UNIT – IV

SHEET METAL PROCESSES

SYLLABUS

Sheet metal characteristics – shearing, bending and drawing operations – Stretch forming operations – Formability of sheet metal – Test methods –special forming processes-Working principle and applications – Hydro forming – Rubber pad forming – Metal spinning– Introduction of Explosive forming, magnetic pulse forming, peen forming, Super plastic forming – Micro forming

INTRODUCTION

Sheet metal is metal formed by an industrial process into thin, flat pieces. It is one of the fundamental forms used in metalworking and it can be cut and bent into a variety of shapes. Countless everyday objects are constructed with sheet metal. Thicknesses can vary significantly; extremely thin thicknesses are considered foil or leaf, and pieces thicker than 6 mm (0.25 in) are considered plate.

Sheet metal is available in flat pieces or coiled strips. The coils are formed by running a continuous sheet of metal through a roll slitter.

The thickness of sheet metal is commonly specified by a traditional, non-linear measure known as its gauge. The larger the gauge number, the thinner the metal. Commonly used steel sheet metal ranges from 30 gauges to about 7 gauges. Gauge differs between ferrous (iron based) metals and a nonferrous metal such as aluminum or copper; copper thickness, for example is measured in ounces (and represents the thickness of 1 ounce of copper rolled out to an area of 1 square foot).

There are many different metals that can be made into sheet metal, such as aluminum, brass, copper, steel, tin, nickel and titanium. For decorative uses, important sheet metals include silver, gold, and platinum (platinum sheet metal is also utilized as a catalyst.)

Sheet metal is used for car bodies, airplane wings, medical tables, roofs for buildings (architecture) and many other applications. Sheet metal of iron and other materials with high magnetic permeability, also known as laminated steel cores, has applications in transformersand electric machines. Historically, an important use of sheet metal was in plate armor worn by cavalry, and sheet metal continues to have many decorative uses, including in horse tack. Sheet metal workers are also known as "tin bashers" (or "tin knockers")

Sheet Metal Characteristics

TABLE 4.1

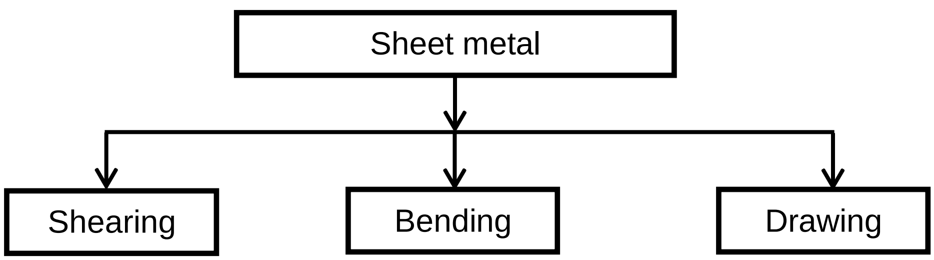
Characteristic	Description
Elongation	: The capability of the sheet metal to stretch without necking and failure are determined; high strain-hardening exponent (n) and strain-rate sensitivity exponent (m) desirable.
Yield-point elongation	: Observed with mild-steel sheets; also called Lueder’s bands and stretcher strains; causes flame like depressions on the sheet surfaces; can be eliminated by temper rolling, but sheet must be formed within a certain time after rolling.
Anisotropy (planar)	: Exhibits different behavior in different planar directions; present in cold-rolled sheets because of preferred orientation or mechanical fibering; causes earing in drawing; can be reduced or eliminated by annealing but at lowered strength.
Anisotropy (normal)	: Determines thinning behavior of sheet metals during stretching; important in deep drawing operations.
Grain size	: Determines surface roughness on stretched sheet metal; the coarser the grain, the rougher the appearance (orange peel); also affects material strength.
Residual stresses	: Caused by non-uniform deformation during forming; causes part distortion when sectioned and can lead to stress-corrosion cracking; reduced or eliminated by stress relieving.
Spring back	: Caused by elastic recovery of the plastically deformed sheet after unloading; causes distortion of part and loss of dimensional accuracy; can be controlled by techniques such as over bending and bottoming of the punch.
Wrinkling	: Caused by compressive stresses in the plane of the sheet; can be objectionable or can be useful in

imparting stiffness to parts; can be controlled by proper tool and die design.

Quality of sheared edges : Depends on process used; edges can be rough, not square, and contain cracks, residual stresses, and a work-hardened layer, which are all detrimental to the formability of the sheet; quality can be improved by control of clearance, tool and die design, fine blanking, shaving, and lubrication.

