4.

Sheet Metal Operation

By S K Mondal

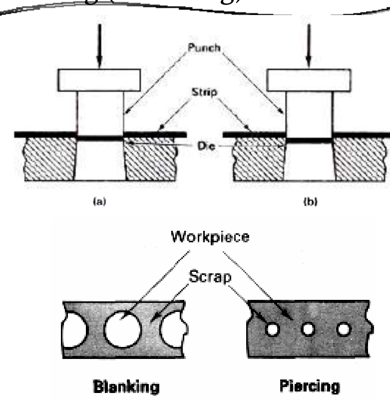
Sheet Metal

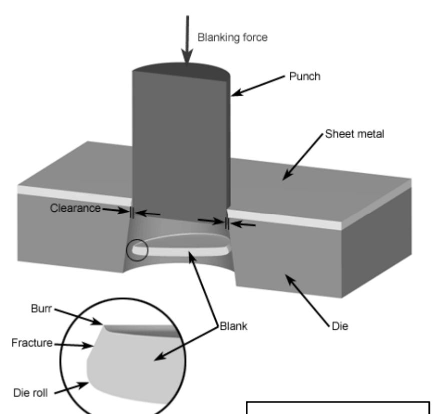
- Product has light weight and versatile shape as compared to forging/casting
- Most commonly used – low carbon steel sheet (cost, strength, formability)
- Aluminium and titanium for aircraft and aerospace
- Sheet metal has become a significant material for,
  - automotive bodies and frames,
  - office furniture
  - frames for home appliances

Piercing (Punching) and Blanking

- Piercing and blanking are shearing operations.
- **In blanking, the piece being punched out becomes the workpiece and any major burrs or undesirable features should be left on the remaining strip.**
- **In piercing (Punching), the punch-out is the scrap and the remaining strip is the workpiece.**
- Both done on some form of mechanical press.

Piercing (Punching) and Blanking





Clearance (VIMP)

- Die opening must be larger than punch and known as 'clearance'.
- **Punching**

  Punch = size of hole

  Die = punch size +2 clearance

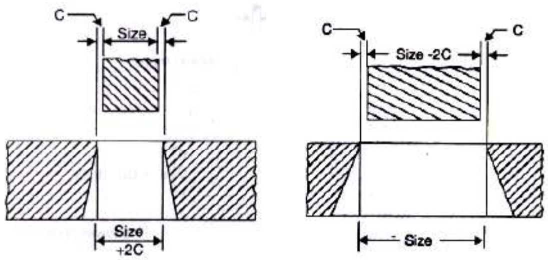
  - **Remember:** In punching punch is correct size.

- **Blanking**

  Die = size of product

  Punch = Die size -2 clearance

  - **Remember:** In blanking die size will be correct.



Punching Blanking

Clearance Contd....

The clearance may also be determined with following equation

$$c = 0.0032t\sqrt{\tau}$$

Where τ is the shear strength of the material in N/mm²

The total clearance between punch and die size will be twice these 'C' i.e. 2C

Example

Determine the die and punch sizes for blanking a circular disc of 20-mm diameter from a sheet whose thickness is 1.5 mm.

Shear strength of sheet material = 294 MPa

Punching Force and Blanking Force

$$F_{\max} = Lt\tau$$

The punching force for holes which are smaller than the stock thickness may be estimated as follows:

$$F_{\max} = \frac{\pi d t \sigma}{\sqrt[3]{\frac{d}{t}}}$$

Capacity of Press for Punching and Blanking

Press capacity will be = $F_{\max} \times C$

[Where C is a constant and equal to 1.1 to 1.75 depending upon the profile]

Minimum Diameter of Piercing

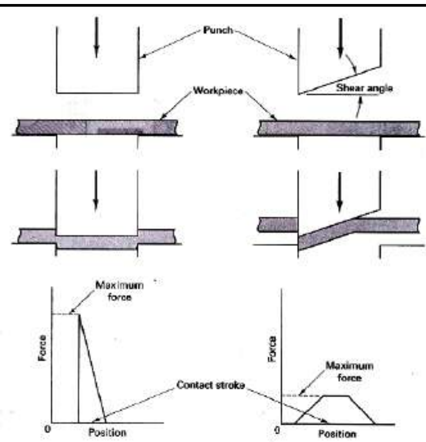
Piercing pressure, $\tau_s \pi d.t$ = Strength of punch, $\sigma_c \times \frac{\pi}{4} d^2$

Example

Estimate the blanking force to cut a blank 25 mm wide and 30 mm long from a 1.5 mm thick metal strip, if the ultimate shear strength of the material is 450 N/mm². Also determine the work done if the percentage penetration is 25 percent of material thickness.

Shear on Punch

- To reduce shearing force, shear is ground on the face of the die or punch.
- It distribute the cutting action over a period of time.
- Shear only reduces the maximum force to be applied but total work done remains same.



Force required with shear on Punch

$$F = \frac{F_{max}(tp)}{S} = \frac{L\tau t(tp)}{S}$$

Where p = penetration of punch as a fraction

S = shear on the punch or die, mm

Example

- A hole, 100 mm diameter, is to be punched in steel plate 5.6 mm thick. The ultimate shear stress is 550 N/mm² . With normal clearance on the tools, cutting is complete at 40 per cent penetration of the punch. Give suitable shear angle for the punch to bring the work within the capacity of a 30T press.

Example

A washer with a 12.7 mm internal hole and an outside diameter of 25.4 mm is to be made from 1.5 mm thick strip. The ultimate shearing strength of the material of the washer is 280 N/mm².

