SHEET METAL PROCESSES

BENDING

Bending is one very common sheet metal forming operation used not only to form shapes like seams, corrugations, and flanges but also to provide stiffness to the part (by increasing its moment of inertia). As a sheet metal is bent (Fig 6.1), its fibres experience a distortion such that those nearer its outside, convex surface are forced to stretch and come in tension, while the inner fibres come in compression. Somewhere, in the cross section, there is a plane which separates the tension and compression zones. This plane is parallel to the surface around which the sheet is bending, and is called neutral axis. The position of neutral axis depends on the radius and angle of bend. Further, because of the Poisson's ratio, the width of the part L in the outer region is smaller, and in the inner region it is larger, than the initial original width.

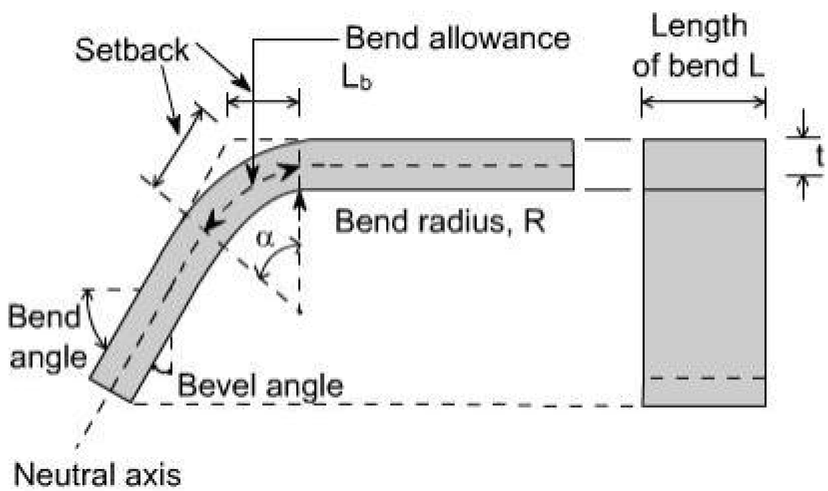

Fig 6.1 Sheet metal bending. It may be noted that the bend radius is measured to the inner surface of the bent part.

BEND ALLOWANCE

It is the length of the neutral axis in the bend,Fig 6.1. This determines the blank length needed for a bent part. It can be approximately estimated from the relation

$L_b = a (R + kt)$

where, L_b = bend allowance (mm)

a = bend angle (radian)

R = bend radius (mm)

t = thickness of sheet (mm), and

k = constant, whose value may be taken as 1/3 when R < 2t, and as 1/2 when R ³ 2t.

Example : A 20 mm wide and 4 mm thick C 20 steel sheet is required to be bent at 60^0 at bend radius 10 mm. Determine the bend allowance.

Solution.

Here, bend radius R = 10 mm

Sheet thickness t = 4 mm

$$\alpha = 2\pi \times \frac{60}{360} \text{ radian}$$

Since R > 2t, k = 0.5

Bend allowance

$$= \left(2\pi \times \frac{60}{360}\right)(10 + 0.5 \times 4)$$

$$= 12.56 \text{ mm}$$

MINIMUM BEND RADIUS

As the ratio of the bend radius to the thickness of sheet (R / t) decreases, the tensile strain on the outer fibres of sheet increases. If R / t decreases beyond a certain limit, cracks start appearing on the surface of material. This limit is called *Minimum Bend Radius* for the material.

Minimum bend radius is generally expressed in terms of the thickness of material, such as 2t, 3t, 4t, etc. Table 6.1gives the minimum bend radius allowed for different materials.

Table 6.1 Minimum Bend radius for Various Materials at Room Temperature

Material	**Condition**	
	Soft	**Hard**
Aluminum alloys	0	6t
Beryllium copper	0	4t
Brass,low-leaded	0	2t
Magnesium	5t	13t
Steels		
Austenitic stainless	0.5t	6t
Low-carbon,low-alloy	0.5t	4t
Titanium	0.7t	3t
Titanium alloys	2.5t	4t

Bending Force :

There are two general types of die bending : V - die bending and wiping die bending. V - die bending is used expensively in brake die operations and stamping die operations. The bending force can be estimated from the following simple relation.

$P = k.Y.L.t^2 / D$

where P is bending force, g is the yield stress of the material, L is the bend length (bend allowance), t is the sheet thickness, D is the die opening and k is a constant whose value can be taken as 1.3 for a V-die and 0.3 for a wiping die.Fig 6.2shows various types of bending dies.

Fig 6.2 Die-bending operations.

