Module 4

Metal Forming process

Manufacturing Processes can be classified as

- Casting
- Welding
- Machining
- Mechanical working
- Powder Metallurgy
- Plastic Technology etc.,

In Mechanical working Process the raw material is converted to a given shape by the application of external force. The metal is subjected to stress.It is a process of changing the shape and size of the material under the influence of external force or stress.Plastic Deformation occurs.

Classification of Metal Working Processes

1. General classification

i. Rolling
ii. Forging
iii. Extrusion
iv. Wire Drawing
v. Sheet Metal Forming

2. Based on Temperature of Working

i. Hot Working
ii. Cold Working
iii. Warm Working

3. Based on the applied stress

i. Direct Compressive Stress
ii. Indirect Compressive Stress
iii. Tensile Stress
iv. Bending Stress
v. Shear Stress

Classification of Metal Working based on temperature.

Hot working: It is defined as the mechanical working of metal at an elevated (higher) temperature above a particular temperature. This temperature is referred to RCT(Re Crystallization Temperature).

Cold Working: It is defined as the mechanical working of metal below RCT.

Warm Working: It is defined as the mechanical working of metal at a temperature between that of Hot working and Cold Working. Ingot is the starting raw metal for all metal working process. Molten metal from the furnace is taken and poured into metallic moulds and allowed to cool or solidify. The cooled solid metal mass is then taken out of the mould. This solid metal is referred to as Ingot. This Ingot is later on converted to other forms by mechanical working.

What is a Cast Product?

It is a product obtained by just pouring molten metal into the mould and allowing it to solidify to room temperature.

It will have the final size and shape. Engine block ,Piston etc.,

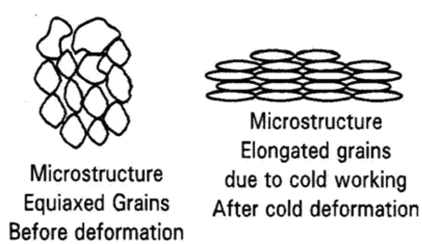
What is a wrought Product?

It is a product obtained by subjecting the hot ingot to mechanical working process to get a variety of products.Ex., spanner, screw driver, connecting rod, crank shaft etc.,

Characteristics of a Wrought Product

*Grains are oriented in a particular direction.

*The metal will show flow lines which are due to the presence of inclusions present between the metal layers.. The Metal will shows higher properties in the direction of metal flow. The defects get welded due to mechanical working.



Effect of cold working on grain structure

Difference between Cast and Wrought product.

Cast Product	Wrought Product
1.It is obtained by conversion of liquid metal to solid state, to get the required shape of the component in one step. The cast product may undergo machining operation.	1. It is obtained by subjecting the metal to external load or mechanical working to get the shape. It may be subjected to further operation.
2. The cast product will have uniform properties. The product is Isotropic in nature. Properties are same in all directions.	2. The wrought product will have directional properties . Properties are enhanced . The Product is anisotropic in nature. ie., properties are different in different directions.
3. The product will have small amount of porosity which cannot be eliminated completely.	4. Due to mechanical working the porosity level is almost zero.
4.·Cast product will have any shape size and complexity. Small to very huge components can be produced easily.	5. Wrought products are smaller in size but large size and moderately complex shapes can also be produced with some difficulty.

Based on the type of applied stress
Direct compression stress: Rolling and Forging
Indirect Compression: Extrusion and Wire
drawing. Tensile stress: Stretch forming
Bending stress: Sheet bending/ roll
bending Shear stress: Cutting of sheet

Advantages of metal working process

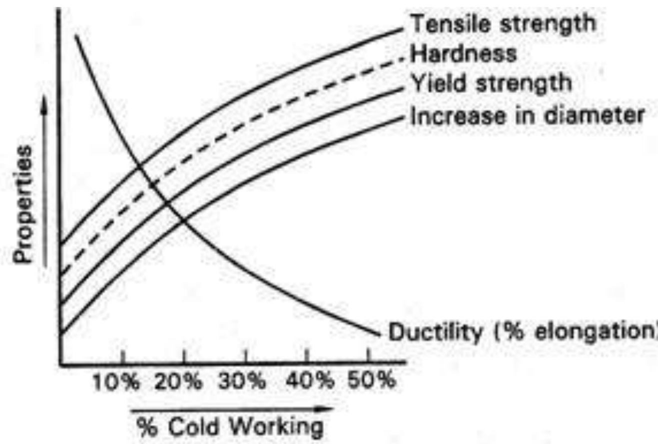
- Product with consistent high quality can be manufactured.
- Defects such as porosity and discontinuities are minimized.
- Inclusions get distributed evenly throughout the product.
- Grains are oriented in a particular direction and directional properties are obtained.
- In hot working the grains will be uniform and the properties are also uniform.
- In cold working the properties are enhanced due to strain hardening effect.
- Large tonnage can be easily produced.
- *The process can be easily mechanized.

Limitations of Mechanical working process

- The product becomes highly anisotropic in nature.
- Final product has to be obtained after machining of the wrought product except in the case of structural components.
- Needs additional equipment and machinery for metal working process. Hence, initial investment is high.
- Maintenance cost is high.
- More safety precautions are to be exercised as hot metal and additional equipments are used.

Concept of cold working

Consider a cylindrical metal piece with a known height, H and diameter, D. Let us subject the piece to compressive load at room temperature. We shall take that the height is reduced by 10%,20%,30% ….. etc., Each of these reduction in height represents %cold working. For each of these the diameter the Tensile strength, hardness, yield strength, %elongation were measured. It is seen that the %elongation decreases with increase in %cold working whereas other properties UTS, YS, Hardness increases and the diameter of the specimen also increases. Similarly the specimen can be subjected to tensile load also. The changes that take place in the material due to cold working is an important aspect which needs to be born in mind while designing various steps in MW process

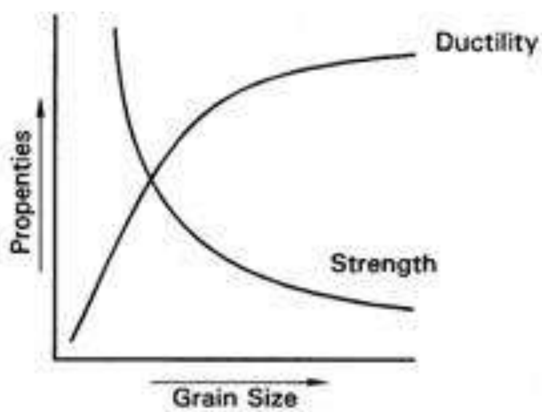


Effect of cold working on properties

Effect of Mechanical Working on the properties of the Metal

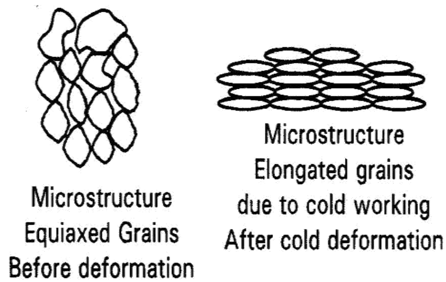
Due to working of the metal there will be changes in the grain structure. The grains may be elongated in one direction from its equiaxed shape. The pores are reduced and the inclusions are fragmented and distributed evenly in the metal. In hot working the coarse equiaxed grains will become fine equiaxed. The changes obtained in cold working is appreciable.