(a) Find the total cutting force if both punches act at the same time and no shear is applied to either punch or the die.

(b) What will be the cutting force if the punches are staggered, so that only one punch acts at a time.

(c) Taking 60% penetration and shear on punch of 1 mm, what will be the cutting force if both punches act together.

Energy and Power for Punching and Blanking

Ideal Energy (E in J)= maximum force x punch travel $= F_{max} \times (p \times t)$

(Unit: F_{max} in kJ and t in mm othrwise use F_{max} in J and t in m)

Where p is percentage penetration required for rupture

$$Ideal\ power\ in\ press\ (P\ in\ W) = \frac{E \times N}{60}$$

[Where N = actual number of stroke per minute]

$$Actual\ Energy\ (E\ in\ J) = F_{max} \times (p \times t) \times C$$

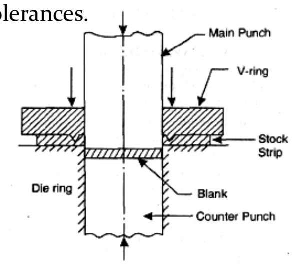
Where C is a constant and equal to 1.1 to 1.75 depending upon the profile

$$Actual\ power\ in\ press\ (P\ in\ W) = \frac{E \times N}{60 \times \eta}$$

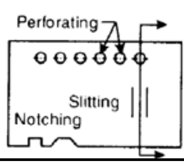
Where E is actual energy and η is efficiency of the press

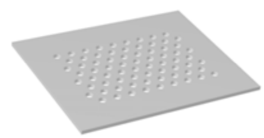
Fine Blanking

Fine Blanking - dies are designed that have small clearances and pressure pads that hold the material while it is sheared. The final result is blanks that have extremely close tolerances.

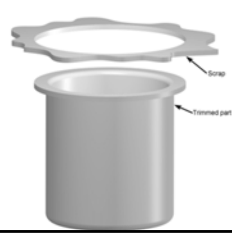


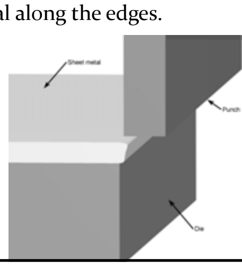
- **Slitting** - moving rollers trace out complex paths during cutting (like a can opener).
- **Perforating: M**ultiple holes which are very small and close together are cut in flat work material.
- **Notching:** Metal pieces are cut from the edge of a sheet, strip or blank.



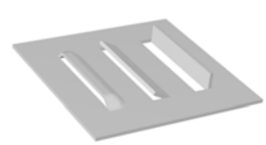


- **Trimming** - Cutting unwanted excess material from the periphery of a previously formed component.
- **Shaving** - Accurate dimensions of the part are obtained by removing a thin strip of metal along the edges.



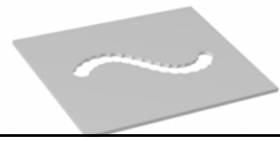


- **Lancing – A** hole is partially cut and then one side is bent down to form a sort of tab or louver. No metal removal, no scrap.



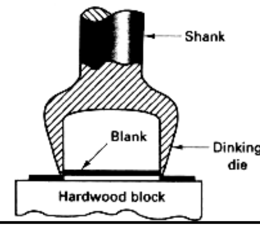
- **Squeezing** - Metal is caused to flow to all portions of a die cavity under the action of compressive forces.

- **Steel Rules** - soft materials are cut with a steel strip shaped so that the edge is the pattern to be cut.
- **Nibbling** - a single punch is moved up and down rapidly, each time cutting off a small amount of material. This allows a simple die to cut complex slots.



Dinking

- Used to blank shapes from low-strength materials, such as rubber, fiber, or cloth.
- The shank of a die is either struck with a hammer or mallet or the entire die is driven downward by some form of mechanical press.



Elastic recovery or spring back

- Total deformation = elastic deformation + plastic deformation.
- At the end of a metal working operation, when the pressure is released, there is an elastic recovery and the total deformation will get reduced a little. This phenomenon is called as "spring back".

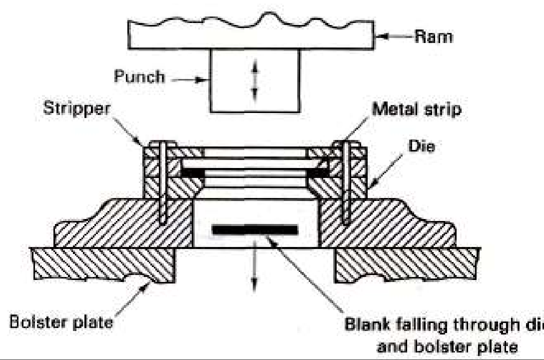
Elastic recovery or spring back Contd..

- More important in cold working.
- It depends on the yield strength. Higher the yield strength, greater spring back.
- To compensate this, the cold deformation be carried beyond the desired limit by an amount equal to the spring back.

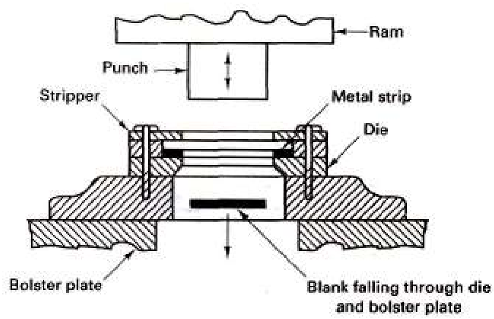
Punch and Die material

- Commonly used – tool steel
- For high production - carbides

Punching Press



Bolster plate

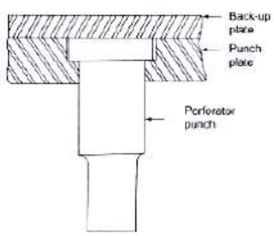


Bolster plate Contd....

