during the forming process as the material gets K^{n} work hardened considerably. In such cases, an average flow stress is determined from the flow curve. The average flow stress is given as:

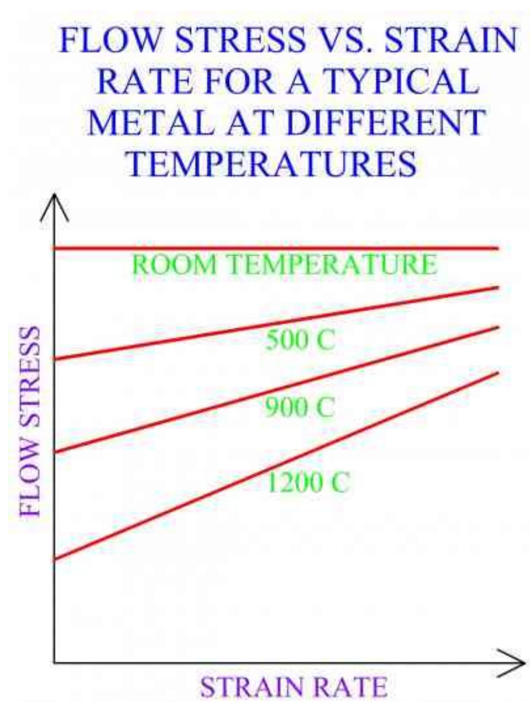
$\sigma_{av} = \frac{\varepsilon}{1+n}$ where ε is maximum strain during deformation process and n is strain hardening exponent.



Knowing the final strain in the forming process, one can calculate flow stress using above equation.

Strain Rate

The strain rate for any particular manufacturing metal forming process is directly related to the speed at which deformation is occurring. A greater rate of deformation of the work piece will mean a higher strain rate. The specific process and the physical action of the equipment being used has a lot to do with strain rate. Strain rate will affect the amount of flow stress. The effect strain rate has on flow stress is dependent upon the metal and the temperature at which the metal is formed. The strain rate with relation to flow stress of a typical metal at different temperatures is shown in fig.



prevail under large deformation speeds, resulting in large rise in temperature of the work piece. This may cause incipient melting. Therefore, strain rate also influences the temperature rise during working.

For low carbon steel, the temperature rise for a true strain of 1 has been estimated to be 553 K. This is without heat lost from the billet.

Effect of Friction And Lubrication In Metal Forming

Metal forming processes are characteristic of high pressures between two contacting surfaces. In hot forming operations, these high pressures are accompanied by extreme temperatures. Friction and die wear are a serious consideration in metal forming manufacturing. A certain amount of friction will be necessary for some metal forming processes, but excessive friction is always undesirable. Friction increases the amount of force required to perform an operation, causes wear on tooling, and can affect metal flow, creating defects in the work.

Where friction is involved, lubricants can usually help. For some metal forming processes and materials no lubrication is used, but for many lubrication is applied to contacting surfaces to reduce friction forces. Lubricants used in industry are different depending upon the type of metal forming process, the temperature at which the operation occurs, and the type of material formed. Lubricants should be effective and not produce any toxic fumes. Lubricants used in manufacturing industry for metal forming processes include, vegetable and mineral oils, soaps, graphite dispensed in grease, water based solutions, solid polymers, wax, and molten glass.

Yield criteria:

Commencement of plastic deformation in materials is predicted by yield criteria. Yield criteria are also called theories of yielding. A number of yield criteria have been developed for ductile and brittle materials.

Tresca yield criterion:

It states that when the maximum shear stress within an element is equal to or greater than a critical value, yielding will begin.

$\tau max \geq k$

Where k is shear yield strength.

Or $\tau_{max} = (\sigma_1 - \sigma_3)/2 = k$ where σ_1 and σ_3 are principal stresses

Or $\sigma_1 - \sigma_3 = Y$

For uniaxial tension, we have k = Y/2

Here Y or k are material properties. The intermediate stress σ_2 has no effect on yielding.

Von Mises criterion:

According to this criterion, yielding occurs when

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2Y^2 = 6k^2$$

For plane strain condition, we have: $\sigma_2 = (\sigma_1 + \sigma_3)/2$

Hence, from the distortion energy criterion, we have $\sigma_1 - \sigma_3 = \frac{2}{\sqrt{3}}Y$ Here, $\frac{2}{\sqrt{3}}Y$ is called plane strain yield strength. Von Mises criterion can also be interpreted as the yield criterion which states that when octahedral shear stress reaches critical value, yielding commences.

The octahedral shear stress is the shear stresses acting on the faces of an octahedron, given by:

$$\tau_{oct} = \frac{1}{3}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]1/2$$

According to Tresca criteria we know, $(\sigma_1 - \sigma_3)/2 = k$. Therefore,

$k = \frac{Y}{\sqrt{3}}$

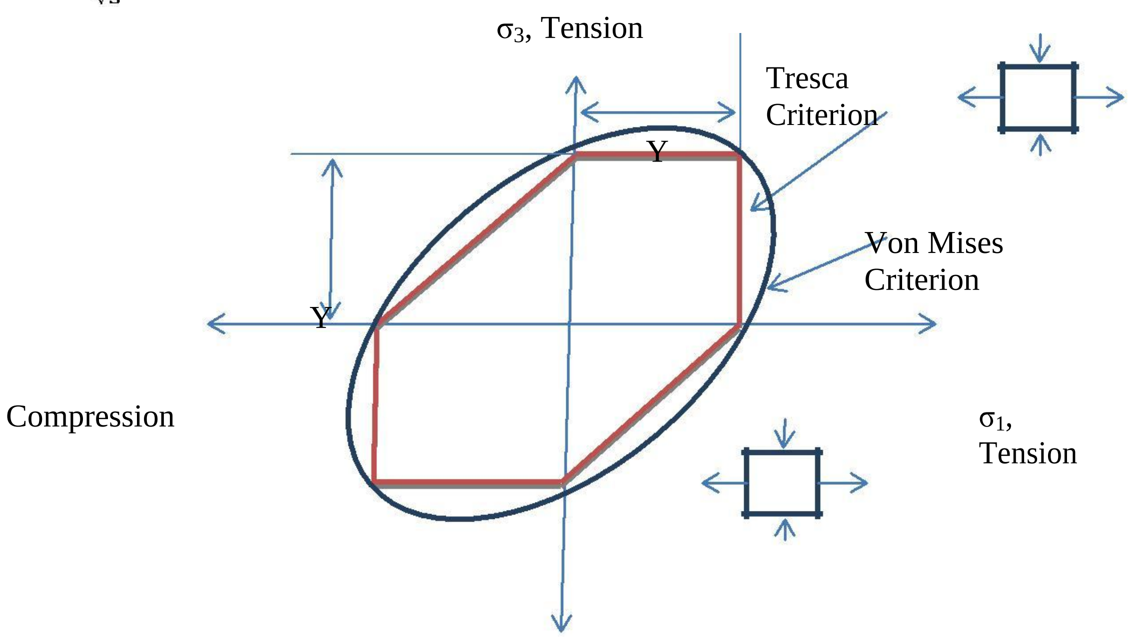


Fig 1.11 Yield loci for the two yield criteria in plane stress

Von Mises yield criterion is found to be suitable for most of the ductile materials used in forming operations. More often in metal forming, this criterion is used for the analysis. The suitability of the yield criteria has been experimentally verified by conducting torsion test on thin walled tube, as the thin walled tube ensures plane stress. However, the use of Tresca criterion is found to result in negligible difference between the two criteria. The von Mises criterion is able to predict the yielding independent of the sign of the stresses because this criterion has square terms of the shear stresses.

Unit-III
Forging

Definition:

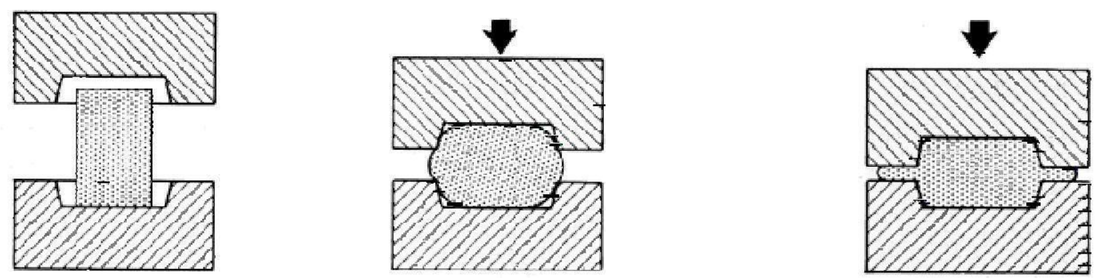
Forging is a metal working process in which useful shape is obtained in solid state by hammering or pressing metal.

It is one of the oldest metalworking arts with its origin about some thousands of years back. Some examples of shapes obtained by forging process: Crane hook, connecting rod of IC engine, spanner, gear blanks ..etc.

Different Forging Operations

1. **Upsetting**

The thickness of the work reduces and length increases



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

Fig1. Upsetting

2. Edging

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

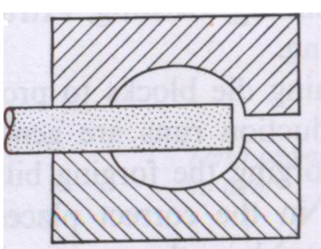


Fig 2. Edging

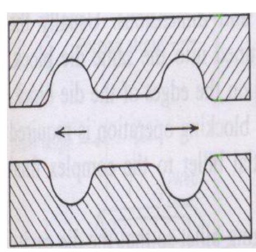


Fig 3. Fullering

3. Fullering

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

4. Drawing

The cross sectional area of the work is reduced with corresponding increase in length using convex dies.

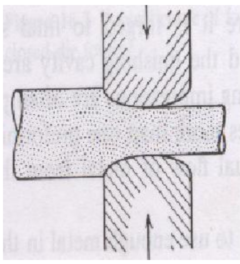


Fig 4. Drawing

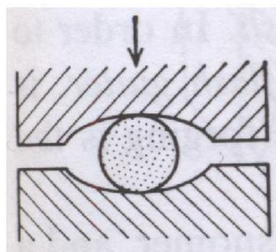


Fig 5. Swaging

5. Swaging: The cross sectional area of the bar is reduced using concave dies.

6. Piercing: The metal flows around the die cavity as a moving die pierces the metal.

7. Punching: It is a cutting operation in which a required hole is produced using a punching die.

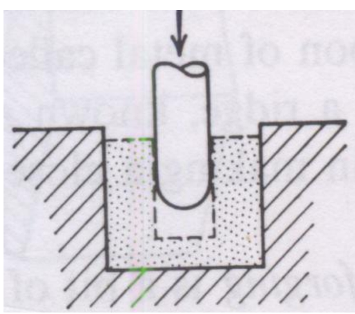


Fig 6. Piercing

Punch

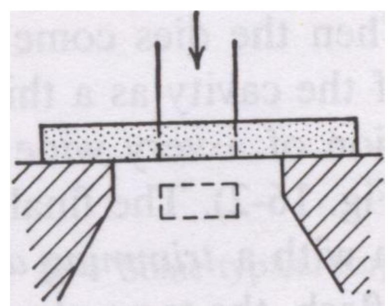


Fig 7. Punching

8. Bending: The metal is bent around a die/anvil.

Classification of Forging Processes

Based on Temperature of the work piece:

1. Hot Forging: (most widely used)

Forging is carried out at a temperature above the recrystallization temperature of the metal.

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

2. Cold Forging:

Forging is carried out at a temperature below the recrystallization temperature of the metal.

Advantages:

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

Disadvantages of Cold 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 Arrangement of Dies:

1. **Open Die Forging:** Flat dies of simple shape are used.

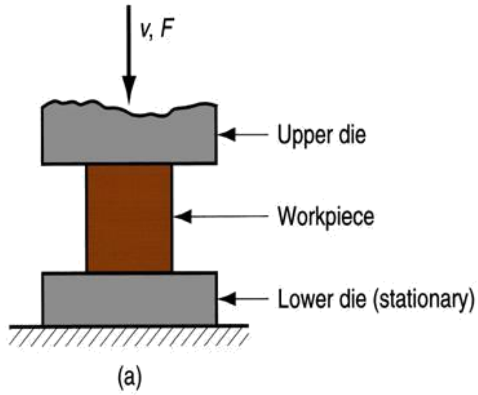


Fig. Open Die Forging

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

2. Closed Die Forging:

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

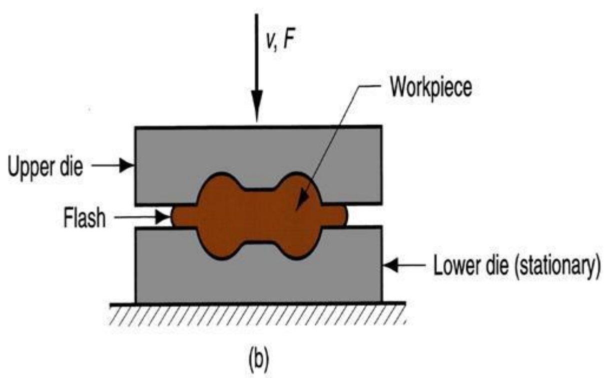


Fig. Closed DieForging

Features of 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.