Bending force varies as the punch progresses through the bending operation. The force is zero in the beginning. It rises and reaches the maximum value as the punch progresses and reaches the bottom of the stroke.

Example:

A 400 mm long and 2.5 mm thick piece of carbon steel sheet is required to be bent at 90^0 using a V - die. You may assume the yield stress of the material as 500 MPa and the die opening as 10 times the material thickness. Estimate the force required for the operation.

Solution : Here, Y = 500 MPa

L = 400 mm

t = 2.5 mm

k = 1.3 (for V - die)

D = 25 mm

Bending force $P = k.Y.L.t^2 / D$

$= 1.3 \times 500 \times 400 \times (2.5)^2 / 25$

= 65 KN Ans.

Example : If the material as mentioned in the above example is to be bent at 90^0 using wiping die with radius = 3.75 mm, what is the force requirement?

Solution : Here,Y = 500 MPa

L = 400 mm

t = 2.5 mm

k = 0.3

D = 2.5 + 3.75 + 3.75 = 10mm (seeFig 6.3)

Fig 6.3

Bending force $P = k.Y.L.t^2 / D$

$= 0.3 \times 500 \times 400 \times (2.5)^2 / 10$

$= 37.5$ KN

DRAWING

It is a process of cold forming a flat blank of sheet metal into a hollow vessel without much wrinkling, trimming, or fracturing. The process involves forcing the sheet metal blank into a die cavity with a punch. The punch exerts sufficient force and the metal is drawn over the edge of the die opening and into the die,Fig 6.4. In forming a cup, however, the metal goes completely into the die,Fig 6.5.

Fig 6.4 Drawing operation.

Fig 6.5 Drawing operation.

The metal being drawn must possess a combination of ductility and strength so that it does not rupture in the critical area (where the metal blends from the punch face to the vertical portion of the punch). The metal in this area is subjected to stress that occurs when the metal is pulled from the flat blank into the die.

OPERATION **.** A setup similar to that used for blanking is used for drawing with the difference that the punch and die are given necessary rounding at the corners to permit smooth flow of metal during drawing. The blank of appropriate dimensions is place within the guides on the die plate. The punch descends slowly on the blank and metal is drawn into the die and the blank is formed into the shape of cup as punch reaches the bottom of the die. When the cup reaches the counter - bored portion of the die, the top edge of the cup formed around the punch expands a bit due to the *spring back* . On the return stroke of the punch, the cup is stripped off the punch by this counter - bored portion.

The term *shallow drawing* is used when the height of cup formed is less than half its diameter. When drawing deeper cup (height greater that ½ diameter) the chances of excessive wrinkle formation at the edges of blank increases. To prevent this, a blank holder is normally provided, seeFig 6.4. As the drawing process proceeds the blank holder stops the blank from increasing in thickness beyond a limit and allows the metal to flow radially. The limiting thickness is controlled by the gap between the die and the blank holder, or by the spring pressure in the case of a spring loaded blank holder.

Some lubricant is generally used over the face of the blank to reduce friction and hence drawing load.

Blank Size

It is generally difficult to find the exact size of the blank needed for drawing a given cup, because of thinning and thickening of the metal sheet during the drawing operation. The following simple relations can be used for determine the blank diameter D:

$$D = \sqrt{d^2 + 4dh - 0.5r} \quad \text{when } d \geq 20r$$

$$= \sqrt{d^2 + 4dh - 0.5r} \quad \text{when } d \text{ is between } 15r \text{ and } 20r$$

$$= \sqrt{d^2 + 4dh - 5r} \quad \text{when } d \text{ is between } 10r \text{ and } 15r$$

where d = outside diameter of cup

h = height of cup

r = corner radius on punch.

Drawing Force.

For drawing cylindrical shells having circular cross section, the maximum drawing force P can be determined from the relation

P = k.t.d.t.Y

where d = outside diameter of cup

t = thickness of material

Y = yield strength of material

k = factor whose value is approx. equal to [D/d - 0.6]

D = blank diameter

EMBOSSING

Embossing is an operation in which sheet metal is drawn to shallow depths with male and female matching dies,Fig 6.6. The operation is carried out mostly for the purpose of stiffening flat panels.The operation is also sometimes used for making decoration items like number plates or name plates, jewelry, etc.