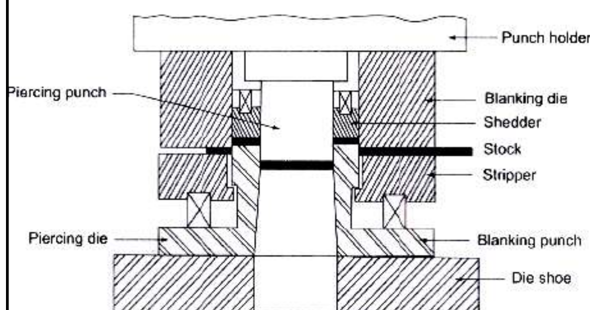
- When many dies are to run in the same press at different times, the wear occurring on the press bed is high. The bolster plate is incorporated to take this wear.
- Relatively cheap and easy to replace.
- Attached to the press bed and the die shoe is then attached to it.

Punch plate

- Used to locate and hold the punch in position.
- This is a useful way of mounting, especially for small punches.



Stripper



Stripper Contd....

- The stripper removes the stock from the punch after a piercing or blanking operation.

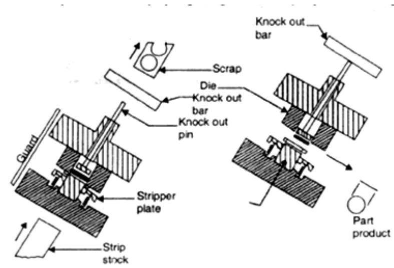
$$P_s = KLt$$

Where P_s = stripping force, kN
L = perimeter of cut, mm
t = stock thickness, mm

K = stripping constant,
= 0.0103 for low- carbon steels thinner than 1.5 mm with the cut at the edge or near a preceding cut
= 0.0145 for same materials but for other cuts
= 0.0207 for low- carbon steels above 1.5-mm thickness
= 0.0241 for harder materials

Knockout

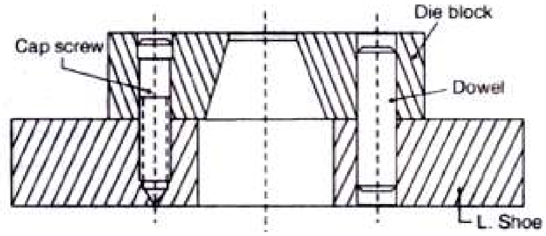
- Knockout is a mechanism, usually connected to and operated by the press ram, for freeing a work piece from a die.

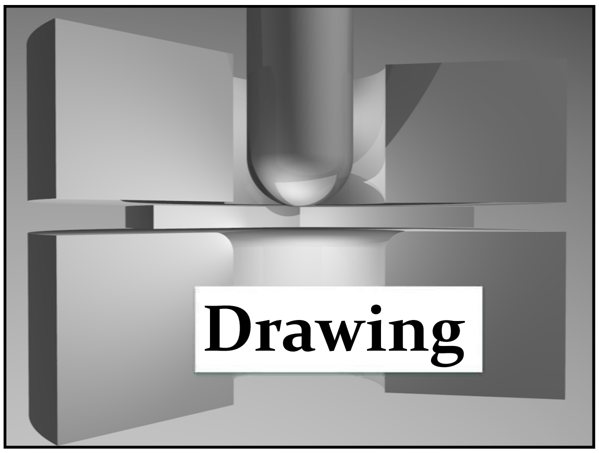


Pitman

- It is a connecting rod which is used to transmit motion from the main drive shaft to the press slide.

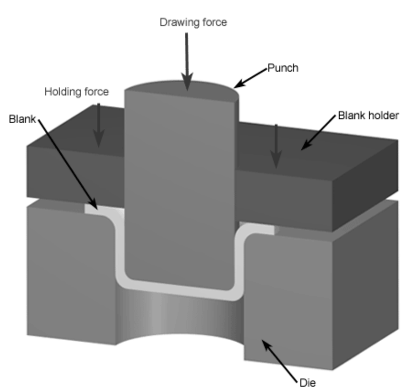
Dowel pin





Drawing

- Drawing is a plastic deformation process in which a flat sheet or plate is formed into a three-dimensional part with a depth more than several times the thickness of the metal.
- As a punch descends into a mating die, the metal assumes the desired configuration.

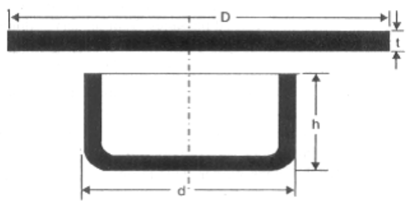


Drawing

- Hot drawing is used for thick-walled parts of simple geometries, thinning takes place.
- Cold drawing uses relatively thin metal, changes the thickness very little or not at all, and produces parts in a wide variety of shapes.

Blank Size

$D = \sqrt{d^2 + 4dh}$ When d > 20r



Drawing Force

$$P = \pi dts\left[\frac{D}{d} - C\right]$$

Blank Holding Force

- Blank holding force required depends on the wrinkling tendency of the cup. The maximum limit is generally to be one-third of the drawing force.