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.

Forging Equipment

They are classified based on the principle of operation.

1. **Forging Hammer**
    - The force is supplied by a falling weight of ram.
    - Deformation of work piece is due to the application of the kinetic energy of the ram.

Types of Forging Press

i) **Mechanical board hammer:**

- It is a stroke restricted machine.
- Repeatedly the board (weight) is raised by rolls and is dropped on the die.
- Rating is in terms of weight of the ram and energy delivered.

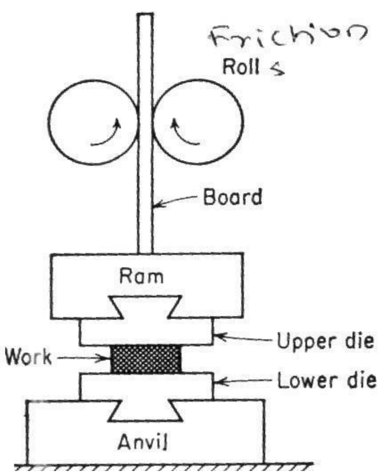


Fig. Mechanical Board Hammer

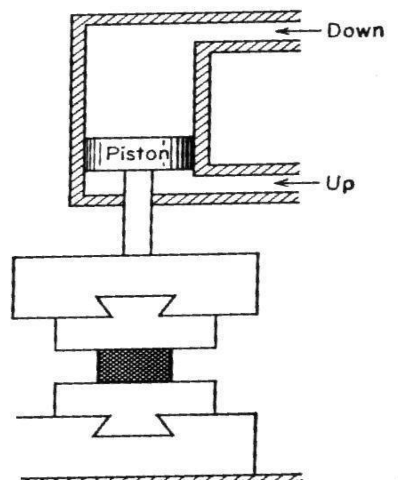


Fig. Steam Hammer

ii) Steam Hammer (Power Hammer) Range: 5 kN to 200 kN

- It uses steam in a piston and cylinder arrangement.
- It has greater forging capacity.
- It can produce forgings ranging from a few kgs to several tonnes.
- Preferred in closed die forging

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

iii) Hydraulic Press:

- It is a load restricted machine.
- It has more of squeezing action than hammering action.
- Hence dies can be smaller and have longer life than with a hammer.

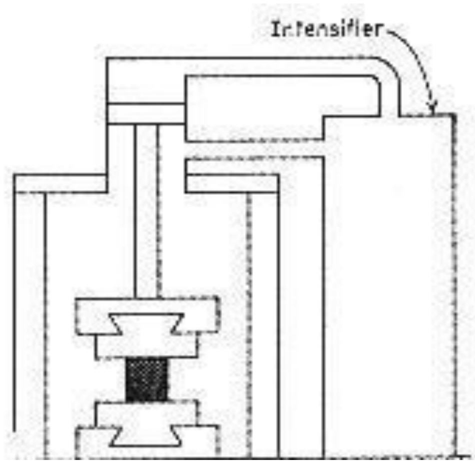


Fig. Hydraulic Press

Features of Hydraulic Press

- Full press load is available during the full stroke of the ram.
- Ram velocity can be controlled and varied during the stroke.
- It is a slow speed machine and hence has longer contact time and hence higher die temperatures.
- The slow squeezing action gives close tolerance on forgings.
- Initial cost is higher compared to hammers.

Determination of forging load

Example 1.

A steel slab is upset forged from: 50mmx200mmx100mm to 25mmx200mmx200mm. If the coefficient of friction between die and the material is 0.1 and yield strength of the steel is 250 N/mm^2, find the forging load.

- **Solution:**

Step i) To decide the dimensions to be used in the calculations:

Data: h=25mm

2a=200mm

w=200mm=constant

Step ii) To determine the condition of friction between die and work

Step iii) to determine the average forging pressure and forging load

Answer: Forging Load= 17.68MN/mm^2

Forging load= Pav x length x width

=39.8 MPa x 0.1m x 0.15m

=597kN

FORGING PRESSURE / LOAD IN CLOSED DIE FORGING (CFD)

The deformation in closed die forging is highly complex and hence designing dies and intermediate steps is very critical and requires high skill.

The main objectives are: – complete die fill and closed dimensional tolerance. Important factors to be considered in CDF are:

1. Flash design : flash controls die fill and creates high forging loads
2. Proper understanding of the flow stress of the material: ensures successful forging operation
3. Frictional conditions
4. Optimal geometry of the die: Result of proper understanding of flow stress, friction conditions and flow of the metal in the die
5. To prevent rapid cooling of the work piece by cold die's :
    - die's are preheated for many difficult aerospace applications- called isothermal heating
    - Results in lower flow stress and forging loads
    - Gives complete die fill and close dimensional tolerances

The design of a workpiece (part) made by CDF involves the prediction of the following :

1. Vol. and wt. of the workpiece
2. No. of pre-forming or intermediate steps and their configuration

3. Flash dimension in finishing die

4. Load & en-requirement for each operation

Forging load in CDF:

Prediction of forging load in CDF is quite difficult because of complexity involved Usual prediction methods are:

1. **Past Experience**:

   To estimate forging load of a new part/geometry: using information available from previous forging s of similar materials and shapes is used.

2. **Using empirical relations**:

   One of the widely used equations is:

$P = \sigma . A_t C_1$

Where σ = effective true stress

A_t = cross sectional area of the forging at the parting line, including the flash Where C_1 = a constant, depends on the complexity of the forging

C_1 = 1.2 to 2.5 for upsetting a cylinder between flat dies

= 3 to 8 for simple closed die forging

= 8 to 12 for more complex shapes

3. **Slab Analysis**- with suitable modifications for situations in CDF Basic approach:

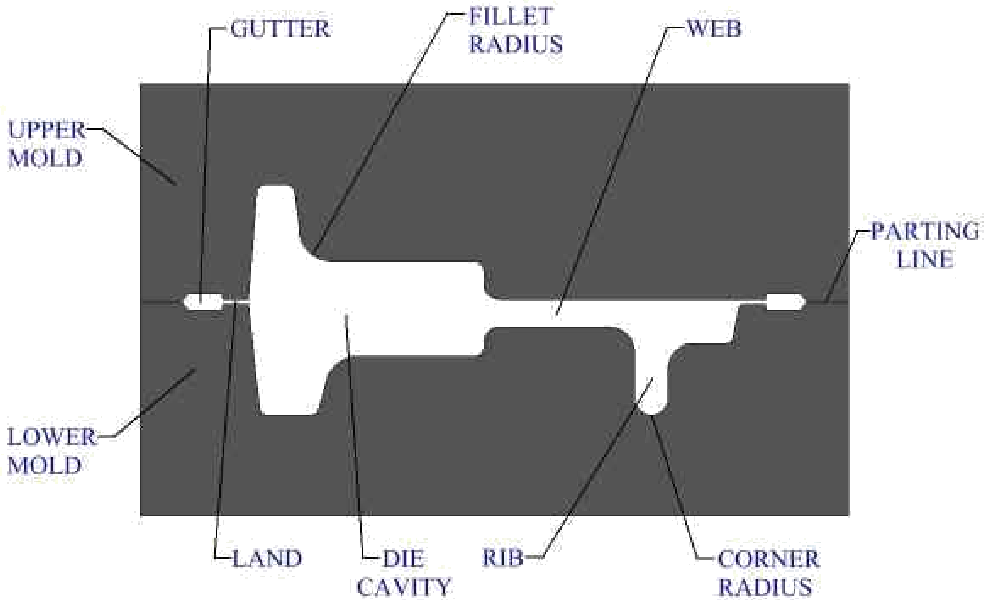
   - The forging required is divided into simple geometric shapes, which are separately treated by slab analysis
   - The addition of all the loads of parts gives the total forging load

Forge die design procedure

DIE DESIGN PARAMETERS

- Die design depends on the forging required and its design requires the knowledge of:
  1. Strength and ductility of work piece materials
  2. Sensitivity of the materials to the rate of deformation and temperature
  3. Frictional characteristics
  4. Shape and complexity of work piece
  5. Die distortion under high forging loads- for close dimensional tolerance

FORGING DIE DESIGN



1. **Parting Line**
   - is at the largest c/s of the part
   - is a st. line at centre for simple shapes
   - may not be in a single plane for complex shape

2. **Flash and Gutter**
   - Flash material is allowred to flow into a gutter
   - Prevents unnecessary increase of forging load (because of excess/ extra flash)

- Guidelines for flash and clearance between dies:
   - 3% of max. thickness of the forgings
   - The length of the land = 2 to 5 times the flash thickness

3. **Draft Angles**
   - For easy removal of forgings from the die
   - Similar to draft <u>in casting design</u>
   - Internal draft angles are larger – 7^o- 10^o
   - External draft angles are smaller – 3^o- 5^o

4. **Fillet :** It is a small radius provided at corners.
   - To ensure smooth flow of metal into die cavity
   - To improve die life

- As a general rule, should be as large as possible

Small fillet radii lead to;
- Improper metal flow
- Rapid wear of die
- Fatigue cracking of dies

5. **Die material : requirements are**
   - Strength and toughness at elevated temperature
   - Hardenability and ability to harden uniformly
   - Resistance to mechanical and thermal shocks
   - Wear resistance – to resist abrasion wear due to scales present on work piece

Selection of proper die material depends on :

Die size

Composition and properties of work piece

Complexity of shape- no of performing steps

Forging temperature

Type of forging operation

Cost of die material

No. of forgings required

Heat transfer from work piece to dies

- **Die materials used:**
- Tool and die steels with Cr, Ni, Mo, Va

Die Manufacturing: It consists of the following steps:

- -- Initially castings
- – then forged
- – finally machined and finished to required shape and surface finish.

Material Flow Lines in Forgings:

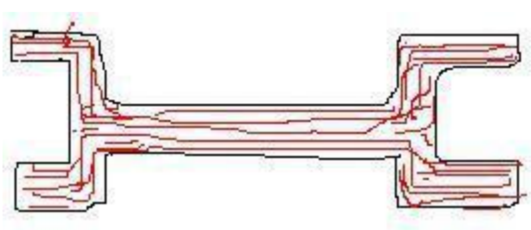


Fig. Material Flow Lines

- The deformation produced by forging gives a certain degree of **directionality** to the microstructure of the work material.

- Due to this, second phases and inclusions are oriented parallel to the direction of greatest deformation.

- When magnified, this appears as flow lines or fiber structure, **a major characteristic** of all forgings.

Limitation of flow lines:

- Flow lines (fiber structure) lead to lower tensile ductility and lower fatigue properties in the direction normal to it (in transverse direction).

- Hence **optimal balance** between ductility in longitudinal and transverse directions is very essential. (Deformation limited to 50% to 70% reduction in c/s area.

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. High sulfur in furnace leading to 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.

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. Scale pockets and under fills:

- They are loose scale/ lubricant residue which accumulate in deep recesses of the die.
- Cause: Incomplete descaling of the work
- Remedy: Proper decaling of work prior to forging

6. Internal cracks

Cause: Secondary tensile stresses developed during forging

Remedy: Proper die design

Residual stresses in Forging:

Causes: 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.

Concept of Powder Metallurgy forging

As in conventional PM, powder forging begins with custom-blended metal powders being fed into a die, then being compacted into a ―green‖ shape, which is then ejected from the die. This compact, called a ―preform,‖ is different from the shape the final part will acquire after being forged. Again as in the conventional PM process, the green compact is sintered (solid-state diffused) at a temperature below the melting point of the base metal in a controlled atmosphere furnace, creating metallurgical bonds between the powder particles and imparting mechanical strength to the preform.

Powder forging produces parts that possess mechanical properties equal to wrought materials. Since they're made using a net-shape technology, PF parts require only minor secondary machining and offer greater dimensional precision and less flash than conventional precision forgings.

Parts fabricated through the PF process are subject to certain limitations. Tooling and the maximum press tonnage capabilities impose size and shape constraints on parts, just as in impression die hot forging. Annual production quantities in excess of 25,000 pieces are typically required to amortize the development costs of tool set-ups and maintenance. Finally, material systems are somewhat limited (all commercial PF products are steel).

Typical Powder Forged Products—connecting rods, cams, bearing races, transmission components

Typical Markets Using Powder Forged Parts—automotive, truck, off-road equipment, power tools

Unit-III
Rolling Process

Introduction

Rolling is one of the most important industrial metal forming operations. Hot Rolling is employed for breaking the ingots down into wrought products such as into blooms and billets, which are subsequently rolled to other products like plates, sheets etc.

Rolling is the plastic deformation of materials caused by compressive force applied through a set of rolls. The cross section of the work piece is reduced by the process. The material gets squeezed between a pair of rolls, as a result of which the thickness gets reduced and the length gets increased.

Mostly, rolling is done at high temperature, called hot rolling because of requirement of large deformations. Hot rolling results in residual stress-free product. However, scaling is a major problem, due to which dimensional accuracy is not maintained. Cold rolling of sheets, foils etc is gaining importance, due to high accuracy and lack of oxide scaling. Cold rolling also strengthens the product due to work hardening.