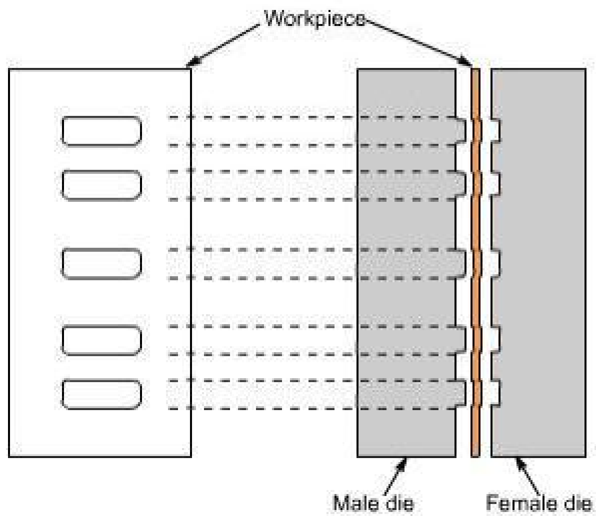

Fig 6.6 Embossing operation with two dies. Letters, numbers and designs on sheet-metal parts can be produced by this operation.

COINING

Coining is a severe metal squeezing operation in which the flow of metal occurs only at the top layers of the material and not throughout the values. The operation is carried out in closed dies mainly for the purpose of producing fine details such as needed in minting coins, and medal or jewelry making. The blank is kept in the die cavity and pressures as high as five to six times the strength of material are applied. Depending upon the details required to be coined on the part, more than one coining operations may be used.

The difference between coining and embossing is that the same design is created on both sides of the work piece in embossing (one side depressed and the other raised), whereas in coining operation, a different design is created on each side of work piece.

PRESSES FOR SHEET METAL WORKING

Classification of presses.

Types of presses for sheet metal working can be classified by one or a combination of characteristics, such as source of power, number of slides, type of frame and construction, type of drive, and intended applications.

Classification on the basis of source of power.

- Manual Presses. These are either hand or foot operated through levers, screws or gears. A common press of this type is the arbor press used for assembly operations.
- Mechanical presses.These presses utilize flywheel energy which is transferred to the work piece by gears, cranks, eccentrics, or levers.
- Hydraulic Presses. These presses provide working force through the application of fluid pressure on a piston by means of pumps, valves, intensifiers, and accumulators. These presses have better performance and reliability than mechanical presses.
- Pneumatic Presses. These presses utilize air cylinders to exert the required force. These are generally smaller in size and capacity than hydraulic or mechanical presses, and therefore find use for light duty operations only.

Classification on the basis of number of slides.

- Single Action Presses. A single action press has one reciprocation slide that carries the tool for the metal forming operation. The press has a fixed bed. It is the most widely used press for operations like blanking, coining, embossing, and drawing.
- Double Action Presses. A double action press has two slides moving in the same direction against a fixed bed. It is more suitable for drawing operations, especially deep drawing, than single action press. For this reason, its two slides are generally referred to as outer blank holder slide and the inner draw slide. The blank holder slide is a hollow rectangle, while the inner slide is a solid rectangle that reciprocates within

the blank holder. The blank holder slide has a shorter stroke and dwells at the bottom end of its stroke, before the punch mounted on the inner slide touches the workpiece. In this way, practically the complete capacity of the press is available for drawing operation.

Another advantage of double action press is that the four corners of the blank holder are individually adjustable. This permits the application of non uniform forces on the work if needed.

A double action press is widely used for deep drawing operations and irregular shaped stampings.

- Triple Action Presses. A triple action press has three moving slides. Two slides (the blank holder and the inner slide) move in the same direction as in a double - action press and the third or lower slide moves upward through the fixed bed in a direction opposite to that of the other two slides. This action allows reverse - drawing, forming or bending operations against the inner slide while both upper actions are dwelling.

Cycle time for a triple - action press is longer than for a double - action press because of the time required for the third action.

Classification on the basis of frame and construction.

- Arch - Frame Presses. These presses have their frame in the shape of an arch. These are not common.
- Gap Frame Presses. These presses have a C-shaped frame. These are most versatile and common in use, as they provide un - obstructed access to the dies from three sides and their backs are usually open for the ejection of stampings and / or scrap.
- Straight Side Presses. These presses are stronger since the heavy loads can be taken in a vertical direction by the massive side frame and there is little tendency for the punch and die alignment to be affected by the strain. The capacity of these presses is usually greater than 10 MN.
- Horn Presses. These presses generally have a heavy shaft projecting from the machine frame instead of the usual bed. This press is used mainly on cylindrical parts involving punching, riveting, embossing, and flanging edges.

Fig 7.1shows typical frame designs.