Surface condition of sheet : Depends on rolling practice; important in sheet forming as it can cause tearing and poor surface quality

Classification of sheet metal working processes



The term "shearing or cutting process" is refers to a specific cutting process that produces straight line cuts to separate a piece of sheet metal. Most commonly, shearing is used to cut a sheet parallel to an existing edge which is held square, but angled cuts can be made as well. For this reason, shearing is primarily used to cut sheet stock into smaller sizes in preparation for other processes. Shearing has the following capabilities:

- Sheet thickness: 0.005-0.25 inches
- Tolerance: ±0.1 inches (±0.005 inches feasible)
- Surface finish: 250-1000 μin (125-2000 μin feasible)

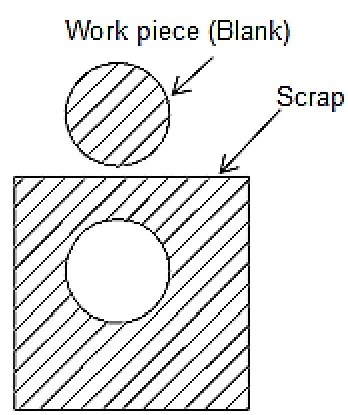
The shearing process is performed on a shear machine, often called a squaring shear or power shear, that can be operated manually (by hand or foot) or by hydraulic, pneumatic, or electric power.

A variety of cutting processes that utilize shearing forces exist to separate or remove material from a piece of sheet stock in different ways. Each process is capable of forming a specific type of cut, some with an open path to separate a portion of material and some with a closed path to cutout and remove that material. By using many of these processes together, sheet metal parts can be fabricated with cutouts and profiles of any 2D geometry. Such cutting processes include the following:

- Shearing - Separating material into two parts
- Blanking - Removing material to use for parts
  - Conventional blanking
  - Fine blanking
- Punching - Removing material as scrap
  - Piercing
  - Slotting
  - Perforating
  - Notching
  - Nibbling
  - Lancing
  - Slitting
  - Parting
  - Cutoff
  - Trimming
  - Shaving
  - Dinking

Blanking

Blanking is a cutting process in which a piece of sheet metal is removed from a larger piece of stock by applying a great enough shearing force. In this process, the piece removed, called theblank, is not scrap but rather the desired part. Blanking can be used to cutout parts in almost any 2D shape, but is most commonly used to cut workpieces with simple geometries that will be further shaped in subsequent processes.



Final parts that are produced using blanking include gears, jewelry, and watch or clock components. Blanked parts typically require secondary finishing smoothing out burrs along the bottom edge.

The hydraulic press drives the punch downward at high speed into the sheet. A small clearance, typically 10-20% of the material thickness, exists between the punch and die. When the punch impacts the sheet, the metal in this clearance quickly bends and then fractures. The blank which has been sheared from the stock now falls freely into the gap in the die. This process is extremely fast, with some blanking presses capable of performing over 1000 strokes per minute.

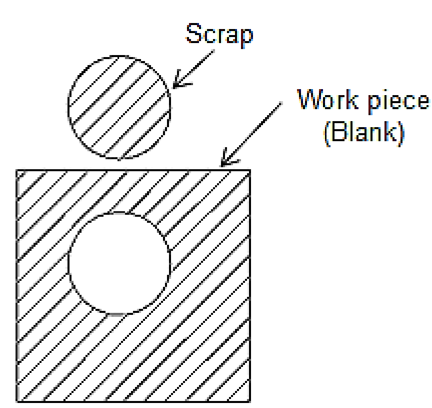
Fine blanking

Fine blanking is a specialized type of blanking in which the blank is sheared from the sheet stock by applying 3 separate forces. This technique produces a part with better flatness, a smoother edge with minimal burrs, and tolerances as tight as ±0.0003. As a result, high quality parts can be blanked that do not require any secondary operations. However, the additional equipment and tooling does add to the initial cost and makes fine blanking better suited to high volume production. Parts made with fine blanking include automotive parts, electronic components, cutlery, and power tools.

In fine blanking, the clearance between the punch and the die is smaller, around 0.01 inches, and the blanking is performed at slower speeds. As a result, instead of the material fracturing to free the blank, the blank flows and is extruded from the sheet, providing a smoother edge.

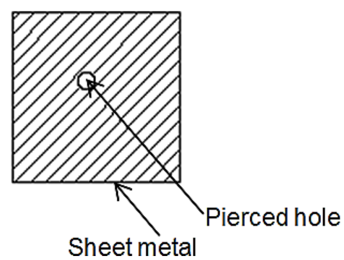
Punching

Punching is a cutting process in which material is removed from a piece of sheet metal by applying a great enough shearing force. Punching is very similar to blanking except that the removed material, called the slug, is scrap and leaves behind the desired internal feature in the sheet, such as a hole or slot. Punching can be used to produce holes and cutouts of various shapes and sizes. The most common punched holes are simple geometric shapes (circle, square, rectangle, etc.) or combinations thereof. The edges of these punched features will have some burrs from being sheared but are of fairly good quality. Secondary finishing operations are typically performed to attain smoother edges.



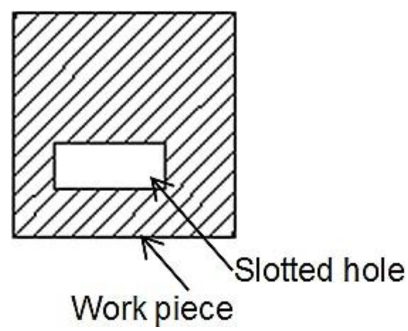
The punching process requires a punch press, sheet metal stock, punch, and die. The punch press drives the punch downward at high speed through the sheet and into the die below. There is a small clearance between the edge of the punch and the die, causing the material to quickly bend and fracture. The slug that is punched out of the sheet falls freely through the tapered opening in the die. This process can be performed on a manual punch press, the punch press can be hydraulically, pneumatically, or electrically powered and deliver around 600 punches per minute.