Steel ingot is the cast metal with porosity and blowholes. The ingot is soaked at the hot rolling temperature of $1200^{o}C$ and then rolled into blooms or billets or slabs.

Bloom is has a square cross section, with area more than 230 cm^2. A slab, also from ingot, has rectangular cross-section, with area of at least 100 cm^2 and width at least three times the thickness. A billet is rolled out of bloom, has at least 40 mm X 40 mm cross-section.

Blooms are used for rolling structural products such as I-sections, channels, rails etc. Billets are rolled into bars, rods. Bars and rods are raw materials for extrusion, drawing, forging, machining etc. Slabs are meant for rolling sheets, strips, plates etc.

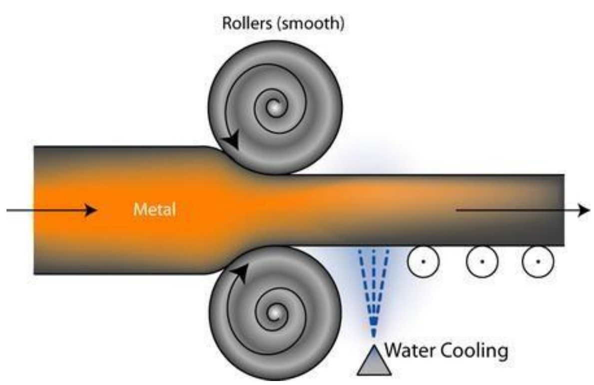


Fig Rolling process

Rolling mills:

Rolling mill consists of rolls, bearings to support the rolls, gear box, motor, speed control devices, hydraulic systems etc. The basic type of rolling mill is two high rolling mills. In this mill, two opposing rolls are used. The direction of rotation of the rolls can be changed in case of reversing mills, so that the work can be fed into the rolls from either direction. Such mills increase the productivity. Non reversing mills have rolls rotating in same direction. Therefore, the work piece cannot be fed from the other side. Typical roll diameters may be 1.4 m.

A three high rolling mill has three rolls. First rolling in one direction takes place along one direction. Next the work is reversed in direction and fed through the next pair of roll. This improves the productivity.

Rolling power is directly proportional to roll diameter. Smaller dia rolls can therefore reduce power input. Strength of small diameter rolls are poor. Therefore, rolls may bend. As a result, larger dia backup rolls are used for supporting the smaller rolls. Four high rolling mill is one such mill. Thin sections can be rolled using smaller diameter rolls. Cluster mill and Sendzimir mill are used for rolling thin strips of high strength materials and foils [0.0025 mm thick]. The work roll in these mills may be as small as 6 mm diameter – made of tungsten carbide. Several rolling mills arranged in succession so as to increase productivity is called rolling stand. In such arrangement, anuncoiler and windup reels are used. They help in exerting back tension and front tension.

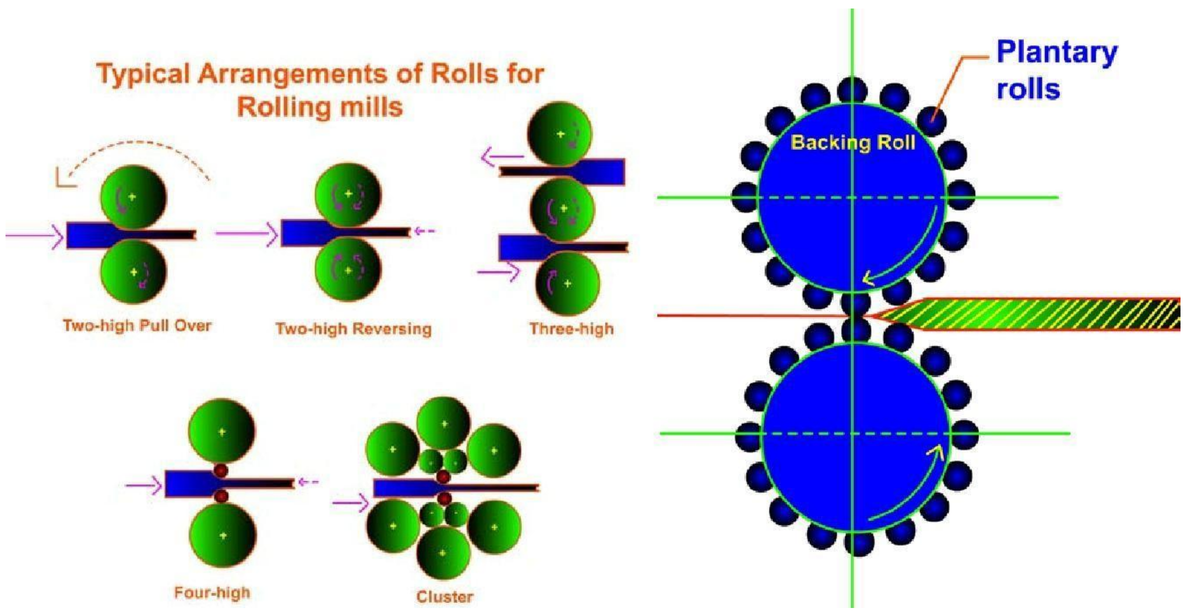


Fig .Rolling mills

Planetary mill has a pair of large heavy rolls, surrounded by a number of smaller rolls around their circumference. In this mill, a slab can be reduced to strip directly in one pass. Feeder rolls may be needed in order to feed the work piece into the rolls.

Merchant mill is specifically used for rolling bars.

Hot rolling is usually done with two high reversing mill in order to breakdown ingots into blooms and billets. For increased productivity, universal mill has two vertical rolls which can control the width of the work simultaneously.

Non ferrous materials are cold rolled into sheets from hot rolled strips. Four high tandem mills are generally used for aluminium and copper alloys. In order to achieve upto 90% reduction in thickness in cold rolling, a series of rolling mills may be used to share the total reduction.

One important application of cold rolling is the removal of yield point from mild steel sheets using skin pass rolling [temper rolling]. In this the steel sheet is given a light reduction of 0.5 to 1.5% . Such a process eliminates yield point elongation. If yield elongation of steel occurs during sheet metal operation, such as deep drawing, the surface of the sheet metal becomes rough due to formation of Luder bands, also called stretcher strains.

Flatness of rolled sheets can be increased by roller leveling. In this process, the sheet is passed between a pair of rolls which are driven by individual motors and are slightly offset.

Rolls should have high stiffness, hardness and strength. Cast iron, cast steel and forged steel are also used as rolls.

Grain structure in rolling:

When the wrought or cast product gets hot rolled, the grain structure, which is coarse grained, becomes finer in size, but elongated along the direction of rolling. This type of textured grain structure results in directional property [anisotropy] for the rolled product. In order to refine the grains, heat treatment is performed immediately after rolling, which results in recrystallization after rolling.

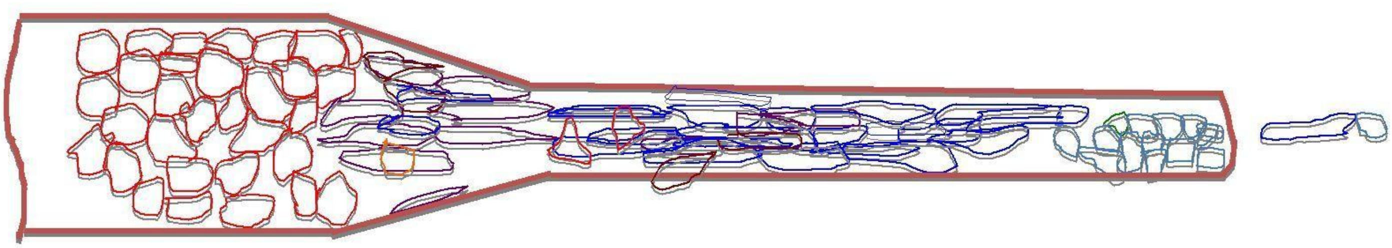


Fig. Variation of grain structure, size during longitudinal rolling

Defects in Rolled Products

a) General b) Operational

a) **General**

The defects may arise due to

i) Surface irregularities: The ingot or the raw material may be having irregularities due to scaling which will get trapped in the metal and remain inside the metal surface as laps. This needs to be removed by grinding and there will be metal loss. If the defect is deep and severe the product may get rejected.

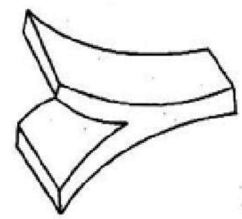
ii) Non-metallic inclusions: The inclusions may results from oxides or nitrides or silicates etc., especially in steels. These are present in the molten metal during the preparation. If less in volume may cause small cracks in the metal and if more in volume will result in severe cracks called crocodile cracks separating the product into two halves.

iii) Internal Pores: There may be pores in the product due to the presence of gases like hydrogen,oxygen,nitrogen etc., If too much gases are present leads to elongation of the pores and the product may become weaker. Sometimes separation may take place resulting in cracks.

i) Barrel: Due to friction at the edges of the product barrel action takes place. Surface in contact experience severe friction as compared to center of the work. Hence, with heavy reduction in the work the center tends to expand laterally more than the outer surfaces in contact with the dies and produces barreled edges.

Barelling

Non uniform defomation



Alligator Cracks

ii) Non uniform deformation: When the rolling conditions a re such that only surface of the work piece is deformed. The cross section of the slab is deformed into the shape as shown.

The middle portion is less deformed as compared to the outer surface.

This may be due to variation in temperature in the metal. Surface temperature being more than the inside temperature of the slab.

iii) Alligator Cracks: If there is any metallurgical weakness in the metal (due to the presence of inclusions) along the centre line of the slab, fracture will occur. This results in the separation of the layer giving rise to opening of the slab which looks like an alligator mouth in opening position. Hence, the name.

Others:

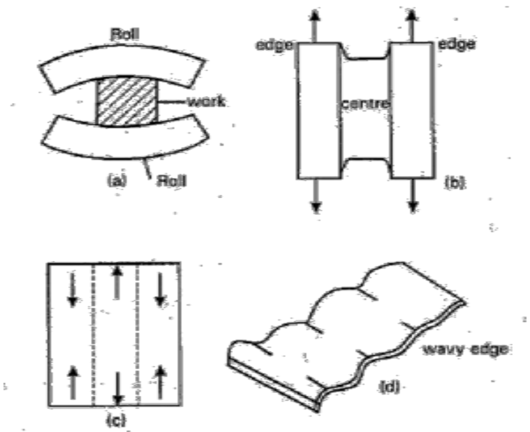
i) **Hydrogen cracks:** During preparation of the melt in the furnace several gases tries to get into the melt. Out of this Hydrogen gas diffuses into the melt to a large extent and is retained in the solid metal. Due the presence of hydrogen in excess internal cracks appear through the cross section during rolling and cannot be used. It is a major problem with alloy steels especially.

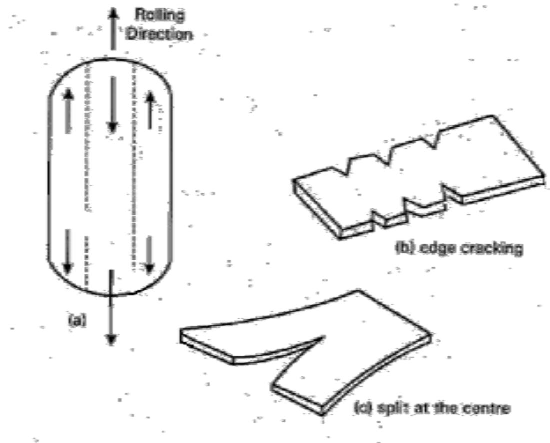
ii) **Non metallic inclusion:** Inclusions are non metallics appearing in the metal as a result of entrapment. During the preparation of the molten metal non metallic like oxides, nitrides, silicates enter the melt and remain as such in the solid metal. These are discontinuities in the metal and reduce the properties of the metal. On rolling they may result in cracks which may reach a critical value and make the product rejectable.

Defects: Operational

i) Waviness..Varying thickness.

ii) Edge Cracking





i) Waviness..Varying thickness.

Variation in the work across the width in sheet rolling occurs because the roll gap is not perfectly parallel (a).

Since width and volume are constant and thickness is varying, the edges elongate more than the center (b).

But the sheet is a continuous body; the strains readjust to maintain continuity.

Thus the center portion is in tension and the edges are in compression (c). The

result is a wavy edge (d).

ii) Edge Cracking

The length of the center portion increases but the edges are prevented due to frictional force. As a result the material gets rounded off (a).
The edges are strained in tension leading to edge cracking along the width of the slab (b).
When the difference in the strains become excess i.e. under severe condition, split at the center of the slab occurs (c).

Extrusion process

Introduction

Extrusion is a compressive deformation process in which a block of metal is squeezed through an orifice or die opening in order to obtain a reduction in diameter and increase in length of the metal block. The resultant product will have the desired cross-section. Extrusion involves forming of axisymmetric parts. Dies of circular on non-circular cross-section are used for extrusion.