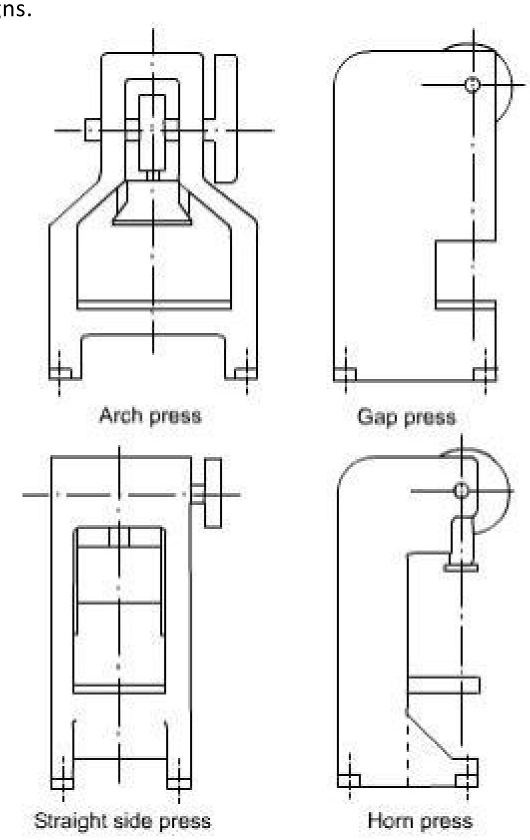

Fig 7.1 Typical frame designs used for power presses.

Press Selection:

Proper selection of a press is necessary for successful and economical operation. Press is a costly machine, and the return on investment depends upon how well it performs the job. There is no press that can provide maximum productively and economy for all application so, when a press is required to be used for several widely varying jobs, compromise is generally made between economy and productivity.

Important factors affecting the selection of a press are size, force, energy and speed requirements.

Size. Bed and slide areas of the press should be of enough size so as to accommodate the dies to be used and to make available adequate space for die changing and maintenance. Stroke requirements are related to the height of the parts to be produced. Press with short stroke should be preferred because it would permit faster operation, thus increasing productivity. Size and type of press to be selected also depends upon the method and nature of part feeding, the type of operation, and the material being formed.

Force and Energy. Press selected should have the capacity to provide the force and energy necessary for carrying out the operation. The major source of energy in mechanical presses is the flywheel, and the energy available is a function of mass of flywheel and square of its speed.

Press Speed. Fast speeds are generally desirable, but they are limited by the operations performed. High speed may not, however, be most productive or efficient. Size, shape and material of workpiece, die life, maintenance costs, and other factors should be considered while attemping to achicve the highest production rate at the lowest cost per piece.

Mechanical versus Hydraulic Presses:

Mechanical presses are very widely used for blanking, forming and drawing operations required to be done on sheet metal. For certain operations which require very high force, for example, hydraulic presses are more advantageous.Table 7.1gives a comparison of characteristics and preferred application of the two types of press.

Table 7.1 Comparison of Mechanical and Hydraulic Presses

Characteristic	Mechanical Presses	Hydraulic Presses
Force	Depends upon slide position.	Dose not depend upon slide position. Relatively constant.
Stroke length	Short strokes	Long strokes,even as much as 3 m.
Slide speed	High. Highest at mid-stroke. Can be variable	Slow. Rapid advance and retraction. Variable speeds uniform throughout stroke.
Capacity	About 50 MN (maximum)	About 500 MN, or even more.
Control	Full stroke generally required before reversel.	Adjustable, slide reversal possible from any position.
Application	Operations requiring maximum pressure near bottom of stroke. Cutting operations(blanking, shearing, piercing, Forming and drawing to depths of about 100 mm.	Operations requiring steady pressure through-out stoke. Deep drawing. Drawing irregular shaped parts. Straightening. Operations requiring variable forces and /or strokes.

Press Feeding Devices:

Safety is an important consideration in press operation and every precaution must be taken to protect the operator. Material must be tried to be fed to the press that eliminates any chance of the operator having his or her hands near the dies. The use of feeding device allows faster and uniform press feeding in addition to the safety features.

- **Blank and Stamping Feeds.**

Feeding of blanks or previously formed stampings to presses can be done in several ways. Selection of a specific method depends upon factors like production rate needed, cost, and safety considerations.

Manual feeding . Feeding of blanks or stampings by hand is generally limited to low production rate requirements which do not warrant the cost of automatic or semi- automatic feeding devices. Manual feeding, however, is accomplished with the use of a guard or, if a guard is not possible, hand feeding tools and a point – of – operation safety device. Some commonly used hand feeding tools are special pliers, tongs, tweezes, vacuum lifters and magnetic pick – ups.