The behaviour of the metal with changes in grain size is shown in the figure. As grain size becomes coarse the strength property comes down and ductility increases.



Variation of properties with respect to grain size

As the percentage of cold working increases the material becomes strain hardened, the hardness and strength properties are increased but the ductility property decreases as shown in the figure It can be summarized as follows. Equiaxed grains will give uniform properties in all directions. Deformed grains show higher strength properties in the elongated direction.



Effect of cold working on grain structure

Concept of strain hardening

Straining of the metal/alloy occurs when subjected to cold working process. The metal will show more and more resistance for the external load as the cold working is Continued. At some it may become very difficult to deform the metal. This phenomenon is referred to as strain hardening effect. This can be explained in simple terms as given below.

All metals have atoms arranged in a repetitive manner in three dimensions referred to as crystalline structure. The structure is associated with imperfections in the form of dislocations. These dislocations starts moving towards the grain boundary region under the influence of external load. The dislocations get piled up near the grain boundaries. The density of dislocations increases due to Frank Reed source and may reach a value as high as 10^8-10^{12}/cm^2 Since, dislocations pile up near the grain boundary the density increases and the mean free path for the movement of dislocations decreases. The metal offers more resistance to external force. The metal will realize higher strength and this goes on building up till all the dislocations are brought near the grain boundary. Then annihilation of like and unlike dislocations takes place. The net existing dislocations will then become effective. During this period the load required for deformation increases. This phenomenon is referred to as"Strain Hardening". If the cold working stress exceeds this range the metal will fracture.

To take care of this the metal is subjected to annealing before further working. In Mechanical working of metals, the metal is subjected to external load and is deformed plastically. The given shape is obtained and is retained even after the removal of the load. The metal is subjected to stress and is strained. Hence, to understand the different mechanical working process, it is necessary to understand the stress strain relationship of metals, types of stress and strains, deformation process, theories used for the prediction of plastic deformation etc., For easy mechanical working of metals the nature of stress strain curve needs to be **reviewed.** The factors associated with stress strain needs to be studied.

Different stress- strain curves

Some typical stress strain curves are shown below. Different stress strain curves. There exists relationship between stress and strain for all materials and it is very useful information for a

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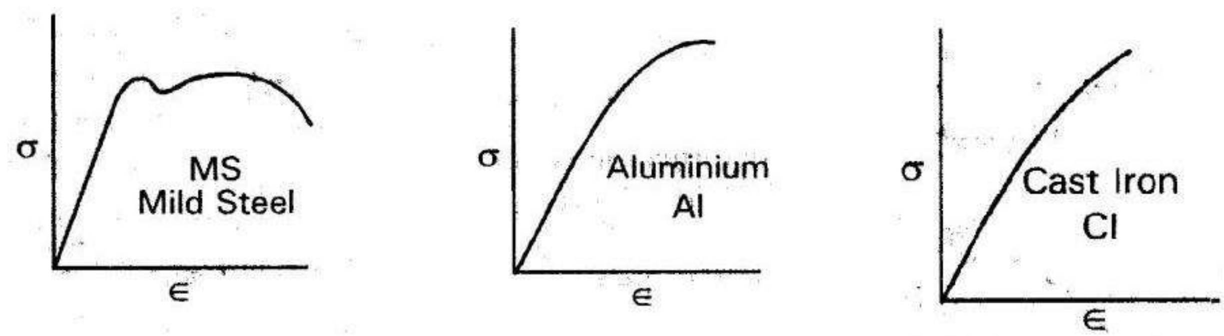
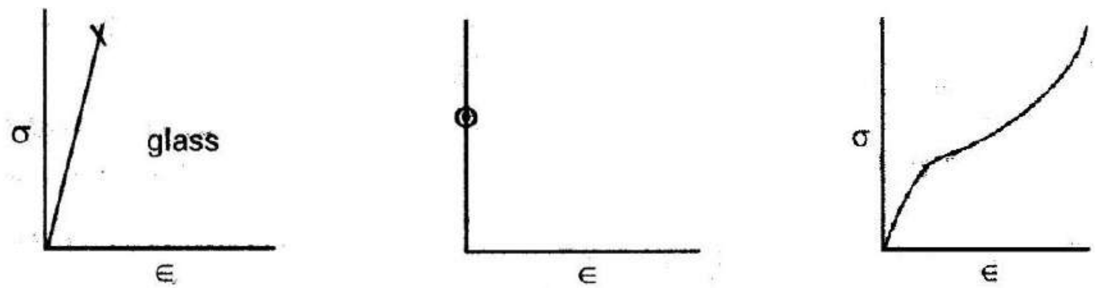


a) Highly ductile material b) Mildly ductile material c) Brittle material



d) Highly brittle material e) Highly Rigid material f) Polymer material

Typical stress strain curves for easy deformation

In Mechanical working of metals it is important to know that efforts are to be made to make the metal undergo deformation easily with less effort. The following figures illustrate what are the typical characteristics involved in the material.

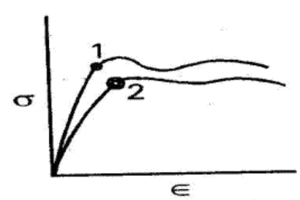
For easy deformation of metal the stress strain curve should have:

1. Lower yield point.
2. Gentle slope.
3. Larger elongation behavior.

Stress strain curve should have Lower yield point.

The load required for deformation is directly proportional to the yield point. Hence, if the yield point is high, higherload is required and lower the yield point of the material, lower is the loads required for deformation.The material with lower yield point can be easily shaped.

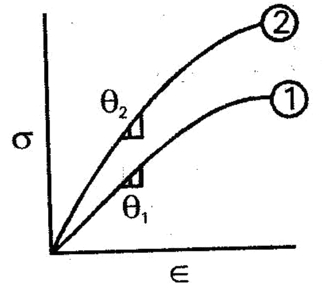
In the figure material 2 has the lower yield point as compared to 1. Hence, it is easier to deform material 2. Whenever a material is heated to higher temperature the yield point is reduced and it becomes easier to deform.