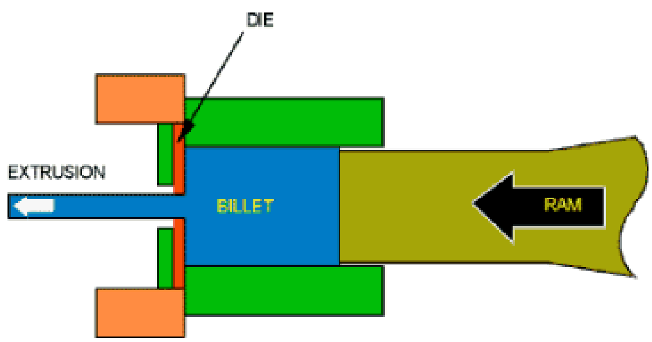


Figure 1

Generally, extrusion involves greater forming forces. Large hydrostatic stress in extrusion helps in the process by enhancing the ductility of the material.
Metals like aluminium, which are easily workable, can be extruded at room temperature. Other difficult to work metals are usually hot extruded or warm extruded.
Both circular and non circular parts can be obtained by extrusion. Channels, angles, rods, window frames, door frames, tubes, aluminium fins are some of the extruded parts.

Difficult to form materials such as stainless steels, nickel alloys are extruded due to its inherent advantage, namely, no surface cracking due to reaction between the billet and the extrusion container. Extrusion results in better grain structure, better accuracy and surface finish of the components. Less wastage of material in extrusion is another attractive feature of extrusion.

Lead pipes were extruded in late 1700's in England. Later on lead sheathing of electric cables was done by extrusion.

Types of extrusion:
Extrusion ratio:

It is the ratio of area of cross-section of the billet to the area of cross-section of the extrude.

R = Ao/Af

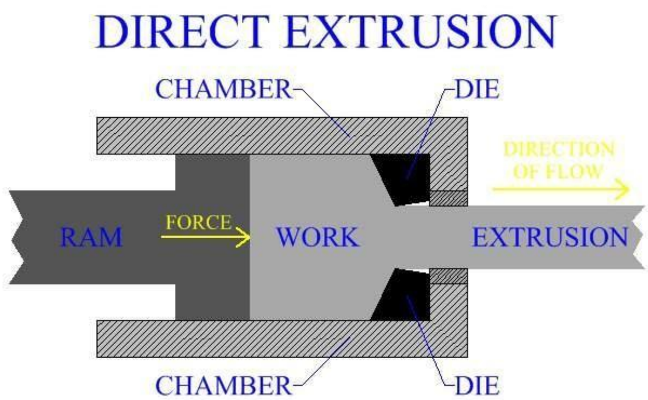
Another parameter used in extrusion is shape factor, ratio of perimeter to the cross-section of the part. An extruded rod has the lowest shape factor.

Extrusion is classified in general into four types. They are: Direct extrusion, indirect extrusion,

impact extrusion and hydrostatic extrusion.
In extrusion process, the billet is placed in a container, pushed through the die opening using a ram and dummy block. Both ram and billet move.

Direct extrusion:

Direct extrusion, also called forward extrusion, is a process in which is the billet moves along the same direction as the ram and punch do. Sliding of billet is against stationary container wall. Friction between the container and billet is high. As a result, greater forces are required. A dummy block of slightly lower diameter than the billet diameter is used in order to prevent oxidation of the billet in hot extrusion. Hollow sections like tubes can be extruded by direct method, by using hollow billet and a mandrel attached to the dummy block.



Extrusion force, which is the force required for extrusion, in direct extrusion, varies with ram travel as shown in figure above. Initially the billet gets compressed to the size of container, before getting extruded. Also, initially static friction exists between billet and container.

As a result the extrusion pressure or force increases steeply as shown. Once the billet starts getting extruded, it length inside the container is reduced. Friction between billet and container now starts reducing.

Therefore, extrusion pressure reduces. The highest pressure at which extrusion starts is called breakthrough pressure. At the end of the extrusion, the small amount of material left in the container gets pulled into the die, making the billet hollow at centre.

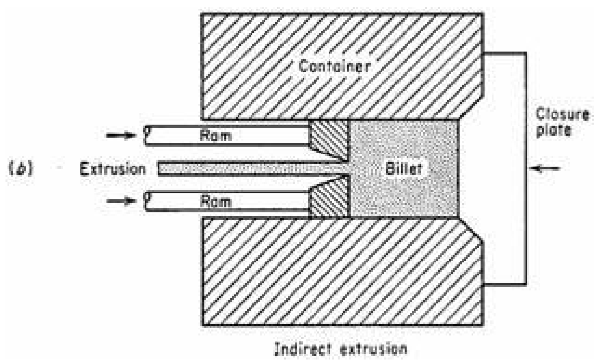
This is called pipe. Beyond pipe formation, the extrusion pressure rapidly increases, as the small size billet present offers higher resistance. As the length of the billet is increased, the corresponding extrusion pressure is also higher because of friction between container and billet. Therefore, billet lengths beyond 5 times the diameter are not preferred in direct extrusion.

Direct extrusion can be employed for extruding solid circular or non-circular sections, hollow sections such as tubes or cups.

Indirect extrusion:

Indirect extrusion (backward extrusion) is a process in which punch moves opposite to that of the billet. Here there is no relative motion between container and billet. Hence, there is less friction and hence reduced forces are required for indirect extrusion. For extruding solid pieces, hollow punch is required.

In hollow extrusion, the material gets forced through the annular space between the solid punch and the container. The variation of extrusion pressure in indirect extrusion is shown above. As seen, extrusion pressure for indirect extrusion is lower than that for direct extrusion. Many components are manufactured by combining direct and indirect extrusions. Indirect extrusion can not be used for extruding long extrudes.



Hydrostatic extrusion:

In hydrostatic extrusion the container is filled with a fluid. Extrusion pressure is transmitted through the fluid to the billet. Friction is eliminated in this process because of there is no contact between billet and container wall. Brittle materials can be extruded by this process.

Highly brittle materials can be extruded into a pressure chamber. Greater reductions are possible by this method. Pressure involved in the process may be as high as 1700 MPa. Pressure is limited by the strength of the container, punch and die materials.

Vegetable oils such as castor oil are used. Normally this process is carried out at room temperature. A couple of disadvantages of the process are: leakage of pressurized oil and uncontrolled speed of extrusion at exit, due to release of stored energy by the oil. This may result in shock in the machinery.

This problem is overcome by making the punch come into contact with the billet and reducing the quantity of oil through less clearance between billet and container. Hydrostatic extrusion is employed for making aluminium or copper wires-especially for reducing their diameters. Ceramics can be extruded by this process. Cladding is another application of the process. Extrusion ratios from 20 (for steels) to as high as 200 (for aluminium) can be achieved in this process.

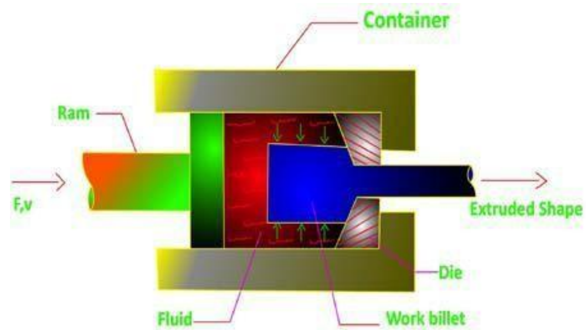


Fig. Hydrostatic extrusion

Impact extrusion: Hollow sections such as cups, toothpaste containers are made by impact extrusion. It is a variation of indirect extrusion. The punch is made to strike the slug at high speed by impact load. Tubes of small wall thickness can be produced. Usually metals like copper, aluminium, lead are impact extruded.

Tube extrusion:

Employing hollow billet and a mandrel at the end of the ram, hollow sections such as tubes can be extruded to closer tolerences. The mandrel extends upto the entrance of the die. Clearance between the mandrel and die wall decides the wall thickness of the tube. The mandrel is made to travel along with the ram in order to make concentric tubes by extrusion.

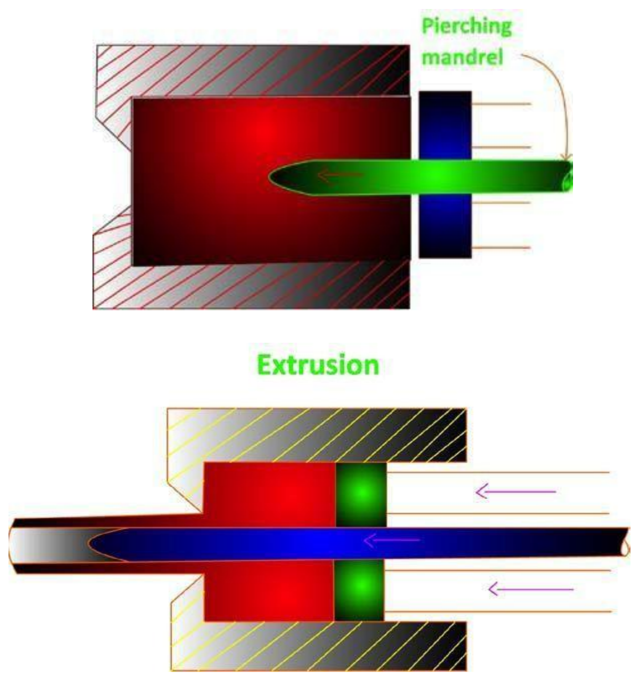


Fig: Extrusion of tubes – piercing and extrusion

Tubes can also be made using solid billet and using a piercing mandrel to produce the hollow. The piercing mandrel is made to move independently with the help of hydraulic press.

It moves along with the ram coaxially. First the ram upsets the billet, keeping the mandrel withdrawn. Next the mandrel pierces the billet and ejects a plug of material from central. Then the ram and mandrel together are moved in and extrude the billet.

Plug rolling and Mannesmann processes are also the other methods of producing seamless tubes.

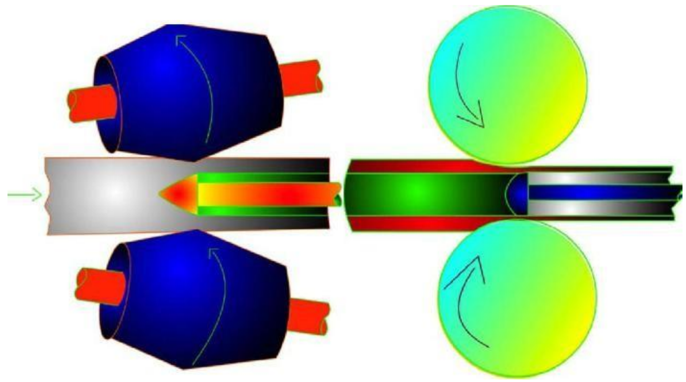


Fig: Mannesmann process and plug rolling process

Port hole extrusion is another method of producing tubes and hollow sections in aluminum, magnesium etc. In this method, a die with a number of ports and a central mandrel supported by a bridge is used. The billet is squeezed through the ports and flows in separate streams. After the die section the extruded streams are joined together by welding in the welding chamber.

Cold and hot extrusion:

Cold extrusion could produce parts with good surface finish, high strength due to strain hardening, improved accuracy, and high rate of production. However, the process requires higher pressure and tools are subjected to higher stresses. Proper lubrication is necessary for preventing seizure of tool and work piece. Phosphate coated billets are lubricated with soap.

Hot extrusion can be employed for higher extrusion ratios. Inhomogeneous deformation can occur due to die wall chilling of the billet. Metal may get oxidized. The oxide layer can increase friction as well as the material flow. Glass is used as lubricant for hot extrusion. Molybdenum disulfide or graphite are the solid lubricants used in hot extrusion. Canned extrusion using thin walled cans made of copper or tin is usually used for extruding highly reactive metals and metal powders.

Extrusion presses:

Hydraulic presses of vertical or horizontal type are used for extrusion. Vertical presses are of capacity ranging from 3 to 20 MN. Horizontal presses occupy less space, but the billets get non uniformly cooled. Horizontal presses upto 50 MN capacity are being used. Tubular extrusions are mostly done in vertical presses, while horizontal presses are used for bar extrusion.

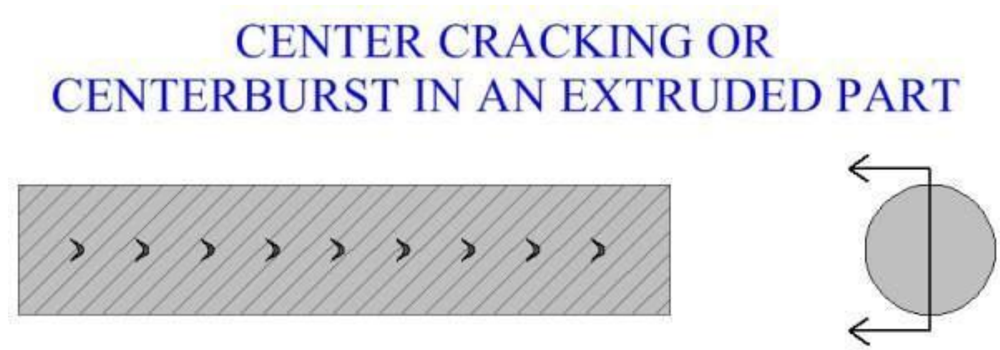
Extrusion Defects

Extrusion defects that occur during the manufacturing process generally fall into three basic categories. Internal breakage, particularly in the center, surface cracking, and piping.