Chute feeds . For feeding small blanks or stampings, simple chutes are often used. The blank slides by gravity along rails in the bottom of the chute. Slide chutes are designed for a specific die and blank and are generally attached permanently to the die so as to reduce setup time. Slide angle of 20^0 - 30^0 is sufficient in most cases. Chute feeds need barrier guard enclosure for operation protection, with just enough opening in the enclosure for the blanks to slide through to the die.

Push feeds . These feeds are used when blanks need orientation in specific relation to the die. Work piece is manually placed in a nest in a slide, one at a time, and the slide pushed until the piece falls into the die nest. An interlock is provided so that the press cannot be operation until the slide has correctly located the part in the die. To increase production rate, push feeds can be automated by actuating the feed slide through mechanical attachment to the press slide.

Lift and transfer devices . In some automatic installations vacuum or suction cups are used for lifting of blanks one at a time from stacks and then moved to the die by transfer units. Separation of the top blank from a stack is achieved by devices which are operated magnetically, pneumatically or mechanically.

- **Dial Feeds.**

Dial feeds consist of rotary indexing tables (or turntables) having fixtures for holding workpiecs as they are taken to the press tooling. Parts are placed in the fixtures at the loading station (which are located away from the place of press operation) manually or by other means like chutes, hoppers, vibratory feeders, robots etc. Such feeds are being increasingly used because of higher safety and productivity associated with them.

- **Coil Stock Feed.**

Two main classifications of automatic press feeds for coil stock are slide (or gripper) and roll feeds. Both of these may be press or independently driven.

Mechanical slide feeds. Press – driven slide feeds have a gripper arrangement which clamps and feeds the stock during its forward movement and releases it on the return stroke. Material is prevented from backing up during the return stroke of the gripper by a drag unit like a frictional brake. Grippers reciprocate on rods or slides between adjustable positive stops to ensure accuracy. Slide feeds are available in a variety of sizes and designs. These are generally best for narrow coil stock and short feed lengths.

Hitch - type feed. This feed differs from press – driven mechanical slide feed in that actuation is by a simple flat cam attached to the ram or punch holder instead of by the press. On the downward stroke of the ram, one or more springs are compressed by the cam action, then on the upstroke, the springs provide the force to feed stock into the die.

These feeds are best suited for coil stock of small to medium thickness and for relatively short feed progression. These are one of the oldest and least expensive feeding devices still used very widely. Due to their low cost, they are generally left permanently attached to the dies, thus reducing setup time.

Pneumatic slide feeds. These feeds are similar to mechanical slide feeds in that they have grippers or clamps that reciprocate on guide rails or slides between adjustable positive stops to push and / or pull stock into a die. However, these differ in that they are powered by an air cylinder, with actuation and timing of valves by cam – operated limit switches.

These feeds are best for short progression, and find wide applications in job shops because of their low cost and versatility.

Roll feeds. In these feeds, coil stock is advanced by pressure exerted between intermittently driven, opposed rolls which allow the stock to dwell during the working part of the press cycle. Intermittent rotation (or indexing) of the feed rolls, with the rolls rotating in only one direction, is accomplished in many ways. In one common design, the rolls are indexed through a one – way clutch by a rack – and – pinion mechanism that is actuated by an adjustable eccentric on the press – crankshaft.

These feeds are available in several types and sizes to suit almost any width and thickness of stock. Though their initial cost is slightly higher, their greater durability and lower maintenance cost account for their extensive use.

HIGH ENERGY RATE FORMING PROCESSES

In these forming processes large amount of energy is applied for a very short interval of time. Many metals tend to deform more readily under extra – fast application of load which make these processes useful to form large size parts out of most metals including those which are otherwise difficult – to – form.

The parts are formed at a rapid rate, and thus these processes are also called high – velocity forming processes. There are several advantages of using these forming processes, like die costs are low, easy maintenance of tolerances, possibility of forming most metals, and material does not show spring-back effect. The production cost of components by such processes is low. The limitation of these processes is the need for skilled personnel.

There are three main high energy rate forming processes: explosive forming, magnetic forming, and electro hydraulic forming. We shall discuss these processes.

Explosive Forming

Explosive forming, is distinguished from conventional forming in that the punch or diaphragm is replaced by an explosive charge. The explosives used are generally high - explosive chemicals, gaseous mixtures, or propellants. There are two techniques of high - explosive forming: stand - off technique and the contact technique.