Draw Clearance

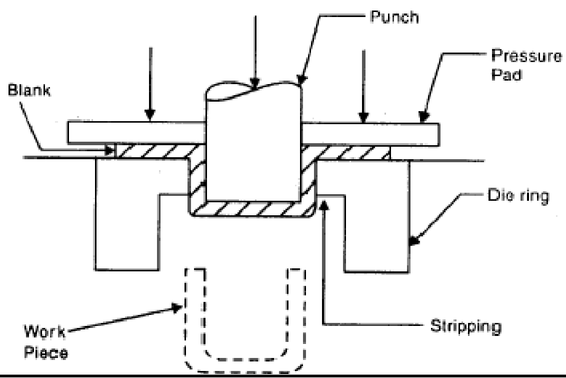
- Punch diameter = Die opening diameter – 2.5 t.

Deep drawing

- Drawing when cup height is more than half the diameter is termed deep drawing.
- Easy with ductile materials.
- Due to the radial flow of material, the side walls increase in thickness as the height is increased.
- A cylindrical vessel with flat bottom can be deep drawn by double action deep drawing.
- Deep drawing - is a combination of drawing and stretching.

Stresses on Deep Drawing

- In flange of blank: Bi-axial tension and compression
- In wall of the cup: simple uni-axial tension



Deep Drawability

- The ratio of the maximum blank diameter to the diameter of the cup drawn . *i.e. D/d.*
- There is a limiting drawing ratio (LDR), after which the punch will pierce a hole in the blank instead of drawing.
- This ratio depends upon material, amount of friction present, etc.
- Limiting drawing ratio (LDR) is 1.6 to 2.3

Limiting Drawing Ratio (LDR)

- The average reduction in deep drawing

$$\frac{d}{D} = 0.5$$

$$\text{Reduction} = \left(1 - \frac{d}{D}\right) \times 100\% = 50\%$$

Thumb rule:

First draw: Reduction = 50 %

Second draw: Reduction = 30 %

Third draw: Reduction = 25 %

Fourth draw: Reduction = 16 %

Fifth draw: Reduction = 13 %

Example

- **A symmetrical cup of 80 mm diameter and 250 mm height is to be fabricated on a deep drawing die. How many drawing operations will be necessary if no intervening annealing is done.**
- **Also find the drawing force**

Draw Die Design

- **Progressive dies**
- **Compound dies**
- **Combination dies**

<u>Progressive dies</u>

Perform two or more operations simultaneously in a single stroke of a punch press, so that a complete component is obtained for each stroke.

<u>Compound dies</u>

All the necessary operations are carried out at a single station, in a single stroke of the ram. To do more than one set of operations, a compound die consists of the necessary sets of punches and dies.

Combination dies

A combination die is same as that of a compound die with the main difference that here non-cutting operations such as bending and forming are also included as part of the operation.

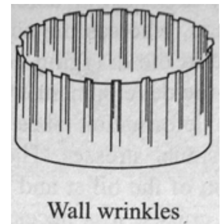
Lubrication

- In drawing operation, proper lubrication is essential for
  1. To improve die life.
  2. To reduce drawing forces.
  3. To reduce temperature.
  4. To improve surface finish.

Defects in Drawing - wrinkle

- An insufficient blank holder pressure causes wrinkles to develop on the flange, which may also extend to the wall of the cup.

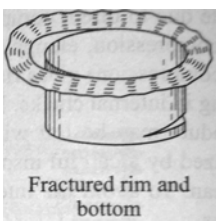
Flange wrinkles



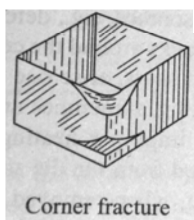
Wall wrinkles

Defects in Drawing - Fracture

- Further, too much of a blank holder pressure and friction may cause a thinning of the walls and a fracture at the flange, bottom, and the corners (if any).



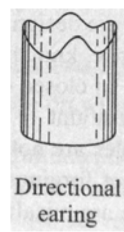
Fractured rim and bottom



Corner fracture

Defects in Drawing -earing

- While drawing a rolled stock, ears or lobes tend to occur because of the anisotropy induced by the rolling operation.



Directional earing

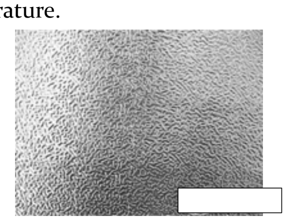
Defects in Drawing – miss strike

- Due to the misplacement of the stock, unsymmetrical flanges may result. This defect is known as miss strike.

Miss strike

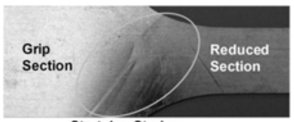
Defects in Drawing – Orange peel

- A surface roughening (defect) encountered in forming products from metal stock that has a coarse grain size.
- It is due to uneven flow or to the appearance of the overly large grains usually the result of annealing at too high a temperature.



Stretcher strains (like Luders Lines)

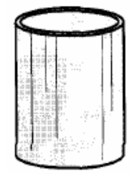
- Caused by plastic deformation due to inhomogeneous yielding.
- These lines can criss-cross the surface of the workpiece and may be visibly objectionable.
- Low carbon steel and aluminium shows more stretcher strains.