Center Cracking

Internal breakage; common names used in manufacturing industry for this type of defect are center cracking, cheveron cracking, arrowhead fracture, and center burst. As the work piece is being extruded through the die, stresses within the work break the material causing cracks to form along the central axis of the extruded section.

Center cracking is a difficult defect to detect since it occurs within the material of the part. Figure shows a metal extrusion subject to center burst, the part has been cut in a half section so that the defect may be observed.



If the stress level becomes too high, then material breakage will occur in the form of internal cracks.

Surface Breakage

Surface breakage defect on a metal extrusion, is breakage on the surface of the part. Most surface defects are in the form of cracks that extend from the surface into the parts material, to varying degrees.

These cracks usually occur along the grain boundaries of the metal. The primary cause of surface cracking defect in metal extrusion manufacture is excessive stresses on the surface of the part's material.

Friction is a large factor in controlling surface breakage, while manufacturing an extruded section. Increased friction will create a more favorable environment for surface cracking. Lubrication can help reduce friction, so can an increased die angle.

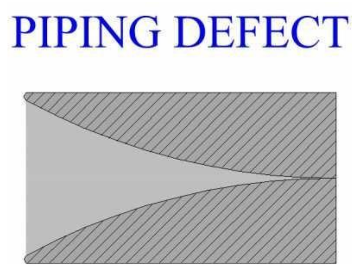
Piping Defect

Piping, also called tailpipe or fishtailing, is a defect common when manufacturing sections by direct extrusion.

The use of a dummy block and good surface preparation of the work can help avoid piping. Piping occurs in the work material at the end opposite to the die.

Piping is a result of improper metal flow during the extrusion operation. Piping manifests itself as a funnel shaped void of material at the end of the work. As mentioned before, metal flow is a very important consideration in any forming operation. The way to solve a piping problem is to enact a smooth metal flow during the extrusion process.

The combination of friction and thermal gradients acting at the die-work interface needs to be observed, and their cumulative effect on the metal flow occurring during the process determined. The manufacturing engineer must control the different process variables to achieve the smoothest material flow possible during the metal extrusion operation.



Unit –IV

Drawing of rods, wires and tubes

Introduction

Drawing is a process in which the material is pulled through a die by means of a tensile force. Usually the constant cross section is circular (bar, rod, wire, tube).

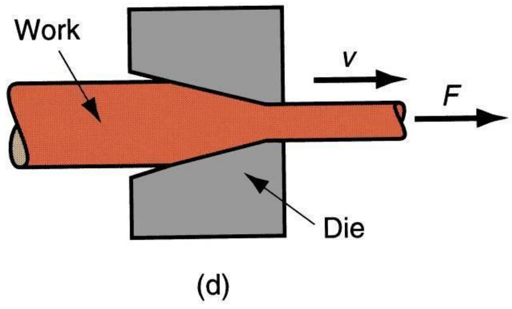


Fig Drawing process

Metal Drawing Process

The metal drawing process in manufacturing industry is usually performed cold. Cold working will impart the drawn product with accurate tolerances, favorable grain structure, improved material properties and good surface finish. Preparation of the work, prior to drawing, is an important part of the operation.

The work is sometimes annealed first, to recover the material from existing stresses. Next the work surfaces are cleaned. Common industrial practice for cleaning metal stock includes shot blasting or submersion in some, (typically acidic), solution.

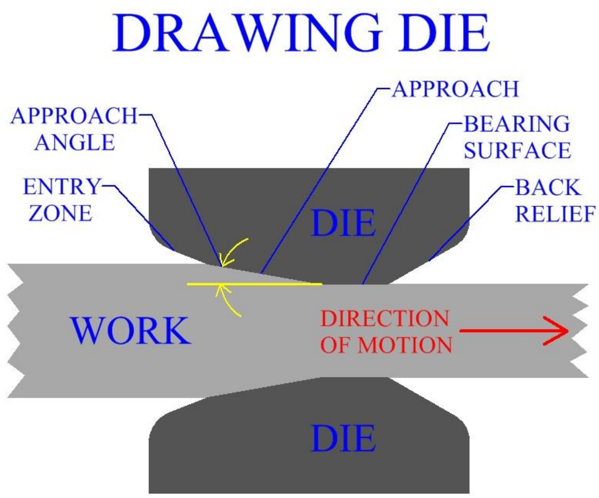
Metal drawing can be either a discrete or continuous operation and can be very economically efficient for certain applications. In commercial industry, this process provides stock material for machining operations and for the manufacture of such items as fences, coat hangers, nails, screws and bolts. Metal wire drawing plays a huge roll in the manufacturing industry in the production of cable and electrical wire.

Drawing Dies

Metal drawing dies, in manufacturing industry, are usually made of cemented carbides or tool steels. Mandrels for tube drawing are often made of similar materials as the die. Occasionally diamond die are employed to form extremely thin wire.

As the work transverses the mold it passes through different sections. The die's first section is a bell curved opening. This area does not contact the work, but helps filter lubricant into the mold and allows for adequate entry of the work into the mold without damage from die edges.

Next, the forming of the work occurs in the approach section. The approach angles down the cross sectional area, connecting with the next section, the bearing surface. Bearing surface, also known as land, holds the precise geometric cross section for a length of the draw. This acts as a sizing operation, ensuring tight tolerances. The last section is the exit zone, this is a steeply angled section similar to the entry zone. Exit zones are used to protect drawn work from the edges of the die.



Defects In Metal Drawing:

Defects that occur in metal drawing manufacture are similar to those that occur while manufacturing by extrusion. Controlling metal flow is essential in preventing defects. Mold characteristics and friction play a critical roll in the process.

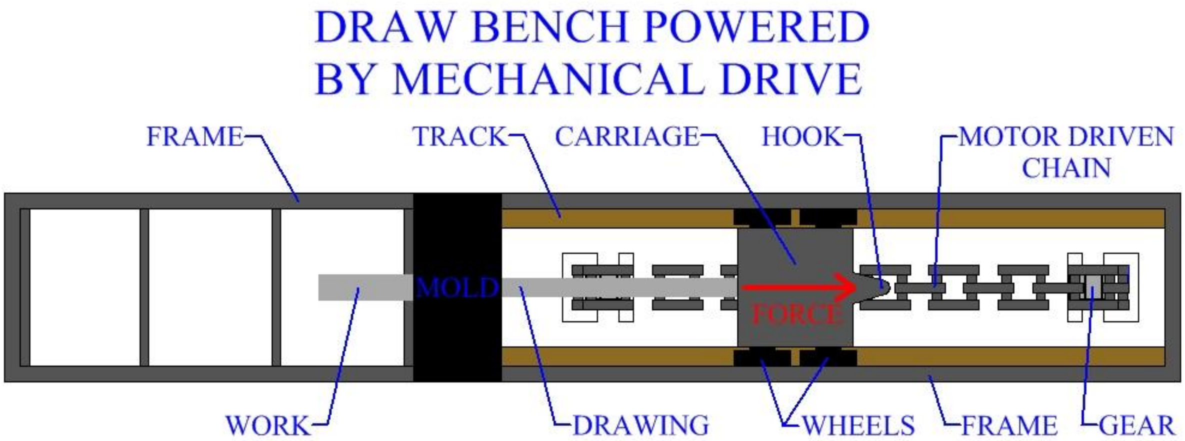
Internal Cracking: Internal breakage may occur in drawn products, particularly along the centerline. This is due to improper metal flow creating high internal stresses. Causes may be high die angles or low friction.

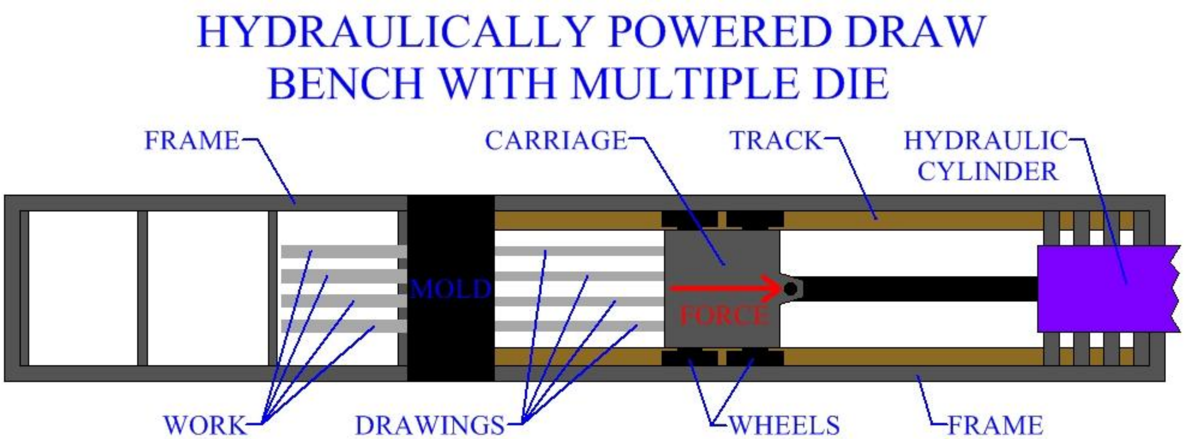
Surface Defect: A wide variety of surface defects can be observed in metal drawing manufacture. Seams, scratches and cracks are all possible defects on the surface of drawn product. Excessive force on the surface of the work during the drawing operation, (such as from friction), can be the cause of breakage. Also, many metal drawing operations form at very high speeds, sufficiently designed entry and exit zones need to be provided in order to avoid damage to the work material from the die. For more detailed information on internal breakage and surface defects see extrusion defects.

Rod and Bar Drawing

Rod or bar drawing is a term used to denote one of two categories of metal drawing. Rod or bar drawing refers to the drawing of work of larger cross sections, while wire drawing refers to the forming of work of a relatively smaller profile. Due to the size of the work, rod and bar drawing involves much more finite lengths of material than wire drawing. This type of process is carried out as a discrete manufacturing operation.

Rod or bar drawing is usually performed on a draw bench. A draw bench consists of a long table, a die stand containing the mold and a carriage used to grip and draw the work. The die stand may contain two or more molds; multiple dies allow more than one part to be drawn with each operation. Draw benches vary in size and can be up to 100 feet in length. Force used to draw the metal is exerted through hydraulic or mechanical means. Pulling force as high as 150 tons has been used during industrial production.



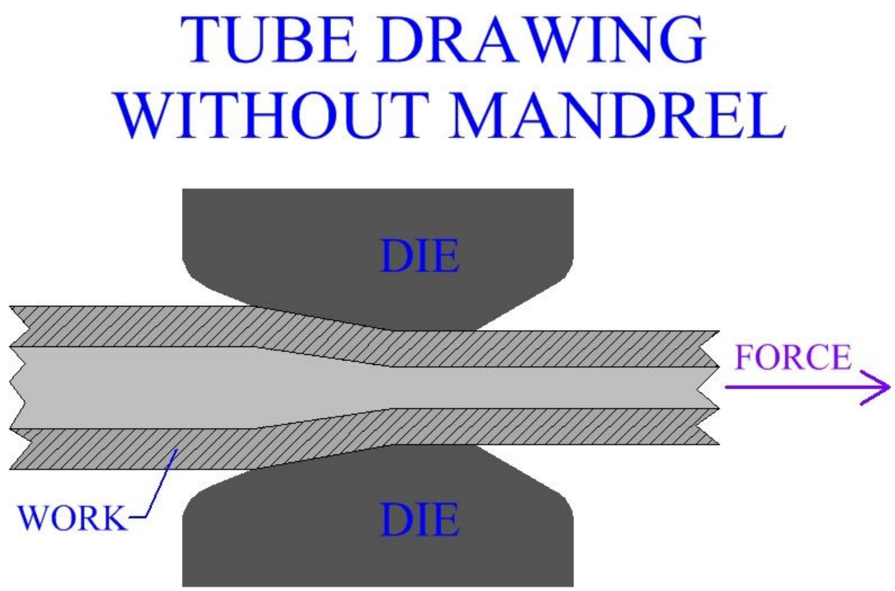


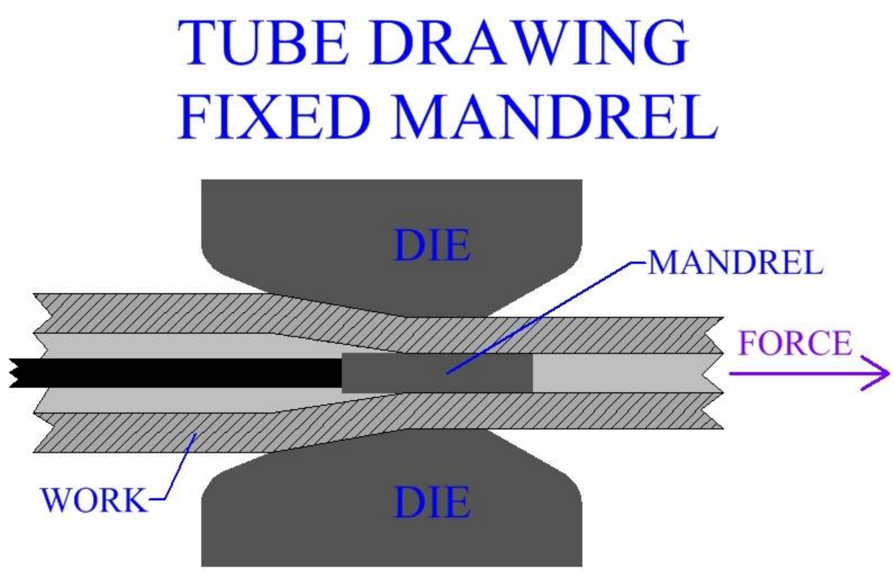
Production of Hollow Tubes and Drawn Shapes

The majority of metal drawing operations produce round or square shapes, however different cross sections such as u-sections and other simple shapes are also manufactured. Hollow profiles, particularly hollow round tubes of different lengths, diameters and wall thicknesses are common in drawing production. Many tubes and special profiles are of larger geometry, and are drawn as a discrete manufacturing operation. Production of drawn shapes and hollow tubes is usually performed on a draw bench and would be classified in the rod and bar category of operations.