Standoff Technique . The sheet metal work piece blank is clamped over a die and the assembly is lowered into a tank filled with water. The air in the die is pumped out. The explosive charge is placed at some predetermined distance from the work piece, seeFig 9.1. On detonation of the explosive, a pressure pulse of very high intensity is produced. A gas bubble is also produced which expands spherically and then collapses. When the pressure pulse impinges against the work piece, the metal is deformed into the die with as high velocity as 120 m/s.

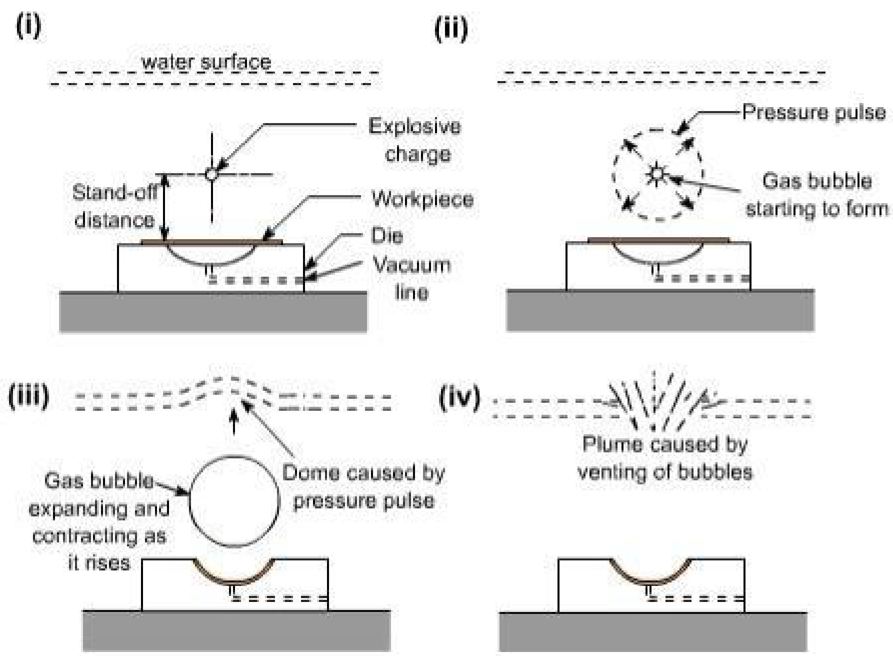

Fig 9.1 Sequeuce of underwater explosive forming operations.(i) explosive charge is set in position (ii) pressure pulse and gas bubble are formed as the detonation of charge occurs, (iii) workpiece is deformed, and (iv) gas bubbles vent at the surface of water.

The use of water as the energy transfer medium ensures a uniform transmission of energy and muffles the sound of the explosive blast. The process is versatile - a large variety of shapes can be formed, there is virtually no limit to the size of the work piece, and it is suitable for low - quantity production as well.

The process has been successfully used to form steel plates 25 mm thick x 4 m diameter and to bulge steel tubes as thick as 25 mm.

Contact Technique. The explosive charge in the form of cartridge is held in direct contact with the work piece while the detonation is initiated. The detonation builds up extremely high pressures (upto 30,000MPa) on the surface of the work piece resulting in metal deformation, and possible fracture. The process is used often for bulging tubes, as shown inFig 9.2.

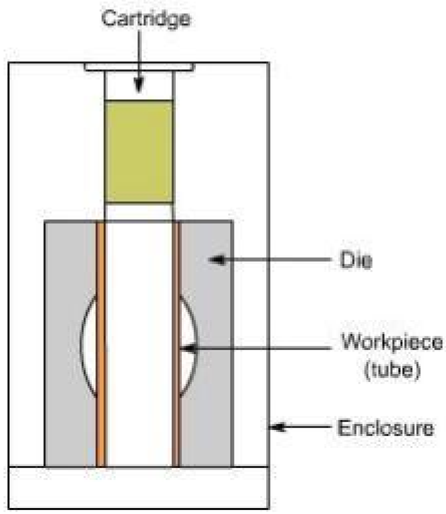

Fig 9.2 Schematic illustration of contact technique of explosive forming.

The process is generally used for bulging of tubes.

Applications. Explosive forming is mainly used in the aerospace industries but has also found successful applications in the production of automotive related components. The process has the greatest potential in limited - production prototype forming and for forming large size components for which conventional tooling costs are prohibitively high.

Electro Magnetic Forming

The process is also called *magnetic pulse forming* and is mainly used for swaging type operations, such as fastening fittings on the ends of tubes and crimping terminal ends of cables. Other applications are blanking, forming, embossing, and drawing. The work coils needed for different applications vary although the same power source may be used.