σ-∈ Curve for easy deformation

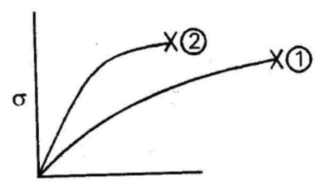
2. Stress strain should have Gentle slope.

The stress strain curve should have lower gradient ie., gentle slope. It means the stiffness of the material must be low. Stress strain curve with lower gradient will have gentle slope. Gentle slope needs lesser strain rate and hence lower rate of loading. In figure material 1 has lower slope as compared to 2. Hence, material 1 is easier to deform.



Slope of σ - ∈ Curve

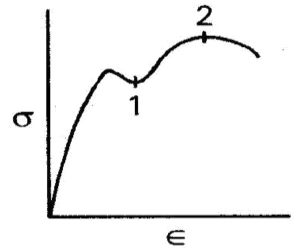
compared to2. Hence, material1 can be easily deformed.



σ - ∈ Curve with larger elongation

Strain hardening Type:

Some materials undergo strain hardening which means higher loads are required for deformation and more resistance is offered by the material. In the stress strain curve the strain hardening portion is represented by 12. If the slope12 is high, strain hardening of the material is more and it becomes difficult to deform. By heating the material it can be softened and strain hardening is eliminated.



σ-∈ showing strain hardening

Forging

Definition:

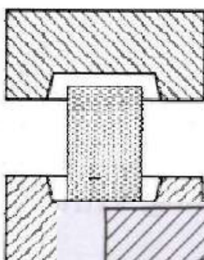
Forging is a metal working process in which useful shape is obtained in solid state by hammering or pressing metal.

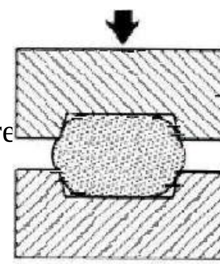
It is one of the oldest metalworking arts with its origin about some thousands of years back. Some examples of shapes obtained by forging process: Crane hook, connecting rod of IC engine, spanner, gear blanks ..etc.

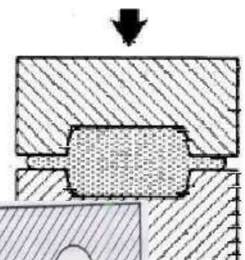
Different Forging Operations

*__Upsetting__

The thickness of the work reduces and length increases







2. Edging

The en shaped to require ng dies.

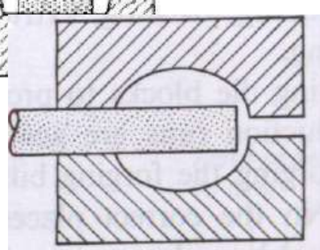


Fig 2. Edging

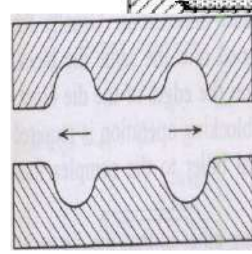


Fig 3. Fullering

2. Fullering

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

3. Drawing

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

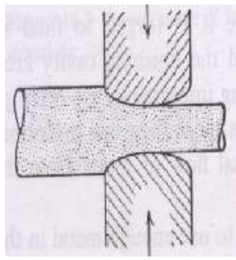


Fig 4. Drawing

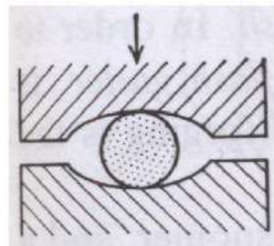


Fig 5. Swaging

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

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

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

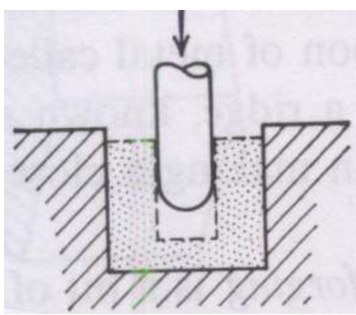


Fig 6. Piercing

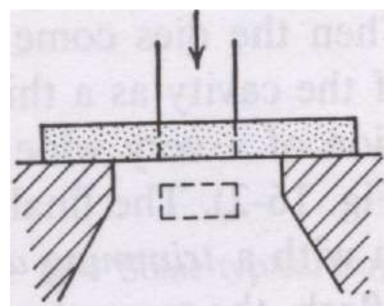


Fig 7. Punching

2. 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:

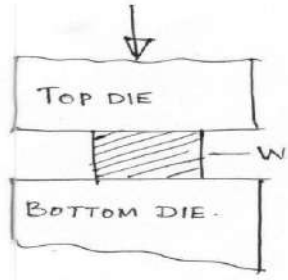
- Less friction between die surface and work piece
- Lubrication is easy
- No oxidation or scaling on the work
- Good surface finish

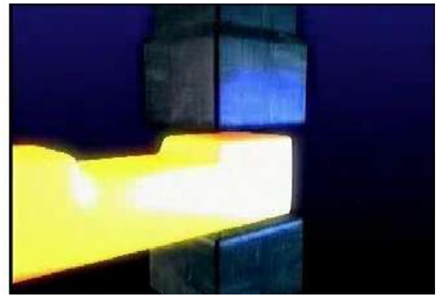
Disadvantages of Cold Working:

- 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



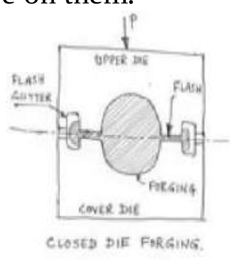


Features of open die forging:

- 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.



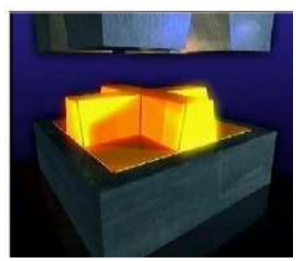


Fig. Closed Die Forgin

Features of Closed Die Forging:

Closed die forging involves two or more steps:

1. **i) Blocking Die**: Work is rough forged, close to final shape.
2. ii**) Finishing Die**: work is forged to final shape and dimensions.
3. Both Blocking Die and Finishing Die are machined into the same die block.
4. More number of dies are required depending on the complexity of the job.
5. Two die halves close-in & work is deformed under high pressure.
6. High dimensional accuracy / close control on tolerances.
7. Suitable for complex shapes.
8. Dies are complex and more expensive.
9. 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 hig 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.