The specifics of the metal deformation are important when drawing different cross sections. Sometimes a series of operations may be needed to form a particular profile.

Often times drawing is used to finish tubes and profiles already manufactured by other methods, such as extrusion or rotary tube piercing. When forming a tube a mandrel may or may not be used. A tube may be formed without a mandrel if its internal dimensions are not critical. It is often required that hollow tubes hold certain tolerances on internal diameter and wall thickness. For that reason, mandrels are often employed. Fixed mandrels are anchored on one side, floating mandrels are not anchored and are designed to fit in place. Floating mandrels may allow for the production of longer lengths of tube.





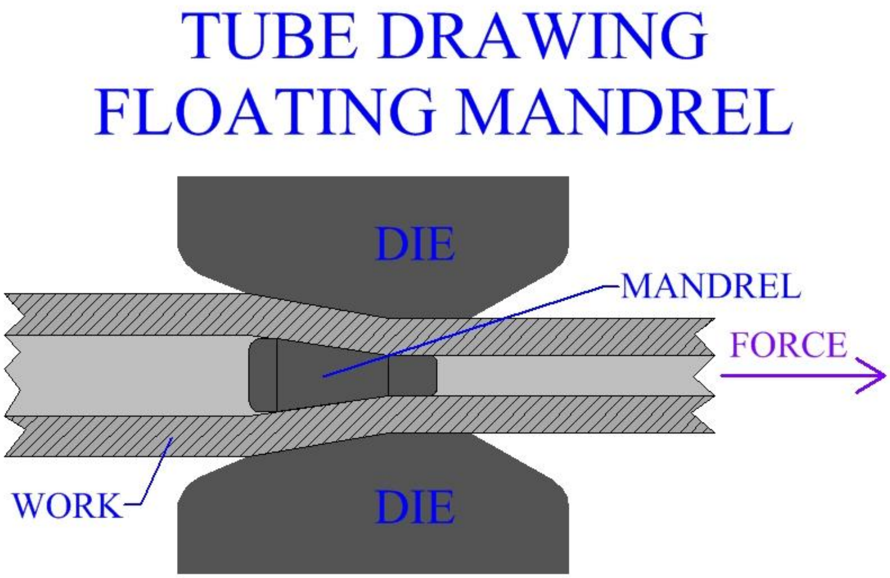
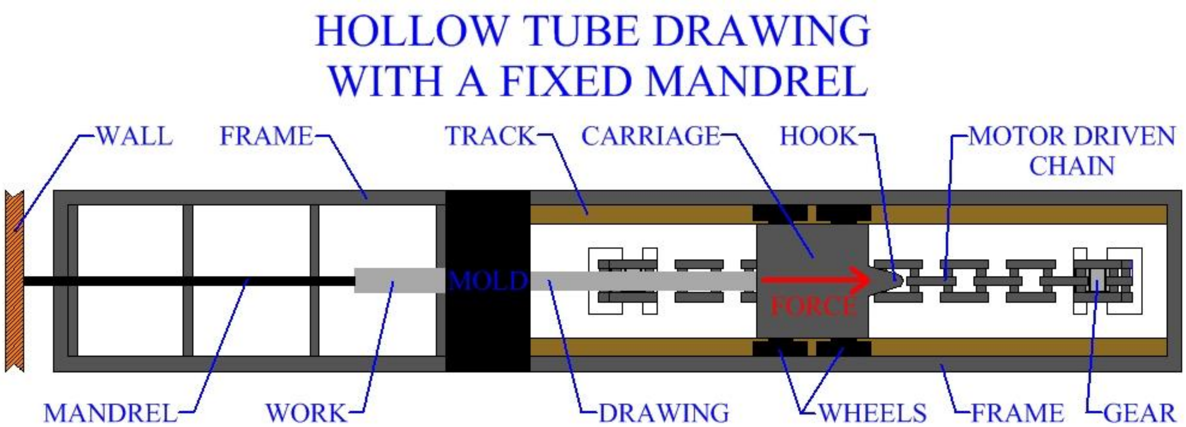


Figure:



Wire Drawing

Wire drawing is the second major category of metal drawing operations. While rod and bar drawing refer to the drawing of larger cross sections, wire drawing refers to the drawing of relatively smaller cross sections.

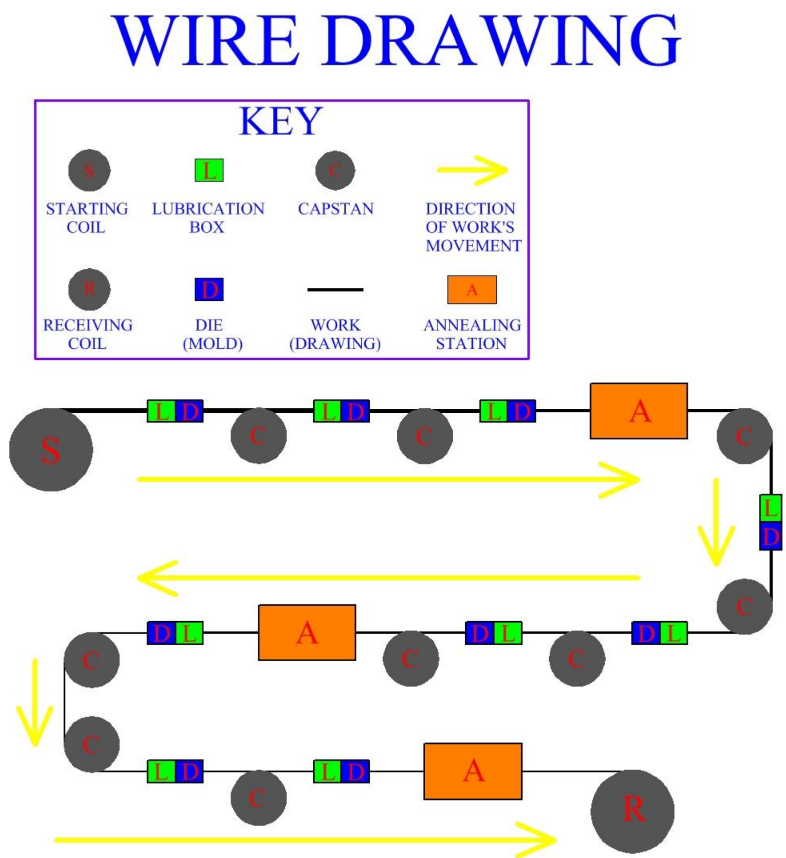
The enormous amount of electrical wire and cable produced by this manufacturing method makes wire drawing a major modern industrial process. Some wire must be manufactured to tremendously small cross sectional areas, such as those used in electromagnets. Wire may be drawn to diameters as low as .0001 inch. Diamond die inserts are often used in the production of extremely fine wire.

Metal work stock in wire drawing will usually undergo several reductions in diameter, since the mechanics of the process limit the amount of reduction in a single draw.

This is accomplished by drawing the work through several die in series, each producing an incremental reduction in the work's diameter. Between dies the wire stock is wrapped several times around a motor driven rotating drum called a capstan, before proceeding to the next die in series.

Annealing of the metal may be performed between groups of operations. The capstans provide the force for the manufacturing process. As the diameter is reduced, the speed of the wire is increased. Velocity of wire leaving the last mold in a series can be significantly higher than the velocity of the work entering the first mold. Typically drawing speeds may be 20-100 feet per minute, but in some cases wire may be drawn at 10,000 feet per minute. Pieces of stock can be end welded together as they are fed into the system of capstans and die so that the process will be completely continuous. Industrial wire drawing operations can manufacture miles of wire at a time.

Figure:



Sheet metal forming;

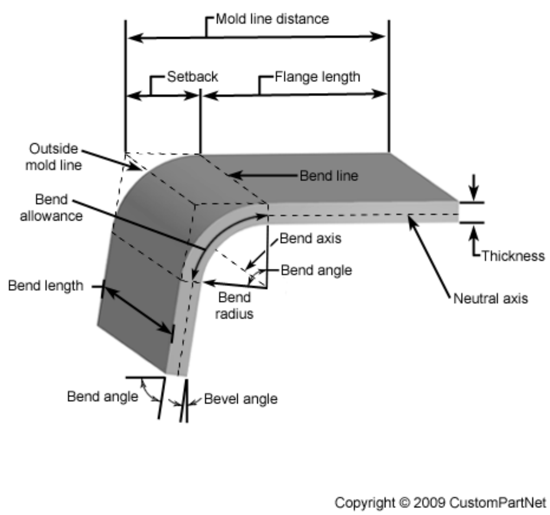
Sheet metal forming processes are those in which force is applied to a piece of sheet metal to modify its geometry rather than remove any material.

The applied force stresses the metal beyond its yield strength, causing the material to plastically deform, but not to fail. By doing so, the sheet can be bent or stretched into a variety of complex shapes. Sheet metal forming processes include the following:

- Bending
- Roll forming
- Spinning
- Deep Drawing
- Stretch forming

Bending

Bending is a metal forming process in which a force is applied to a piece of sheet metal, causing it to bend at an angle and form the desired shape. A bending operation causes deformation along one axis, but a sequence of several different operations can be performed to create a complex part. Bent parts can be quite small, such as a bracket, or up to 20 feet in length, such as a large enclosure or chassis. A bend can be characterized by several different parameters, shown in the image below.

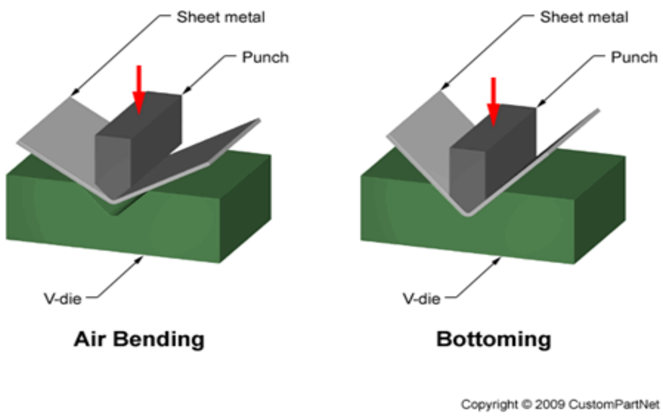


Bending Diagram

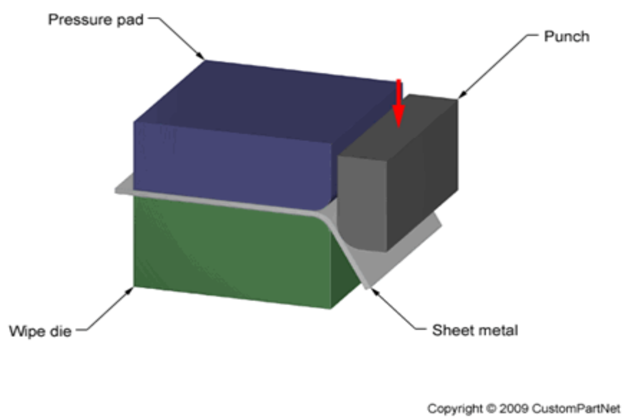
- *Bend line* - The straight line on the surface of the sheet, on either side of the bend, that defines the end of the level flange and the start of the bend.
- *Outside mold line* - The straight line where the outside surfaces of the two flanges would meet, were they to continue. This line defines the edge of a mold that would bound the bent sheet metal.
- *Flange length* - The length of either of the two flanges, extending from the edge of the sheet to the bend line.
- *Mold line distance* - The distance from either end of the sheet to the outside mold line.