To illustrate the principle of electromagnetic forming, consider a tubular work piece. This work piece is placed in or near a coil, Fig 9.3. A high charging voltage is supplied for a short time to a bank of capacitors connected in parallel. (The amount of electrical energy stored in the bank can be increased either by adding capacitors to the bank or by increasing the voltage). When the charging is complete, which takes very little time, a high voltage switch triggers the stored electrical energy through the coil. A high - intensity magnetic field is established which induces eddy currents into the conductive work piece, resulting in the establishment of another magnetic field. The forces produced by the two magnetic fields oppose each other with the consequence that there is a repelling force between the coil and the tubular work piece that causes permanent deformation of the work piece.

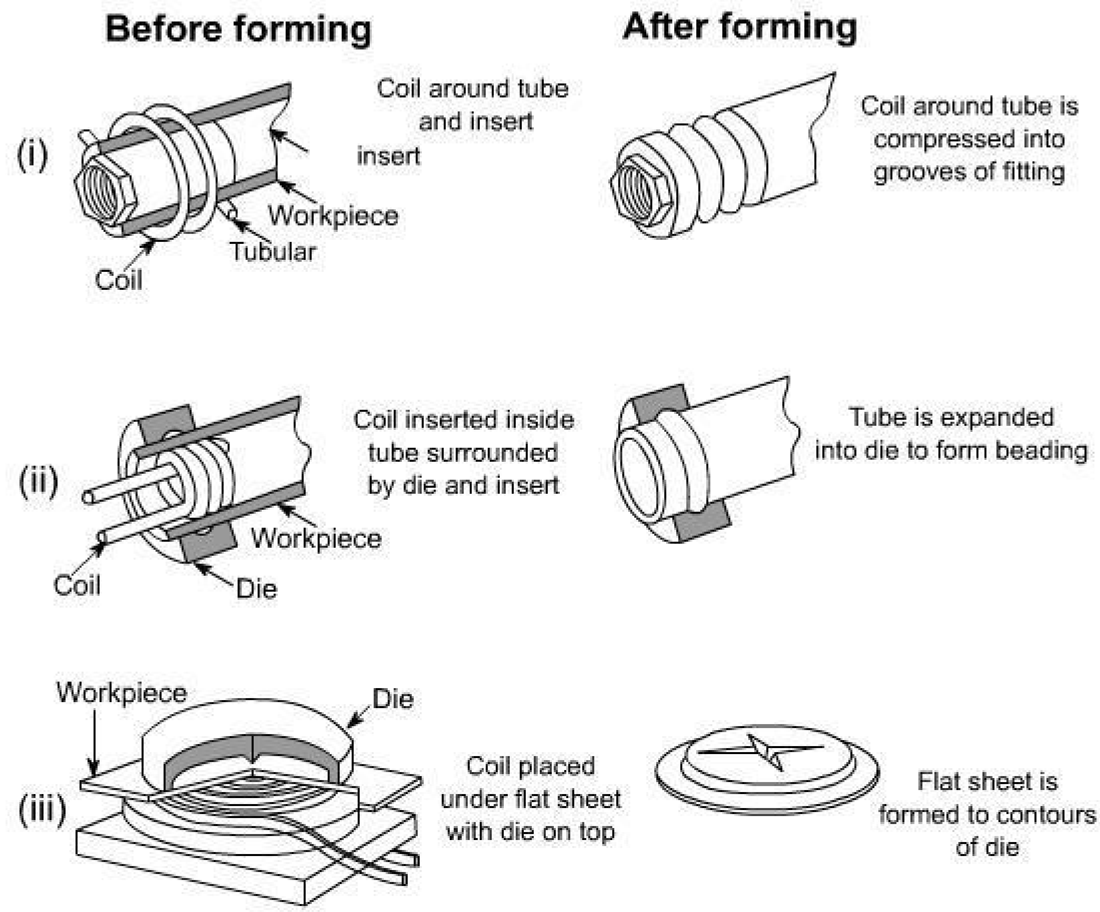

Fig 9.3 Various applications of magnetic forming process. (i) Swaging, (ii) Expanding, and (iii) Embossing or blanking.

Either permanent or expandable coils may be used. Since the repelling force acts on the coil as well the work, the coil itself and the insulation on it must be capable of withstanding the force, or else they will be destroyed. The expandable coils are less costly and are also preferred when high energy level is needed.

Magnetic forming can be accomplished in any of the following three ways, depending upon the requirements.