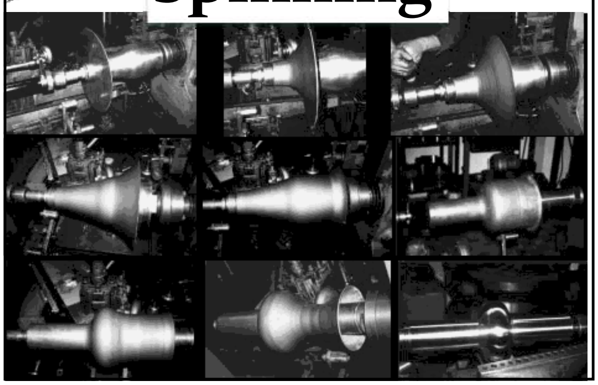
Stretcher Strains

Surface scratches

- Die or punch not having a smooth surface, insufficient lubrication



Spinning

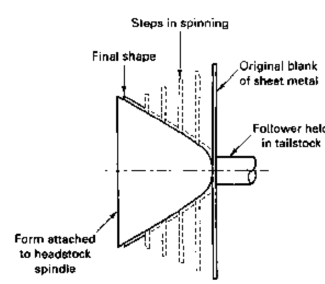


Spinning

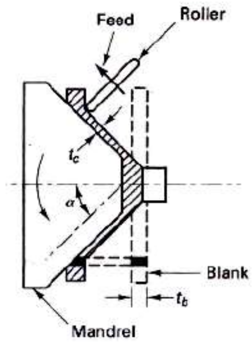
- Spinning is a cold-forming operation in which a rotating disk of sheet metal is shaped over a male form, or mandrel.
- Localized pressure is applied through a simple round-ended wooden or metal tool or small roller, which traverses the entire surface of the part

Spinning

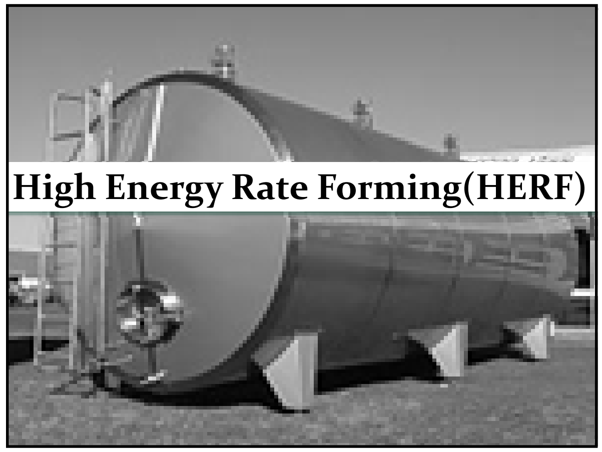
1. A mandrel (or die for internal pieces) is placed on a rotating axis (like a turning center).
2. A blank or tube is held to the face of the mandrel.
3. A roller is pushed against the material near the center of rotation, and slowly moved outwards, pushing the blank against the mandrel.
4. The part conforms to the shape of the mandrel (with some springback).
5. The process is stopped, and the part is removed and trimmed.



$$t_c = t_b \sin\alpha$$



High Energy Rate Forming(HERF)



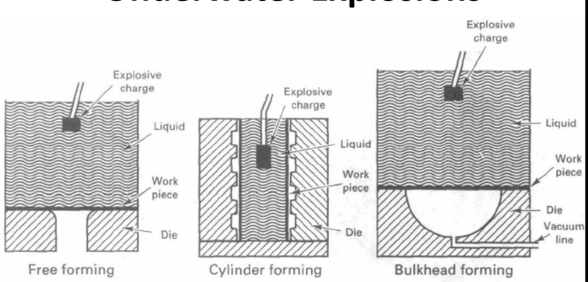
HERF

- High Energy Rate Forming, also known as HERF or explosive forming can be utilised to form a wide variety of metals, from aluminum to high strength alloys.
- Applied a large amount of energy in a very sort time interval.
- HERF makes it possible to form large work pieces and difficult-to-form metals with less-expensive equipment and tooling required.
- No springback

HERF

- Underwater explosions.
- Underwater spark discharge (electro-hydraulic).
- Pneumatic-mechanical means
- Internal combustion of gaseous mixtures.
- Electro-magnetic (the use of rapidly formed magnetic fields).

Underwater Explosions

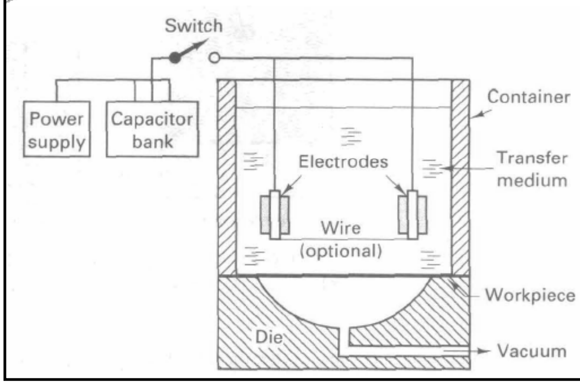


Underwater explosions

- A shock wave in the fluid medium (normally water) is generated by detonating an explosive charge.
- TNT and dynamite for higher energy and gun powder for lower energy is used.
- Used for parts of thick materials.
- Employed in Aerospace, aircraft industries and automobile related components.