- *Setback* - The distance from either bend line to the outside mold line. Also equal to the difference between the mold line distance and the flange length.
- *Bend axis* - The straight line that defines the center around which the sheet metal is bent.
- *Bend length* - The length of the bend, measured along the bend axis.
- *Bend radius* - The distance from the bend axis to the inside surface of the material, between the bend lines. Sometimes specified as the inside bend radius. The outside bend radius is equal to the inside bend radius plus the sheet thickness.
- Bend angle - The angle of the bend, measured between the bent flange and its original position, or as the included angle between perpendicular lines drawn from the bend lines.
- *Bevel angle* - The complimentary angle to the bend angle.

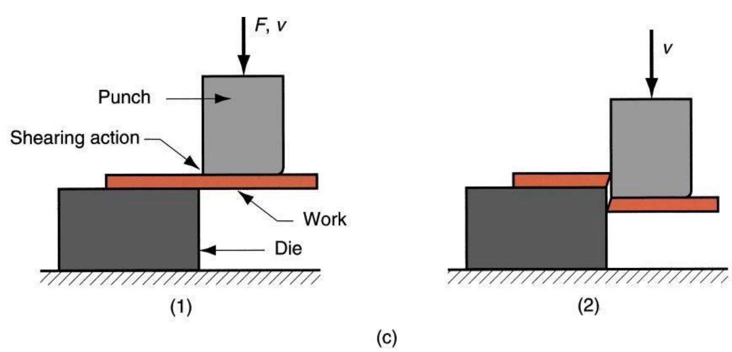
'V' type of Bending



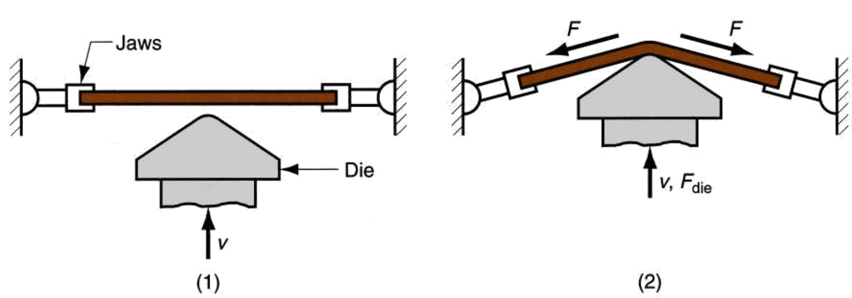
Wipe bending



Shearing and Blanking (Separation of the materials by two cutting edges)

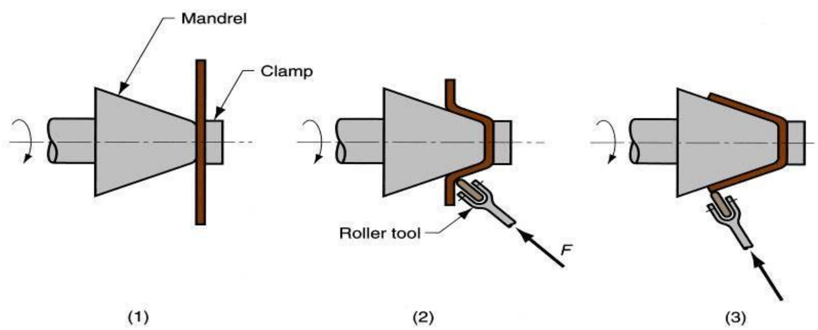


Stretching (Forming by tensile stresses over a tool)



Spinning (Forming against a rotating form block with a tool)

Spinning, sometimes called spin forming, is a metal forming process used to form cylindrical parts by rotating a piece of sheet metal while forces are applied to one side. A sheet metal disc is rotated at high speeds while rollers press the sheet against a tool, called a mandrel, to form the shape of the desired part. Spun metal parts have a rotationally symmetric, hollow shape, such as a cylinder, cone, or hemisphere. Examples include cookware, hubcaps, satellite dishes, rocket nose cones, and musical instruments.



Deep drawing

Deep drawing is a metal forming process in which sheet metal is stretched into the desired part shape. A tool pushes downward on the sheet metal, forcing it into a die cavity in the shape of the desired part.

The tensile forces applied to the sheet cause it to plastically deform into a cup-shaped part. Deep drawn parts are characterized by a depth equal to more than half of the diameter of the part.

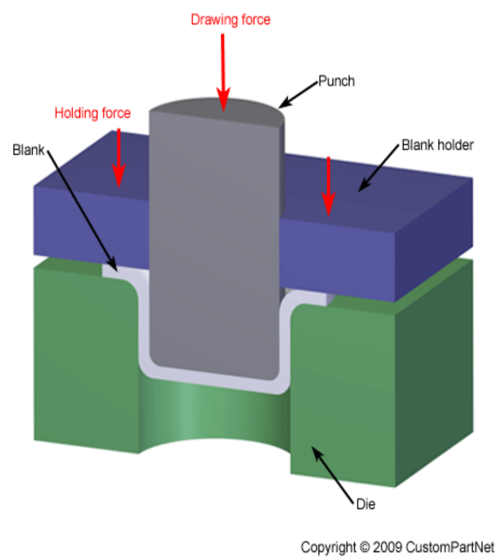
These parts can have a variety of cross sections with straight, tapered, or even curved walls, but cylindrical or rectangular parts are most common. Deep drawing is most effective with ductile metals, such as aluminum, brass, copper, and mild steel.

Examples of parts formed with deep drawing include automotive bodies and fuel tanks, cans, cups, kitchen sinks, and pots and pans.

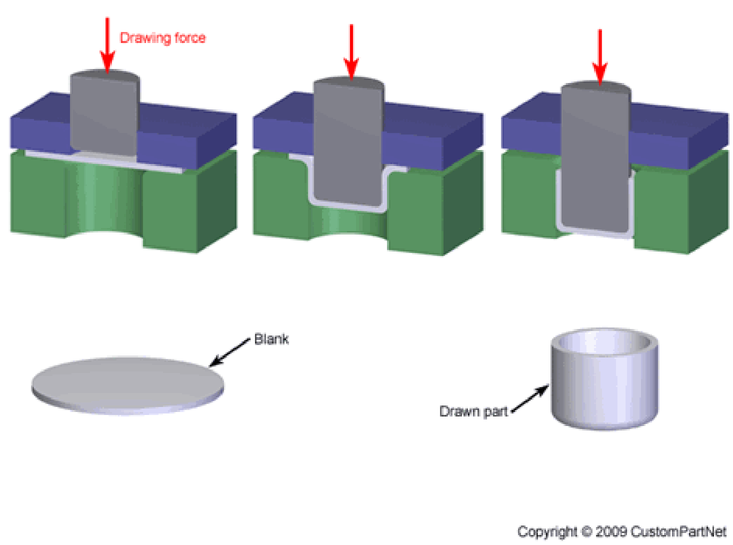
The deep drawing process requires a blank, blank holder, punch, and die. The blank is a piece of sheet metal, typically a disc or rectangle, which is pre-cut from stock material and will be formed into the part. The blank is clamped down by the blank holder over the die, which has a cavity in the external shape of the part.

A tool called a punch moves downward into the blank and draws, or stretches, the material into the die cavity. The movement of the punch is usually hydraulically powered to apply enough force to the blank. Both the die and punch experience wear from the forces applied to the sheet metal and are therefore made from tool steel or carbon steel.

The process of drawing the part sometimes occurs in a series of operations, called draw reductions. In each step, a punch forces the part into a different die, stretching the part to a greater depth each time. After a part is completely drawn, the punch and blank holder can be raised and the part removed from the die. The portion of the sheet metal that was clamped under the blank holder may form a flange around the part that can be trimmed off.



Deep Drawing



Deep Drawing Sequence

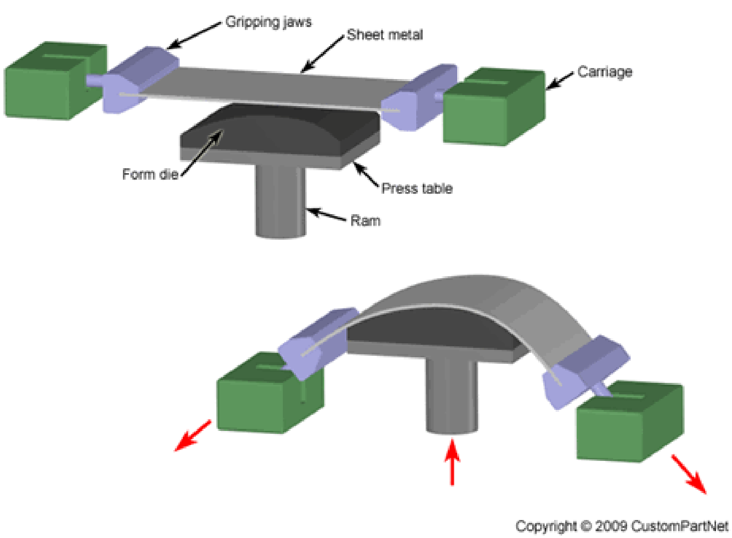
Stretch forming

Stretch forming is a metal forming process in which a piece of sheet metal is stretched and bent simultaneously over a die in order to form large contoured parts.

Stretch forming is performed on a stretch press, in which a piece of sheet metal is securely gripped along its edges by gripping jaws. The gripping jaws are each attached to a carriage that is pulled by pneumatic or hydraulic force to stretch the sheet.

The tooling used in this process is a stretch form block, called a form die, which is a solid contoured piece against which the sheet metal will be pressed. The most common stretch presses are oriented vertically, in which the form die rests on a press table that can be raised into the sheet by a hydraulic ram.

As the form die is driven into the sheet, which is gripped tightly at its edges, the tensile forces increase and the sheet plastically deforms into a new shape. Horizontal stretch presses mount the form die sideways on a stationary press table, while the gripping jaws pull the sheet horizontally around the form die.



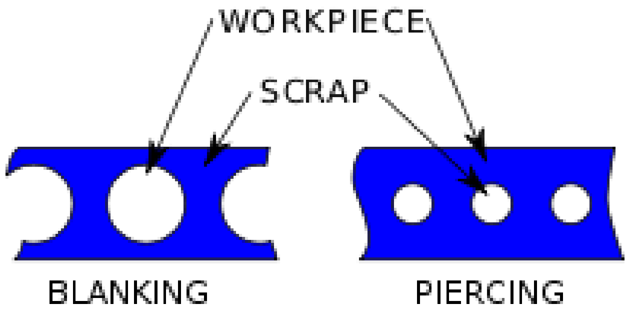
Stretch Forming

Stretch formed parts are typically large and possess large radius bends. The shapes that can be produced vary from a simple curved surface to complex non-uniform cross sections. Stretch forming is capable of shaping parts with very high accuracy and smooth surfaces.

Ductile materials are preferable, the most commonly used being aluminum, steel, and titanium. Typical stretch formed parts are large curved panels such as door panels in cars or wing panels on aircraft. Other stretch formed parts can be found in window frames and enclosures.

Blanking and piercing

Blanking and piercing are shearing processes in which a punch and die are used to modify webs. The tooling and processes are the same between the two, only the terminology is different: in blanking the punched out piece is used and called a blank; in piercing the punched out piece is scrap. The process for parts manufactured simultaneously with both techniques is often termed "pierce and blank." An alternative name of piercing is punching.



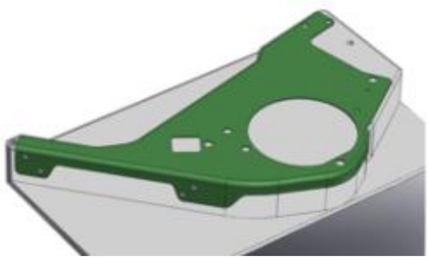
Rubber pad forming

- The rubber pad forming technology, the alternative for deep drawing in small series
- Rubber pad forming is a sheet metal forming process in which a rubber pad is used to form sheet metal. Due to the material properties of the rubber, the pad will regain its original shape when retracted from the tool.
- The great advantage is that only one tool is needed, the rubber takes over the function of the counter die and the blank holder. This results in low tooling costs, a short time to market and minimal damage of the material surface. An important additional operation within the process is 3D cutting of the product with a CNC driven 3D laser cutting machine.

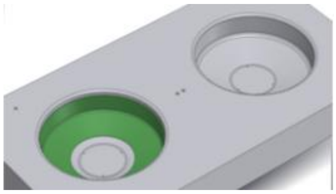
A metal sheet is positioned on a one sided tool.

A steel casing containing a rubber pad is pressed down over or in the tooling (one sided die) .

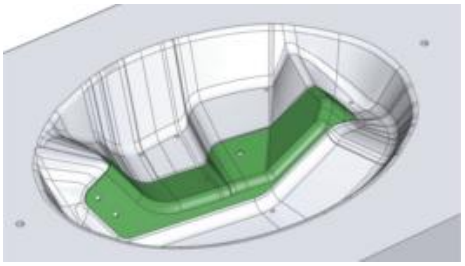
After forming the sheet metal, the rubber pad takes up its original shape.



In positive pressing the sheet is pressed over the tool.



In negative pressing the sheet is pressed inside the die.



When combining both tools, a positive and a negative die, even more demanding designs can be created.