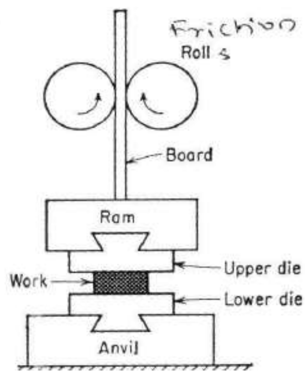


Fig. Mechanical Board Hammer

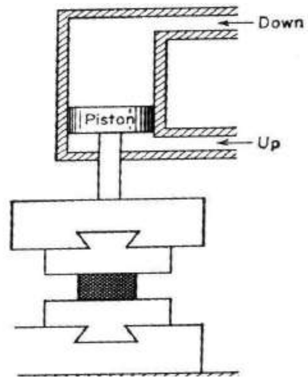


Fig. Steam Hammer

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

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.

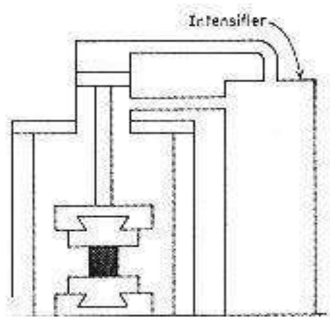


Fig. Hydraulic Press

Features of Hydraulic Press

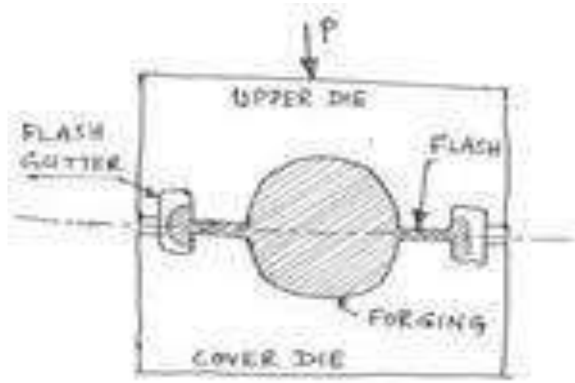
- Full press load is available during the full stroke of the ram.
- Ram velocity can be controlled and varied during the stroke.
- It is a slow speed machine and hence has longer contact time and hence higher die temperatures.
- The slow squeezing action gives close tolerance on forgings.
- Initial cost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

DIE DESIGN PARAMETERS

Die design depends on the forging required and its design requires the knowledge of:

- Strength and ductility of work piece materials
- Sensitivity of the materials to the rate of deformation and temperature
- Frictional characteristics
- Shape and complexity of work piece
- Die distortion under high forging loads- for close dimensional tolerance

Die Design Parameters



CLOSED DIE FORGING.

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 in casting design
   - 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 Underfills**:

- 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

7. 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.

ROLLING

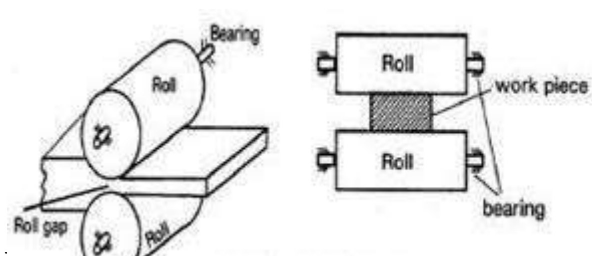
The work piece is subjected to compressive forces and is deformed plastically. The cross section decreases and length gets elongated whereas the total volume remains constant. It is the main metal working process and offers itself to mass production. Close control of the final product is possible. Rotating rolls will squeeze the work piece inducing direct compressive stress in it. Friction dominates the process. Rolling of work piece can be carried out in hot or cold condition. Components produced through rolling have higher mechanical properties than cast products. Slabs, Sheets, Bars, Rods, Structural components like I, U, L etc., in long lengths can be produced easily.

Steps in Rolling Process

The starting raw material in rolling is the ingot which is obtained by using a metal die.
Ingot will have a length of about 1 meter and a cross section of 100x100mm or 250x250mm etc,. Ingot may have any geometrical cross section.

The details of Ingot production are:

- Prepare molten metal in a furnace.
- Pour clean well prepared molten metal with correct temperature into a metal die cavity and allow it to cool.
- Take out the solid metal.* This solid metal is referred to as Ingot or Ingot casting.*The ingot is then passed through the rolls to get the next set of products blooms, billets, bars, slabs, plates, sheets or Structural components. The same is shown in the flow chart.



Typical Rolling Process

Classification of Rolling

Rolling Process can be classified either

i. based on the temperature of the metal during rolling or
ii. based on the arrangement of the rolls and their number or
iii. based on the Products rolled.

i) **Based on the temperature:** Rolling can be classified as Hot Rolling or Cold Rolling. Hot rolling is carried out above RCT and cold rolling is carried out below RCT.

Hot rolling is used to convert ingots to blooms and blooms to billets to slabs to plates, billets to bars, and billets to structural shapes. It is used for heavy or thick sections. Surface finish will be poor but the mechanical properties will be uniform.

Cold rolling is used for converting small sections plates to sheets to foils or bars to wires. Good surface finish is obtained with enhanced properties.

i) **Based on Roll arrangement:** The minimum number of rolls required for rolling to take place is two and the higher end is dictated by the amount of reduction required, type of metal being rolled, configuration of the product etc., The rolls are cylindrical shaped may be plain or may have grooves cut on it.

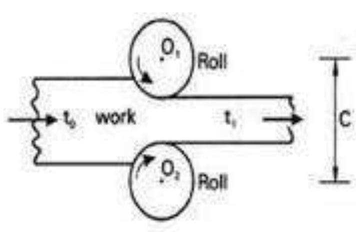
The arrangement of rolls could be:

- 2 high roll mill- two rolls are used here.
- 3 high roll mill- three rolls are used here.
- 4 high roll mill- four rolls are used here.
- Cluster roll mill- a number of rolls are used in conjunction.
- Planetary roll mill- rolls are arrangement in the form of planetary movement.
  Tandem roll mill- continuous arrangement of rolls are used for continuous rolling.
- Sendizmer roll mill-similar to a cluster mill but large number of rolls are used. Greatest reduction in the material is obtained.

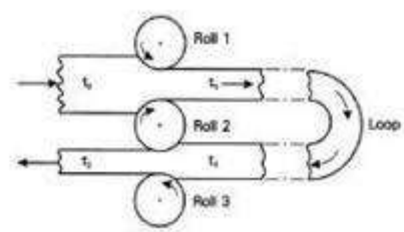
Two high mills

It consists of two rolls located one above the other with their centers in vertical plane. A controlled opening or gap is provided between the rolls. This gap represents the required thickness of the product. The rolls are cylindrical and mounted on bearings.

They are driven by motor and rotate in opposite directions as shown.