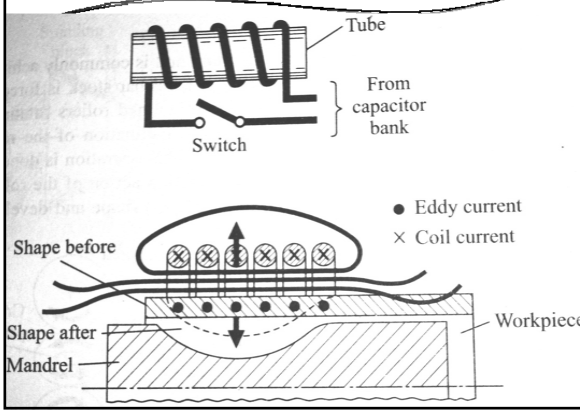
Electro-hydraulic Forming

- An operation using electric discharge in the form of sparks to generate a shock wave in a fluid is called electrohydrulic forming.
- A capacitor bank is charged through the charging circuit, subsequently, a switch is closed, resulting in a spark within the electrode gap to discharge the capacitors.
- Energy level and peak pressure is lower than underwater explosions but easier and safer.
- Used for bulging operations in small parts.



Electromagnetic or Magnetic Pulse Forming

- Based on the principle that the electromagnetic field of an induced current always opposes the electromagnetic field of the inducing current.
- A large capacitor bank is discharged, producing a current surge through a coiled conductor.
- If the coil has been placed within a conductive cylinder, around a cylinder, or adjacent the flat sheet of metal, the discharge induces a secondary current in the workpiece, causing it to be repelled from the coil and conformed to a die or mating workpiece.



Electromagnetic or Magnetic Pulse Forming

- The process is very rapid and is used primarily to expand or contract tubing, or to permanently assemble component parts.
- This process is most effective for relatively thin materials (0.25 to 1.25 mm thick).

Stretch Forming

- Produce large sheet metal parts in low or limited quantities.
- A sheet of metal is gripped by two or more sets of jaws that stretch it and wrap it around a single form block.
- Because most of the deformation is induced by the tensile stretching, the forces on the form block are far less than those normally encountered in bending or forming.
- There is very little springback, and the workpiece conforms very closely to the shape of the tool.
- Because the forces are so low, the form blocks can often be made of wood, low-melting-point metal, or even plastic.

Stretch Forming Contd……

- Popular in the aircraft industry and is frequently used to form aluminum and stainless steel
- Low-carbon steel can be stretch formed to produce large panels for the automotive and truck industry.

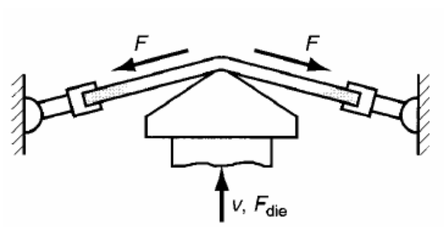
Stretch Forming Contd……

For bi-axial stretching of sheets

$$\varepsilon_1 = \ln\left(\frac{l_{i1}}{l_{o1}}\right) \quad ; \quad \varepsilon_2 = \ln\left(\frac{l_{i2}}{l_{o2}}\right)$$

$$\text{Final thickness} = \frac{\text{Initial thickness(t)}}{e^{\varepsilon_1} \times e^{\varepsilon_2}}$$

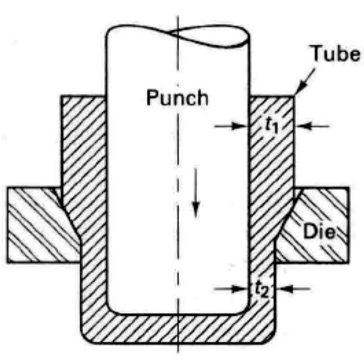
Stretch Forming Contd……



Ironing

- The process of thinning the walls of a drawn cylinder by passing it between a punch and die whose separation is less than the original wall thickness.
- The walls are thinned and lengthened, while the thickness of the base remains unchanged.
- Examples of ironed products include brass cartridge cases and the thin-walled beverage can.

Ironing Contd….



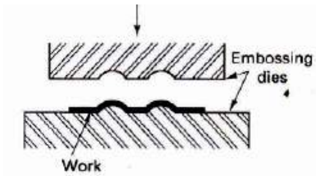
Ironing Force

- Neglecting the friction and shape of the die, the ironing force can be estimated using the following equation.

$$F = \pi d_t t_t \sigma_{av} \ln\left(\frac{t_o}{t_t}\right)$$

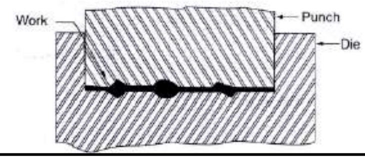
Embossing

- It is a very shallow drawing operation where the depth of the draw is limited to one to three times the thickness of the metal, and the material thickness remains largely unchanged.



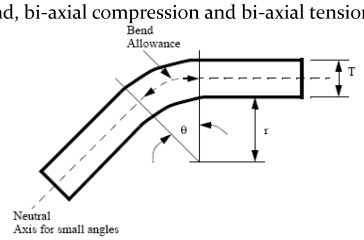
Coining

- Coining is essentially a cold-forging operation except for the fact that the flow of the metal occurs only at the top layers and not the entire volume.
- Coining is used for making coins, medals and similar articles.



Bending

- After basic shearing operation, we can bend a part to give it some shape.
- Bending parts depends upon material properties at the location of the bend.
- At bend, bi-axial compression and bi-axial tension is there.