Advantages of rubber pad forming

- Unique combination in shape, price and lead time
- Low tooling costs
- Smart and efficient design by integrating functionalities
- Lightweight optimised constructions
- More hygiene through design (no welding seams)
- No sharp edges and little to no surface damages.
- Appealing specific design with flowing shapes

UNIT 5
High Energy Rate Forming (HERF) Processes

Introduction:

The forming processes are affected by the rates of strain used.

Effects of strain rates during forming:

1. The flow stress increases with strain rates
2. The temperature of work is increases due to adiabatic heating.
3. Improved lubrication if lubricating film is maintained.
4. Many difficult to form materials like Titanium and Tungsten alloys, can be deformed under high strain rates.

Principle / important features of HERF processes:

- The energy of deformation is delivered at a much higher rate than in conventional practice.
- Larger energy is applied for a very short interval of time.
- High particle velocities are produced in contrast with conventional forming process.
- The velocity of deformation is also very large and hence these are also called High Velocity Forming (HVF) processes.
- Many metals tend to deform more readily under extra fast application of force.
- Large parts can be easily formed by this technique.
- For many metals, the elongation to fracture increases with strain rate beyond the usual metal working range, until a critical strain rate is achieved, where the ductility drops sharply.
- The strain rate dependence of strength increases with increasing temperature.
- The yield stress and flow stress at lower plastic strains are more dependent on strain rate than the tensile strength.
- High rates of strain cause the yield point to appear in tests on low carbon steel that do not show a yield point under ordinary rates of strain.

Advantages of HERF Processes

i) Production rates are higher, as parts are made at a rapid rate.
ii) Die costs are relatively lower.
iii) Tolerances can be easily maintained.
iv) Versatility of the process – it is possible to form most metals including difficult to form metals.
v) No or minimum spring back effect on the material after the process.
vi) Production cost is low as power hammer (or press) is eliminated in the process. Hence it is economically justifiable.
vii) Complex shapes / profiles can be made much easily, as compared to conventional forming.
viii) The required final shape/ dimensions are obtained in one stroke (or step), thus eliminating intermediate forming steps and pre forming dies.
ix) Suitable for a range of production volume such as small numbers, batches or mass production.

Limitations:

i) Highly skilled personnel are required from design to execution.
ii) Transient stresses of high magnitude are applied on the work.
iii) Not suitable to highly brittle materials
iv) Source of energy (chemical explosive or electrical) must be handled carefully.
v) Governmental regulations/ procedures / safety norms must be followed.
vi) Dies need to be much bigger to withstand high energy rates and shocks and to prevent cracking.
vii) Controlling the application of energy is critical as it may crack the die or work.
viii) It is very essential to know the behavior or established performance of the work metal initially.

Applications:

i) In ship building – to form large plates / parts (up to 25 mm thick).
ii) Bending thick tubes/ pipes (up to 25 mm thick).
iii) Crimping of metal strips.
iv) Radar dishes

v) Elliptical domes used in space applications.

vi) Cladding of two large plates of dissimilar metals.

(I) Explosive Forming

Introduction:

A punch in conventional forming is replaced by an explosive charge.

Explosives used can be:

- High energy chemicals like TNT, RDX, and Dynamite.
- Gaseous mixtures
- Propellants.

Factors to be considered while selecting an HERF process:

- Size of work piece
- Geometry of deformation
- Behavior of work material under high strain rates
- Energy requirements/ source
- Cost of tooling / die
- Cycle time
- Overall capital investment
- Safety considerations.

Types of explosive forming:

1) Unconfined type or Stand off technique
2) Confined type or Contact technique

1) Unconfined type (or Standoff technique)

Principle:

The work is firmly supported on the die and the die cavity is evacuated. A definite quantity of explosive is placed suitably in water medium at a definite stand off distance from the work. On detonation of the explosive charge, a pressure pulse (or a shock wave) of very high intensity is produced.

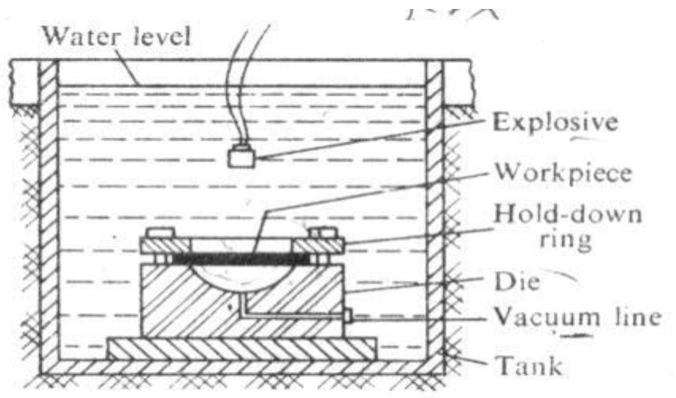


Fig. Unconfined Type Explosive Forming

A gas bubble is also produced which expands spherically and then collapses. When the pressure pulse impinges against the work (plate or sheet0, the metal is deformed into the die with a high velocity of around 120 m/s (430km/h).

The vacuum is necessary in the die to prevent adiabatic heating of the work which may lead to oxidation or melting.

Role of water:

i) Acts as energy transfer medium
ii) Ensures uniform transmission of energy
iii) Muffles the sound of explosion
iv) Cushioning/ smooth application of energy on the work without direct contact.

Process Variables

i) Type and amount of explosive: wide range of explosive sis available.
ii) Stand off distance – SOD- (Distance between work piece and explosive): Optimum SOD must be maintained.
iii) The medium used to transmit energy: water is most widely used.
iv) Work size:

v) Work material properties
vi) Vacuum in the die

Advantages;

i) Shock wave is efficiently transmitted through water and energy is transmitted effectively on the work
ii) Less noise
iii) Less probability of damage to work.
iv) Large and thick parts can be easily formed
v) Economical, when compared to a hydraulic press

Limitations:

i) Optimum SOD is essential for proper forming operation.
ii) Vacuum is essential and hence it adds to the cost.
iii) Dies must be larger and thicker to withstand shocks.
iv) Not suitable for small and thin works.
v) Explosives must be carefully handled according to the regulations of the government.

Applications:

- Ship building,
- Radar dish,
- Elliptical domes in space applications

2) Confined System (or Contact Technique)

Principle:

The pressure pulse or shock wave produced is in direct contact with the work piece (usually tubular) and hence the energy is directly applied on the work without any water medium.

The tube collapses into the die cavity and is formed. It is used for bulging and flaring operations.

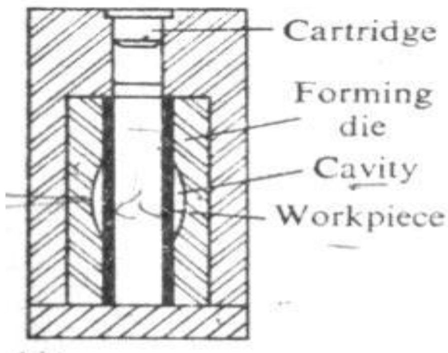


Fig. Confined (Contact) type Explosive Forming

Advantages:

i) Entire shock wave front is utilized as there is no loss in water.
ii) More efficient as compared to unconfined type.
iii)

Disadvantages:

i) More hazard of die failure
ii) Vacuum is required in the die
iii) Air present in the work piece (tube) is compressed leading to heating.
iv) Not suitable for large and thick plates.

Applications;

Bulging and flaring of tubes.

(II) Electro hydraulic Forming

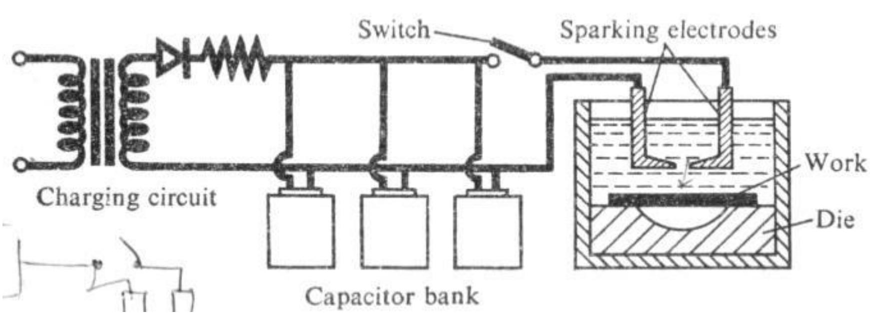


Fig. Electro Hydraulic Forming

Principle

A sudden electrical discharge in the form of sparks is produced between electrodes and this discharge produces a shock wave in the water medium. This shock wave deforms the work plate and collapses it into the die.

The characteristics of this process are similar to those of explosive forming. The major difference, however, is that a chemical explosive is replaced by a capacitor bank, which stores the electrical energy.

The capacitor is charged through a charging circuit. When the switch is closed, a spark is produced between electrodes and a shock wave or pressure pulse is created. The energy released is much lesser than that released in explosive forming.

Process Characteristics:

i) Stand off distance: It must be optimum.
ii) Capacitor used: The energy of the pressure pulse depends on the size of capacitor.
iii) Transfer medium: Usually water is used.
iv) Vacuum: the die cavity must be evacuated to prevent adiabatic heating of the work due to a sudden compression of air.
v) Material properties with regard to the application of high rates of strain.

Advantages:

i) Better control of the pressure pulse as source of energy is electrical- which can be easily controlled.
ii) Safer in handling than the explosive materials.
iii) More suitable if the work size is small to medium.
iv) Thin plates can be formed with smaller amounts of energy.
v) The process does not depend on the electrical properties of the work material.

Limitations:

i) Suitable only for smaller works
ii) Need for vacuum makes the equipment more complicated.
iii) Proper SOD is necessary for effective process.

Applications:

They include smaller radar dish, cone and other shapes in thinner and small works.

(III) Electromagnetic forming

The electrical energy stored in a capacitor bank is used to produce opposing magnetic fields around a tubular work piece, surrounded by current carrying coils. The coil is firmly held and hence the work piece collapses into the die cavity due to magnetic repelling force, thus assuming die shape.

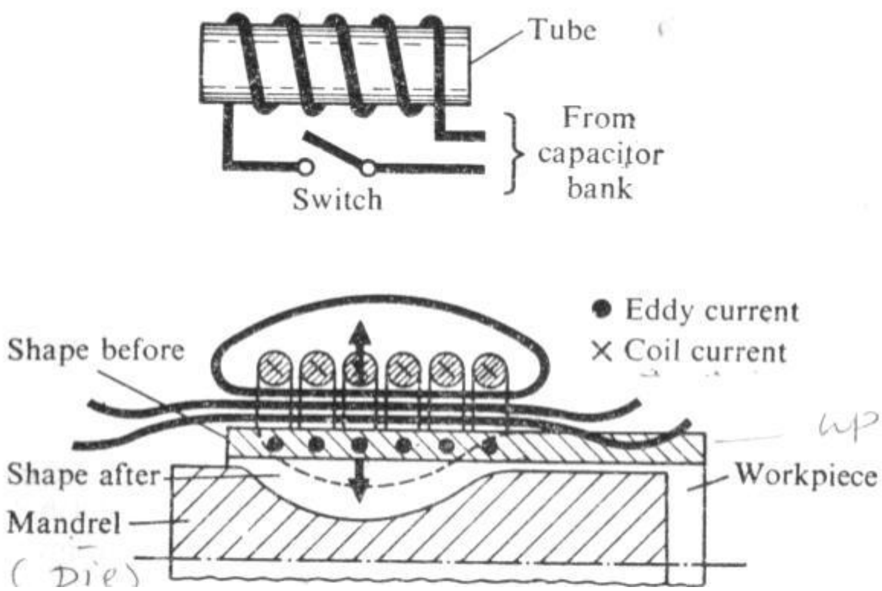


Fig. Electro Magnetic Forming

Process details/ Steps:

i) The electrical energy is stored in the capacitor bank
ii) The tubular work piece is mounted on a mandrel having the die cavity to produce shape on the tube.
iii) A primary coil is placed around the tube and mandrel assembly.
iv) When the switch is closed, the energy is discharged through the coil
v) The coil produces a varying magnetic field around it.
vi) In the tube a secondary current is induced, which creates its own magnetic field in the opposite direction.

vii) The directions of these two magnetic fields oppose one another and hence the rigidly held coil repels the work into the die cavity.

viii) The work tube collapses into the die, assuming its shape.

Process parameters:

i) Work piece size

ii) Electrical conductivity of the work material.

iii) Size of the capacitor bank

iv) The strength of the current, which decides the strength of the magnetic field and the force applied.

v) Insulation on the coil.

vi) Rigidity of the coil.

Advantages:

i) Suitable for small tubes

ii) Operations like collapsing, bending and crimping can be easily done.

iii) Electrical energy applied can be precisely controlled and hence the process is accurately controlled.

iv) The process is safer compared to explosive forming.

v) Wide range of applications.

Limitations:

i) Applicable only for electrically conducting materials.

ii) Not suitable for large work pieces.

iii) Rigid clamping of primary coil is critical.

iv) Shorter life of the coil due to large forces acting on it.

Applications:

i) Crimping of coils, tubes, wires

ii) Bending of tubes into complex shapes

iii) Bulging of thin tubes.