Two high mill



Three High roll Mill

The rolling direction can be changed by changing the direction of rotation of the rolls. The center distance between the rolls (C) can be changed to change the roll gap to vary the thickness of the product. This is mainly used for producing blooms and billets.

Three high mills

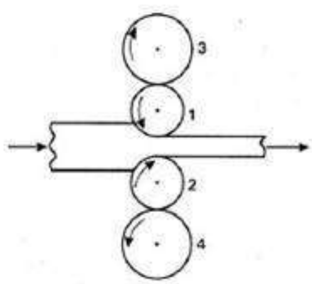
The arrangement consists of three rolls located one above the other, with their centers in a vertical plane. Outer rolls will be rotating in one direction and the center one will be rotating in the opposite direction. Here two passes of the work is possible unlike one pass in two roll mill. Work piece is fed between the gap of top set of rolls and its thickness is reduced. The output of this is fed into the gap between the bottom set of rolls.

One reduction in thickness of the work piece is obtained. Thus rolling will take place in both directions. Since the output of one is taken and fed into the second set of rolls, the work forms a loop as shown. Hence, it is also named as looping mill.

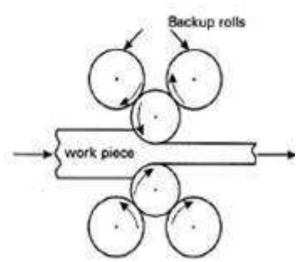
The mill has higher output. Gap between roll1 and roll2= t1 and between roll2 and roll3=t2. Where t1 > t2

Four high mill

Here four rolls are used. Two smaller form the main rolls and come in contact with the work piece and cause deformation. These rolls are backed up by larger diameter rolls. Thus the mill is more rigid and can be used for higher reductions in the work. Back up rolls prevent roll deflection.



Four high mill



Cluster Mill

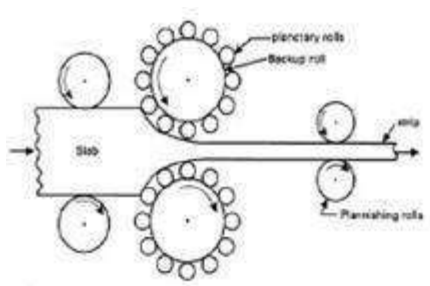
Cluster mill

Here the main rolls are small and are backed up by two sets of rolls on each side. Higher rigidity and stability is imparted to the mill. Higher reductions are possible. Better deformation will take place.

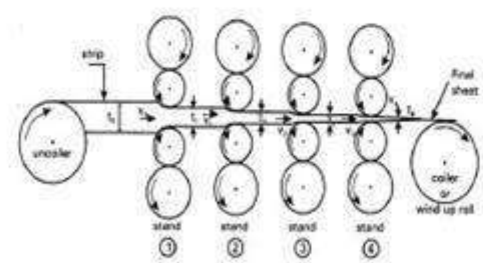
Planetary Mill

Here the large roll has very small rolls located along the circumference. A number of them will be arranged on each roll of a virtually two high roll mill. The arrangement looks like planets on the rolls. Hence, the name planetary mill. In fact the small rolls come in contact with the work piece and the big roll act as back up roll.

Higher reduction of the order 25:1 is possible in one pass. The mill provides forging action as well as rolling action at the same time. There will be two high mill at the beginning feeding the work piece to the planetary mill. At the out let end there will be another set of two high mill to take the out coming work. This arrangement provides roll tension at the beginning and at the out let. The mill is mainly used for converting slab to sheet or strip.



Planetary Mill



Tandem Mill

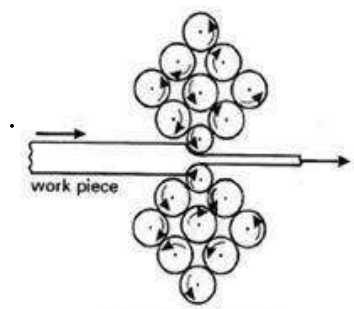
Tandem Mill

A series of four high mills are used one after the other. The work piece passes through each one of them. Reduction in the thickness will take place at each point. Each one of the mill is referred to as stand. There may be as many stands as necessary. This arrangement is referred to as “Tandem Mill”. Continuous reduction will take place at each stand.

There will be coiler and uncoiler which provides winding up of the work at the out let end and act as feed roll by releasing the work piece.Normally this arrangement is used for converting thick sheet to very thin sheet and is a cold roll mill. Coiler and uncoiler provide the necessary tension in the work piece. Very smooth and good surface is obtained in the work piece.

Sendizmer Mill

- It is basically a cluster mill.
- It is used to produce thin sheets and foils.
- Very strong metals can be rolled very easily.
- Basically a cold rolling mill.
- Stainless steels, Alloy steels etc., can be rolled easily.
- Very high reduction ratio is obtained.



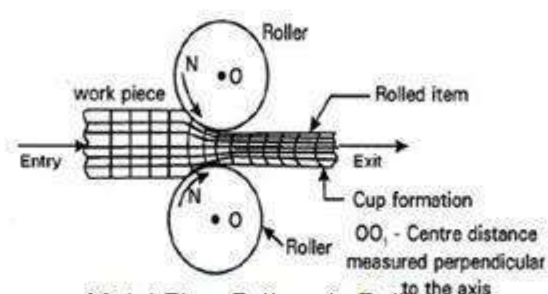
Sendizmer Mill

ii) Based on the product

•**Blooming Mill-** Here only blooms are produced from the Ingot. Blooms will have a dimension of approx.150x150mm.•Billet Mill- Here Billets are produced from Blooms. Billet will have a dimension of approx. 100x100mm.Rod/Bar Mill - Here bars or rods are produced from billets. Bar will have a dimension of 40x40mm.

•**Slab Mill-** Here slab is produced from the bloom. t>b and b=100mm•Plate Mill- Here plate is produced from the slab. t>4mm.•Sheet Mill – Here sheet is produced from plate. t<4mm.Structural Mill- Here structural shapes like I, U,L or channel sections are produced.