Bending

Bend allowance,

$$L_b = \theta(r+kt)$$

where

r = bend radius

k = constant (stretch factor)

$For\ r > 2t \qquad k = 0.5$

$For\ r < 2t \qquad k = 0.33$

t = thickness of material

θ = bend angle (in radian)

Bending

- The strain on the outermost fibers of the bend is

$$\varepsilon = \frac{1}{\frac{2r}{t}+1}$$

Bending Force

$$F = \frac{Kl\sigma_{ut}t^2}{w}$$

Where l = Bend length = width of the stock, mm

σ_{ut} = Ultimate tensile strength, MPa (N/mm^2)

t = blank thickness, mm

w = width of die-opening, mm

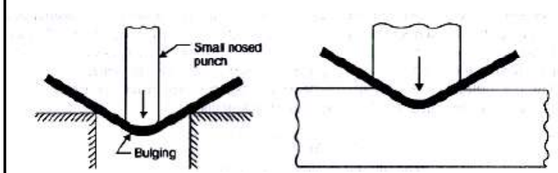
K = die-opening factor, (can be used followin table)

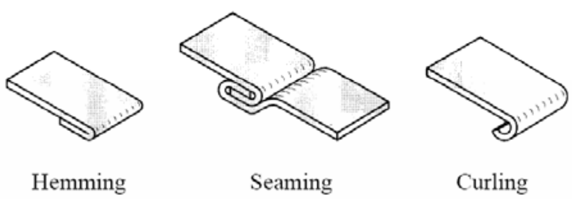
Condition	V-Bending	U-Bending	Edge-Bending
W < 16t	1.33	2.67	0.67
W > = 16t	1.20	2.40	0.6

For U or channel bending force required is double than V – bending
For edge bending it will be about one-half that for V - bending

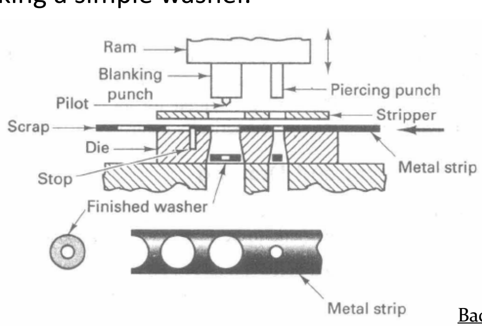
Spanking

- During bending, the area of the sheet under the punch has a tendency to flow and form a bulge on the outer surface.
- The lower die should be provided with mating surfaces, so that when the punch and die are completely closed on the blank, any bulging developed earlier will be completely presses or "spanked" out.



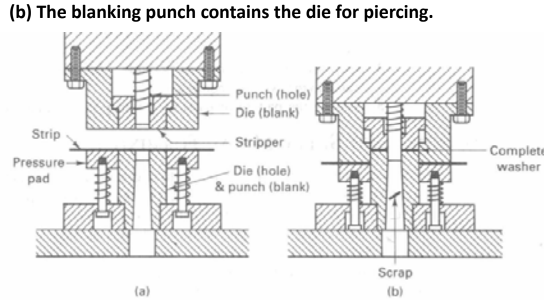


Progressive piercing and blanking die for making a simple washer.



Back

Method for making a simple washer in a compound piercing and blanking die. Part is blanked (a) and subsequently pierced (b) The blanking punch contains the die for piercing.



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Powder Metallurgy

- Powder metallurgy is the name given to the process by which fine powdered materials are blended, pressed into a desired shape (compacted), and then heated (sintered) in a controlled atmosphere to bond the contacting surfaces of the particles and establish the desired properties.

Manufacturing of Powder

Atomization/metal spraying - low melting point metals are sprayed to form irregular particles

Granulations - as metals are cooled they are stirred rapidly

Electrolytic deposition - often used for iron, copper, silver

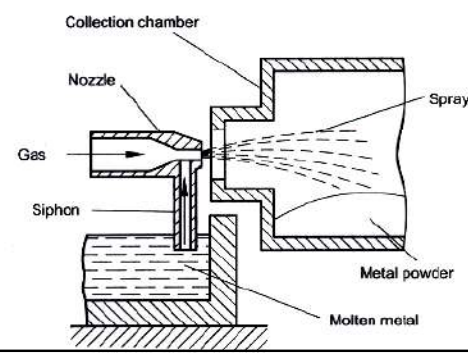
Machining - coarse powders such as magnesium

Milling - crushers and rollers to break down metals

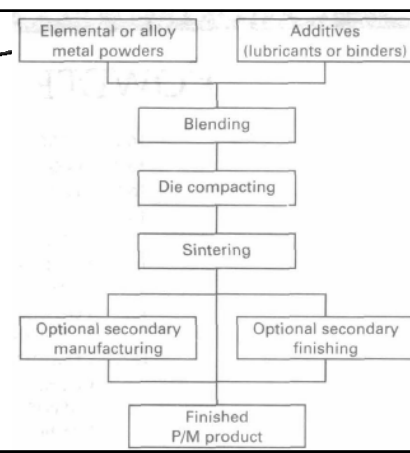
Shotting - drops of molten metal are dropped in water

Reduction - metal oxides are turned to powder when exposed to below melting point gases.

Atomization using a gas stream



- Powders often come in elemental forms and must be blended in correct ratios for metallurgical purposes.
- Lubricants may also be added to increase powder flow, and to reduce mold adhesion during and after compaction.
- During sintering the metal parts are put in ovens with temperatures just below the melting point. (These ovens also have controlled atmospheres). As the parts are heated the compacted particles melt slightly and bond. There is a reduction in part size.