- Coil surrounding work piece. When a tube - like part x is to fit over another part y (shown as insert inFig 9.3(i)), coil is designed to surround x so that when energized, would force the material of x tightly around y to obtain necessary fit.
- Coil inside work piece. Consider fixing of a collar on a tube - like part, as shown inFig 9.3(ii). The magnetic coil is placed inside the tube - like part, so that when energized would expand the material of the part into the collar.
- Coil on flat surface. Flat coil having spiral shaped winding can also be designed to be placed either above or below a flat work piece, seeFig 9.3(iii).These coils are used in conjunction with a die to form, emboss, blank, or dimple the work piece.

In electromagnetic forming, the initial gap between the work piece and the die surface, called the *fly distance* , must be sufficient to permit the material to deform plastically. From energy considerations, the ideal pressure pulse should be of just enough magnitude that accelerates the part material to some maximum velocity and then let the part come to zero velocity by the time it covers the full fly distance. All forming coils fail, expendable coils fail sooner than durable coils, and because extremely high voltages and currents are involved, it is essential that proper safety precautions are observed by the production and maintenance personnel.

Applications

Electromagnetic forming process is capable of a wide variety of forming and assembly operations. It has found extensive applications in the fabrication of hollow, non - circular, or asymmetrical shapes from tubular stock. The compression applications involve swaging to produce compression, tensile, and torque joints or sealed pressure joints, and swaging to apply compression bands or shrink rings for fastening components together. Flat coils have been used on flat sheets to produce stretch (internal) and shrink (external) flanges on ring and disc - shaped work pieces.

Electromagnetic forming has also been used to perform shearing, piercing, and rivettting.

Electro Hydraulic Forming

Electro hydraulic forming (EHF), also known as electro spark forming, is a process in which electrical energy is converted into mechanical energy for the forming of metallic parts. A bank of capacitors is first charged to a high voltage and then discharged across a gap between two electrodes, causing explosions inside the hollow work piece, which is filled with some suitable medium, generally water. These explosions produce shock waves that travel radially in all directions at high velocity until they meet some obstruction. If the discharge energy is sufficiently high, the hollow work piece is deformed. The deformation can be controlled by applying external restraints in the form of die or by varying the amount of energy released,Fig 9.4.

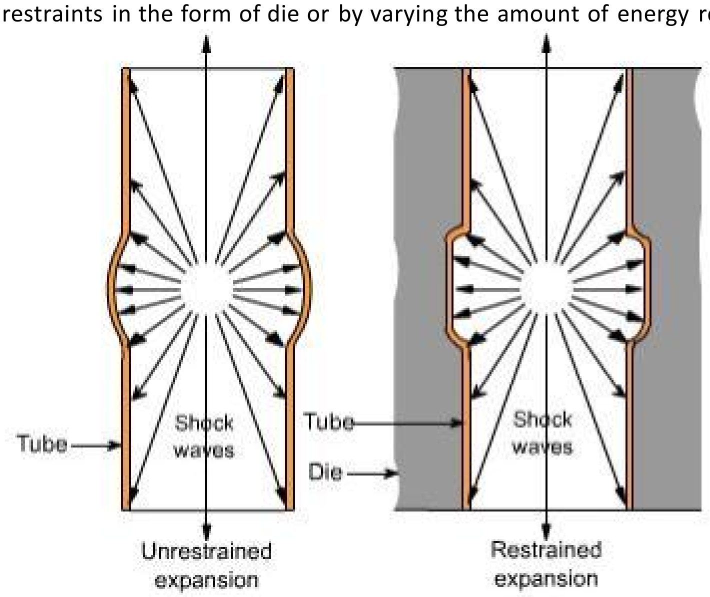

Fig 9.4 Unrestrained and restrained electro-hydraulic forming process.

Advantages

1. EHF can form hollow shapes with much ease and at less cost compared to other forming techniques.
2. EHF is more adaptable to automatic production compared to other high energy rate forming techniques.
3. EHF can produce small - to intermediate sized parts that don't have excessive energy requirements.

Accuracy of parts produced

Accuracy of electro hydraulically formed parts depends on the control of both the magnitude and location of energy discharges and on the dimensional accuracy of the dies used. With the modern equipment, it is now possible to precisely control the energy within specified limits, therefore the primary factor is the dimensional accuracy of the die. External dimensions on tubular parts are possible to achieve within ± 0.05 mm with the current state of technology.

Materials formed

Materials having low ductility or having critical impact velocity less than 30 m/s are generally not considered to be good candidate for EHF. All materials that can be formed by conventional forming processes can be formed by EHF also. These materials are aluminum alloys, nickel alloys, stainless steels, titanium, and Inconel 718.