Metal flow pattern in Rolling



Metal Flow Pattern in Rolling

The velocity of the work piece as it leaves the rolls is greater than the circumferential velocity of the rolls due to stretching of the layers. Thickness of the work piece is reduced and the length is increased as it passes o

Let a slab of constant width 'b' enter the gap between the rolls and leave it with the same width 'b'

R **- is the radius of the rolls**

f the roll
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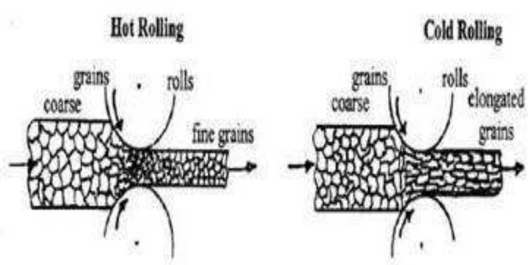
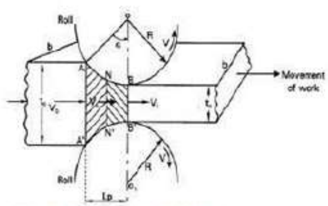




Geometric Relationship in Rolling

The velocity of the work piece increases steadily from entrance to the exit. At one point along the contact surface of the roll and work, the surface velocity of the roll will be equal to the velocity of the work. This point is referred to as "Neutral point" or "No Slip Point

V_n - is the velocity of the slab at the neutral plane

α - angle of contact or angle of bite

$\widehat{AB}$ - arc of contact

L_p - Projected length of arc of contact

$(t_0 - t_1)$ - is the draft

b - is the constant width of the slab at the entrance and at the exit.

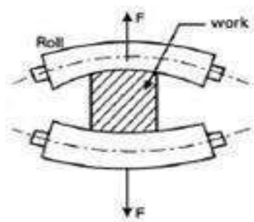
00_1 - is the plane corresponding to the line joining the centers of the rolls.

AA^1B^1B - is the deformation zone

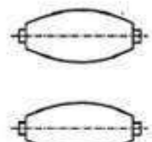
AA^1N^1N - is the Lagging zone $V_0 < V_n$

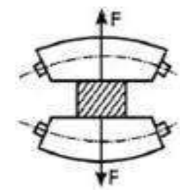
Roll Camber

For a given reduction in thickness of the work piece the roll separating force (influencing roll bending) increases linearly with roll radius. Forces will be set up along the length of the roll and try to deflect and separate the rolls.



Flat rolls undergoing deformation


Rolls with convex surface ie. camber before rolling



Camber rolls after deflection experiencing roll separating force

The convex contour provided on the rolls is called "Roll Camber". Without Roll Camber the thickness of the work piece is more at the centre than at the ends. But with Roll Camber, uniform thickness is maintained across the width of the work.

The Main Parameters in Rolling

The parameters are:

- Roll diameter
- Friction between rolls and work piece
- Deformation resistance of the metal as influenced by metallurgy, temperature and strain rate Presence of roll tensions

Roll Diameter:

- *Rolling load increases with roll diameter at a rate greater than D1/2
- *We know Rolling load $P = p.b.\sqrt{R.\Delta t}$ but $R=D/2$ Therefore $P = p.b.\sqrt{D/2.\Delta t}$ or $P \alpha \sqrt{D}$
- *As roll diameter decreases both rolling load and length of arc of contact decreases.
- *Small diameter rolls supported by large back up rolls can produce greater reduction and keep the work flat.

Friction:

- *Frictional force is needed to pull the metal into the rolls.*Large fraction of rolling load
- comes from the frictional force.*Friction varies from point to point along the arc of contact of the roll, it will be acting from entry to neutral point long the direction of roll rotation and from neutral point to exit point it will be opposing the direction of roll rotation. High friction results in high rolling load and a steep friction hill will be realized.
- *Since it is very difficult to measure the variation in coefficient of friction „μ‟ it is assumed that „μ‟ is constant. For cold rolling it is taken as 0.05-0.1 and for hot rolling it is taken as >= 0.2.*Coeff.of friction is inversely proportional to the rolling speed. As μ decreases rolling speed increases. From F= μ/N μ = F/N Thinner gage sheet can be produced in cold rolling as coeff.of friction is smaller.

Defects in Rolled Products The defects may arise due to

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.

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.

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.

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.

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.

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).

Drawing

Drawing is a metalworking process which uses tensile forces to stretch metal. As the metal is **drawn** (pulled), it stretches thinner, into a desired shape and thickness. Drawing is classified in two types: sheet metal drawing and wire, bar, and tube drawing. The specific definition for sheet metal drawing is that it involves plastic deformation over a curved axis. For wire, bar, and tube drawing the starting stock is drawn through a die to reduce its diameter and increase its length. Drawing is usually done at room temperature, thus classified a cold working process, however it may be performed at elevated temperatures to hot work large wires, rods or hollow sections in order to reduce forces.[1][2] Drawing is one type of extrusion.

Drawing differs from rolling in that the pressure of drawing is not transmitted through the turning action of the mill but instead depends on force applied locally near the area of compression. This means the amount of possible drawing force is limited by the tensile strength of the material, a fact that is particularly evident when drawing thin wires

Sheet metal

The success of forming is in relation to two things, the flow and stretch of material. As a die forms a shape from a flat sheet of metal, there is a need for the material to move into the shape of the die. The flow of material is controlled through pressure applied to the blank and lubrication applied to the die or the blank. If the form moves too easily, wrinkles will occur in the part. To correct this, more pressure or less lubrication is applied to the blank to limit the flow of material and cause the material to stretch or thin. If too much pressure is applied, the part will become too thin and break. Drawing metal is the science of finding the correct balance between wrinkles and breaking to achieve a successful part.

Deep drawing

Sheet metal drawing becomes *deep drawing* when the workpiece is drawing longer than its diameter. It is common that the workpiece is also processed using other forming processes, such as piercing, ironing,necking, rolling, and beading.

Bar, tube & wire

Bar, tube, and wire drawing all work upon the same principle: the starting stock drawn through a die to reduce the diameter and increase the length. Usually the die is mounted on a draw bench. The end of the workpiece is reduced or pointed to get the end through the die. The end is then placed in grips and the rest of the workpiece is pulled through the die. Steels, copper alloys, and aluminium alloys are common materials that are drawn.

Drawing can also be used to produce a cold formed shaped cross-section. Cold drawn cross- sections are more precise and have a better surface finish than hot extruded parts. Inexpensive materials can be used instead of expensive alloys for strength requirements, due to work hardening.

Bars or rods that are drawn cannot be coiled therefore straight-pull draw benches are used. Chain drives are used to draw workpieces up to 30 m (98 ft). Hydraulic cylinders are used for shorter length workpieces.

The reduction in area is usually restricted to 20 to 50%, because greater reductions would exceed the tensile strength of the material, depending on its ductility. To achieve a certain size or shape multiple passes through progressively smaller dies or intermediate anneals may be required.[6]

The Cold Drawing Process for Steel Bars and Wire

Carbide Die Cross Section

Raw Stock: Hot rolled steel bar or rod coils are used as raw material. Because the hot rolled products are produced at elevated temperatures (1700 - 2200 Deg. F. i.e. hot rolling), they generally have a rough and scaled surface and may also exhibit variations in section and size.