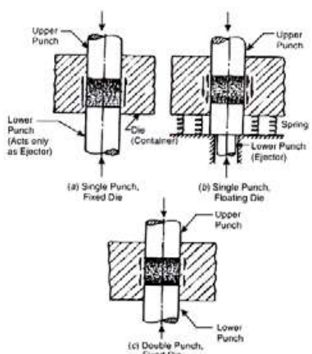
Blending

- Blending or mixing operations can be done either dry or wet.
- Lubricants such as graphite or stearic acid improve the flow characteristics and compressibility at the expense of reduced strength.
- Binders produce the reverse effect of lubricants. Thermoplastics or a water-soluble methylcellulose binder is used.
- Most lubricants or binders are not wanted in the final product and are removed (volatilized or burned off)

Compacting

- Powder is pressed into a "green compact"
- 40 to 1650 MPa pressure (Depends on materials, product complexity)
- Still very porous, ~70% density
- May be done cold or warm (higher density)

Compacting

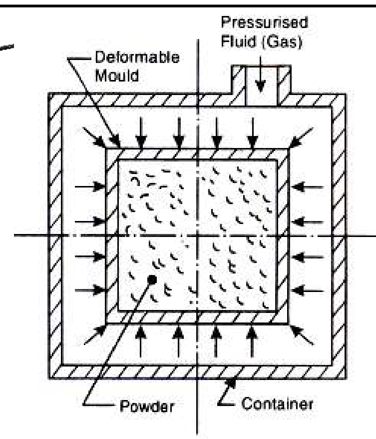


Sintering

- Controlled atmosphere: no oxygen
- Heat to 0.75*T melt
- Particles bind together
- Part shrinks in size
- Density increases, up to 95%
- Strength ~=~ Density

Cold Isostatic Pressing (CIP)

- The powder is contained in a flexible mould made of rubber or some other elastomer material
- The flexible mould is then pressurized by means of high-pressure water or oil. (same pressure in all directions)
- No lubricant is needed
- High and uniform density can be achieved



Hot Isostatic Pressing (HIP)

- Is carried out at high temperature and pressure using a gas such as argon.
- The flexible mould is made of sheet metal. (Due to high temperature)
- Compaction and sintering are completed simultaneously.
- Used in the production of billets of super-alloys, high-speed steels, titanium, ceramics, etc, where the integrity of the materials is a prime consideration

Production of magnets

- 50:50 Fe-Al alloys is used for magnetic parts
- Al-Ni-Fe is used for permanent magnets
- Sintering is done in a wire coil to align the magnetic poles of the material
- H_2 is used to rapidly cool the part (to maintain magnetic alignment)
- Total shrinkage is approximately 3-7% (for accurate parts an extra sintering step may be added before magnetic alignment)
- The sintering temperature is 600°C in H_2

Advantages

- Good tolerances and surface finish
- Highly complex shapes made quickly
- Can produce porous parts and hard to manufacture materials (e.g. cemented oxides)
- Pores in the metal can be filled with other materials/metals
- Surfaces can have high wear resistance
- Porosity can be controlled
- Low waste
- Automation is easy

Advantages Contd....

- Physical properties can be controlled
- Variation from part to part is low
- Hard to machine metals can be used easily
- No molten metals
- No need for many/any finishing operations
- Permits high volume production of complex shapes
- Allows non-traditional alloy combinations
- Good control of final density

Disadvantages

- Metal powders deteriorate quickly when stored improperly
- Fixed and setup costs are high
- Part size is limited by the press, and compression of the powder used.
- Sharp corners and varying thickness can be hard to produce
- Non-moldable features are impossible to produce.

Applications

- Oil-impregnated bearings made from either iron or copper alloys for home appliance and automotive applications
- P/M filters can be made with pores of almost any size.
- Pressure or flow regulators.
- Small gears, cams etc.
- Products where the combined properties of two or more metals (or both metals and nonmetals) are desired.
- Cemented carbides are produced by the cold-compaction of tungsten carbide powder in a binder, such as cobalt (5 to 12%), followed by liquid-phase sintering.

Pre - Sintering

- If a part made by PM needs some machining, it will be rather very difficult if the material is very hard and strong. These machining operations are made easier by the pre-sintering operation which is done before sintering operation.

Repressing

- Repressing is performed to increase the density and improve the mechanical properties.
- Further improvement is achieved by re-sintering.

Infiltration

- Component is dipped into a low melting-temperature alloy liquid
- The liquid would flow into the voids simply by capillary action, thereby decreasing the porosity and improving the strength of the component.
- The process is used quite extensively with ferrous parts using copper as an infiltrate but to avoid erosion, an alloy of copper containing iron and manganese is often used.

Impregnation

- Impregnation is similar to infiltration
- PM component is kept in an oil bath. The oil penetrates into the voids by capillary forces and remains there.
- The oil is used for lubrication of the component when necessary. During the actual service conditions, the oil is released slowly to provide the necessary lubrication.
- The components can absorb between 12% and 30% oil by volume.
- It is being used on P/M **self-lubricating bearing** components since the late 1920's.

Oil-impregnated Porous Bronze Bearings

Conventional Questions

1. Explain why metal powders are blended. Describe what happens during sintering. [IES-2010, 2 Marks]

Conventional Questions

1. Discuss the terms fineness and particle size distribution in powder metallurgy. [IES-2010, 2 Marks]

Ans.

Fineness: Is the diameter of spherical shaped particle and mean diameter of non-spherical shaped particle.

Particle size distribution: Geometric standard deviation (a measure for the bredth or width of a distribution), is the ratio of particle size diameters taken at 84.1 and 50% of the cumulative undersized weight plot, respectively and mean mass diameter define the particle size distribution.

Conventional Questions

Enumerate the steps involved in "powder metallurgy" process. Discuss these steps. Name the materials used in "powder metallurgy". What are the limitations of powder metallurgy? [IES-2005, 10 Marks]