Cleaning: Abrasive scale (iron oxide) on the surface of the hot rolled rough stock is removed.

Coating: The surface of the bar or coil is coated with a drawing lubricant to aid cold drawing.

Pointing: Several inches of the lead ends of the bar or coil are reduced in size by swaging or extruding so that it can pass freely through the drawing die. Note: This is done because the die opening is always smaller than the original bar or coil section size.

Finished Product: The drawn product, which is referred to as Cold Drawn or Cold Finished, exhibits a bright and/or polished finish, increased mechanical properties, improved machining characteristics and precise and uniform dimensional tolerances.

Multi-Pass Drawing: The cold drawing of complex shapes/profiles may require that each bar/coil be drawn several times in order to produce the desired shape and tolerances. This process is called multi-pass drawing and involves drawing through smaller and smaller die openings. Material is generally annealed between each drawing pass to remove cold work and to increase ductility.

Annealing: This is a thermal treatment generally used to soften the material being drawn, to modify the microstructure, the mechanical properties and the machining characteristics of the steel and/or to remove internal stresses in the product. Depending on the desired characteristics of the finished product, annealing may be used before, during (between passes) or after the cold drawing operation, depending on material requirements. by shangar hawrami

Tube drawing

Tube drawing is very similar to bar drawing, except the beginning stock is a tube. It is used to decrease the diameter, improve surface finish and improve dimensional accuracy. A mandrel may or may not be used depending on the specific process used.

Plastic drawing, sometimes referred to as *cold drawing*, is the same process as used on metal bars, but applied to plastics.

Cold drawing is primarily used in manufacturing plastic fibers. The process was discovered by Julian Hill (1904–1996) in 1930 while trying to make fibers from an early polyester.[8] It is performed after the material has been "spun" into filaments; by extruding the polymer melt through pores of a spinneret. During this process, the individual polymer chains tend to somewhat align because of viscous flow. These filaments still have an amorphous structure, so they are drawn to align the fibers further, thus increasing crystallinity, tensile strength and stiffness. This is done on a draw twister machine.

For nylon, the fiber is stretched four times its spun length. The crystals formed during drawing are held together by hydrogen bonds between the amide hydrogens of one chain and the carbonyl oxygens of another chain

Metal drawing is a manufacturing process that forms metal work stock by reducing its cross section. This is accomplished by forcing the work through a mold, (die), of smaller cross sectional area than the work. This process is very similar to metal extrusion, the difference being in the application of force. In extrusion the work is pushed through the die opening, where in drawing it is pulled through. The basic concept of metal drawing is illustrated in the following figure.

Extrusion

Extrusion is a process used to create objects of a fixed cross-sectional profile. A material is pushed or pulled through a die of the desired cross-section. The two main advantages of this process over other manufacturing processes are its ability to create very complex cross-sections, and to work materials that are brittle, because the material only encounters compressive and shear stresses. It also forms parts with an excellent surface finish.

Extrusion may be continuous (theoretically producing indefinitely long material) or semi-continuous (producing many pieces). The extrusion process can be done with the material hot or cold.

Commonly extruded materials include metals, polymers, ceramics, concrete, play dough, and foodstuffs. The products of extrusion are generally called "extrudates". Drawing metal is the main way to produce wire and sheet, and bar and tube are also often drawn.

Hollow cavities within extruded material cannot be produced using a simple flat extrusion die, because there would be no way to support the center barrier of the die. Instead, the die assumes the shape of a block with depth, beginning first with a shape profile that supports the center section. The die shape then internally changes along its length into the final shape, with the suspended center pieces supported from the back of the die.

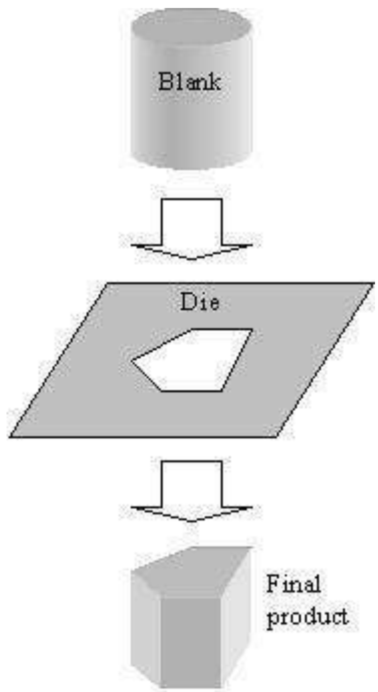
The extrusion process in metals may also increase the strength of the material.

The process begins by heating the stock material (for hot or warm extrusion). It is then loaded into the container in the press. A dummy block is placed behind it where the ram then presses on the material to push it out of the die. Afterward the extrusion is stretched in order to straighten it. If better properties are required then it may be heat treated orcold worked.[2]

The extrusion ratio is defined as the starting cross-sectional area divided by the cross-sectional area of the final extrusion. One of the main advantages of the extrusion process is that this ratio can be very large while still producing quality parts.

Hot extrusion

Hot extrusion is a hot working process, which means it is done above the material's recrystallization temperature to keep the material from work hardening and to make it easier to push the material through the die. Most hot extrusions are done on horizontal hydraulic presses that range from 230 to 11,000 metric tons (250 to 12,130 short tons). Pressures range from 30 to 700 MPa (4,400 to 101,500 psi), therefore lubrication is required, which can be oil or graphite for lower temperature extrusions, or glass powder for higher temperature extrusions. The biggest disadvantage of this process is its cost for machinery and its upkeep



The extrusion process is generally economical when producing between several kilograms (pounds) and many tons, depending on the material being extruded. There is a crossover point where roll forming becomes more economical. For instance, some steels become more economical to roll if producing more than 20,000 kg (50,000 lb)

Cold extrusion

Cold extrusion is done at room temperature or near room temperature. The advantages of this over hot extrusion are the lack of oxidation, higher strength due to cold working, closer tolerances, better surface finish, and fast extrusion speeds if the material is subject to hot shortness. Materials that are commonly cold extruded include: lead, tin, aluminum, copper, zirconium, titanium, molybdenum, beryllium, vanadium, niobium, and steel.

Examples of products produced by this process are: collapsible tubes, fire extinguisher cases, shock absorber cylinders and gear blanks.

Warm extrusion

Warm extrusion is done above room temperature, but below the recrystallization temperature of the material the temperatures ranges from 800 to 1800 °F (424 to 975 °C). It is usually used to achieve the proper balance of required forces, ductility and final extrusion properties.[3]

Extrusion defects

- Surface cracking occurs when the surface of an extrusion splits. This is often caused by the extrusion temperature, friction, or speed being too high. It can also happen at lower temperatures if the extruded product temporarily sticks to the die.
- Pipe – A flow pattern that draws the surface oxides and impurities to the center of the product. Such a pattern is often caused by high friction or cooling of the outer regions of the billet.
- Internal cracking – When the center of the extrusion develops cracks or voids. These cracks are attributed to a state of hydrostatic tensile stress at the centerline in the deformation zone in the

die. (A similar situation to the necked region in a tensile stress specimen)

- **Surface lines** – When there are lines visible on the surface of the extruded profile. This depends heavily on the quality of the die production and how well the die is maintained, as some residues of the material extruded can stick to the die surface and produce the embossed lines.
- **Equipments**

There are many different variations of extrusion equipment. They vary by four major characteristics:

1. Movement of the extrusion with relation to the ram. If the die is held stationary and the ram moves towards it then it is called "direct extrusion". If the ram is held stationary and the die moves towards the ram it is called "indirect extrusion".
2. The position of the press, either vertical or horizontal.
3. The type of drive, either hydraulic or mechanical.
4. The type of load applied, either conventional (variable) or hydrostatic.

A single or twin screw auger, powered by an electric motor, or a ram, driven by hydraulic pressure (often used for steel and titanium alloys), oil pressure (for aluminium), or in other specialized processes such as rollers inside a perforated drum for the production of many simultaneous streams of material.

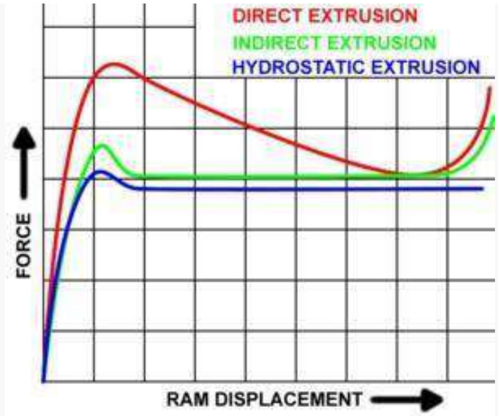
Forming internal cavities

Two-piece aluminum extrusion die set (parts shown separated.) The male part (at right) is for forming the internal cavity in the resulting round tube extrusion.

incorporate the mandrel in the die and have "legs" that hold the mandrel in place. During extrusion the metal divides, flows around the legs, then merges, leaving weld lines in the final product.[4]

Direct extrusion

Direct extrusion, also known as forward extrusion, is the most common extrusion process. It works by placing the billet in a heavy walled container. The billet is pushed through the die by a ram or screw. There is a reusable dummy block between the ram and the billet to keep them separated. The major disadvantage of this process is that the force required to extrude the billet is greater than that needed in the indirect extrusion process because of the frictional forces introduced by the need for the billet to travel the entire length of the container



Plot of forces required by various extrusion processes.

. Because of this the greatest force required is at the beginning of process and slowly decreases as the billet is used up. At the end of the billet the force greatly increases because the billet is thin and the material must flow radially to exit the die. The end of the billet (called the butt end) is not used for this reason.

Indirect extrusion

In indirect extrusion, also known as backwards extrusion, the billet and container move together while the die is stationary. The die is held in place by a "stem" which has to be longer than the container length. The maximum length of the extrusion is ultimately dictated by the column strength of the stem. Because the billet moves with the container the frictional forces are eliminated. This leads to the following advantages:

- A 25 to 30% reduction of friction, which allows for extruding larger billets, increasing speed, and an increased ability to extrude smaller cross-sections
- There is less of a tendency for extrusions to crack because there is no heat formed from friction
- The container liner will last longer due to less wear
- The billet is used more uniformly so extrusion defects and coarse grained peripherals zones

are less likely.

The disadvantages are:

- Impurities and defects on the surface of the billet affect the surface of the extrusion. These defects ruin the piece if it needs to be anodized or the aesthetics are important. In order to get around this the billets may be wire brushed, machined or chemically cleaned before being used.
- This process isn't as versatile as direct extrusions because the cross-sectional area is limited by the maximum size of the stem.

Hydrostatic extrusion

In the hydrostatic extrusion process the billet is completely surrounded by a pressurized liquid, except where the billet contacts the die. This process can be done hot, warm, or cold, however *Constant-rate extrusion*: A ram or plunger is used to pressurize the fluid inside the container.

1. *Constant-pressure extrusion*: A pump is used, possibly with a pressure intensifier, to pressurize the fluid, which is then pumped to the container.

The advantages of this process include:

- No friction between the container and the billet reduces force requirements. This ultimately allows for faster speeds, higher reduction ratios, and lower billet temperatures.
- Usually the ductility of the material increases when high pressures are applied.
- An even flow of material.
- Large billets and large cross-sections can be extruded.
- No billet residue is left on the container walls.

The disadvantages are:

- The billets must be prepared by tapering one end to match the die entry angle. This is needed to form a seal at the beginning of the cycle. Usually the entire billet needs to be machined to remove any surface defects.
- Containing the fluid under high pressures can be difficult.

Drives

Most modern direct or indirect extrusion presses are hydraulically driven, but there are some small mechanical presses still used. Of the hydraulic presses there are two types: direct-drive oil presses and accumulator water drives.

Direct-drive oil presses are the most common because they are reliable and robust. They can deliver over 35 MPa (5000 psi). They supply a constant pressure throughout the whole billet.

Hydrostatic exrusion presses usually use castor oil at pressure up to 1400 MPa (200 ksi). Castor oil is used because it has good lubricity and high pressure properties.

Die design:

The design of an extrusion profile has a large impact on how readily it can be extruded. The maximum size for an extrusion is determined by finding the smallest circle that will fit around the cross-section, this is called the *circumscribing circle*. This diameter, in turn, controls the size of the die required, which ultimately determines if the part will fit in a given press. For example, a larger press can handle 60 cm (24 in) diameter circumscribing circles for aluminium and 55 cm (22 in). diameter circles for steel and titanium.[1]

The complexity of an extruded profile can be roughly quantified by calculating the *shape factor*, which is the amount of surface area generated per unit mass of extrusion. This affects the cost of tooling as well as the rate of production.[9]
Thicker sections generally need an increased section size. In order for the material to flow properly legs should not be more than ten times longer than their thickness. If the cross-section is asymmetrical, adjacent sections should be as close to the same size as possible. Sharp corners should be avoided; for aluminium and magnesium the minimum radius should be 0.4 mm (1/64 in) and for steel corners should be 0.75 mm (0.030 in) and fillets should be 3 mm (0.12 in). The following table lists the minimum cross-section and thickness for various materials.