Typical punching operation is one in which a cylindrical punch tool pierces the sheet metal, forming a single hole. However, a variety of operations are possible to form different features. These operations include the following:



Piercing

The typical punching operation, in which a cylindrical punch pierces a hole into the sheet. The size of hole is very small (i.e. less than 1mm)

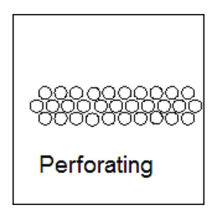


Slotting

A punching operation that forms rectangular holes or any polygonal shape in the sheet. Sometimes described as piercing despite the different shape

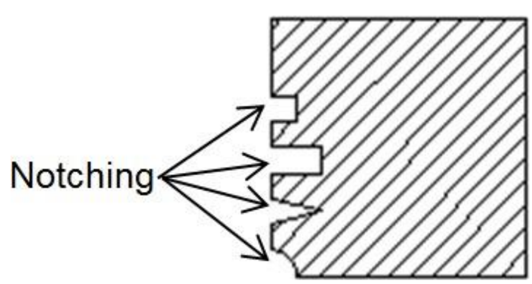
Perforating

Punching a close arrangement of a large number of holes in a single operation



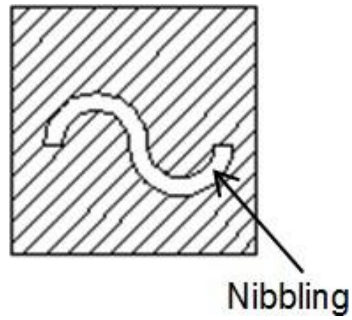
Notching

Punching the edge of a sheet, forming a notch in the shape of a portion of the punch



Nibbling

Punching a series of small overlapping slits or holes along a path to cutout a larger contoured shape. This eliminates the need for a custom punch and die but will require secondary operations to improve the accuracy and finish of the feature.



Lancing

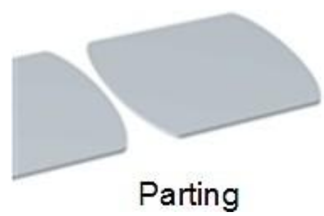
Creating a partial cut in the sheet, so that no material is removed. The material is left attached to be bent and form a shape, such as a tab, vent, or louver.

Slitting

Cutting straight lines in the sheet. No scrap material is produced.

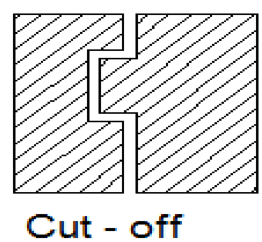
Parting

Separating a part from the remaining sheet, by punching away the material between parts.



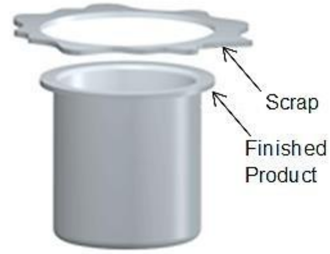
Cutoff

Separating a part from the remaining sheet, without producing any scrap. The punch will produce a cut line that may be straight, angled, or curved.



Trimming

Punching away excess material from the perimeter of a part, such as trimming the flange from a drawn cup.



Shaving

Shearing away minimal material from the edges of a feature or part, using a small die clearance.Used to improve accuracy or finish. Tolerances of ±0.001 inches are possible.

Before shaving

After Shaving

Types of dies used for shearing operation

A typical die and punch set used for blanking operation is shown in Figure. The sheet metal used is called strip or stock. The punch which is held in the punch holder is bolted to the press ram while die is bolted on the press table. During the working stroke, the punch penetrates the strip, and on the return stroke of the press ram the strip is lifted with the punch, but it is removed from the punch by the stripper plate. The stop pin is a gage and it sets the advance of the strip stock within the punch and die. The strip stock is butted against the back stop acting as a datum location for the centre of the blank.

The die opening is given angular clearance to permit escape of good part (blank). The waste skeleton of stock strip, from which blanks have been cut, is recovered as salvaged material.

The clearance angle provided on the diedepends on the material of stock, as well as its thickness. For thicker and softer materials generally higher angular clearance is given. In most cases, 2 degree of angular clearance is sufficient. The height of cutting land of about 3 mm is generally sufficient.

Clearance

In *blanking operation*, the die size is taken as the blank size and the punch is made smaller giving the necessary clearance between the die and the punch.

Die size = blank size

Punch size = blank size – 2 x clearance

Clearance = k .t .

where t = shear strength of material, t = thickness of sheet metal stock, and k is a constant whose value may be taken as 0.003.

In a *piercing operation* , the following equations hold.

Punch size = blank size

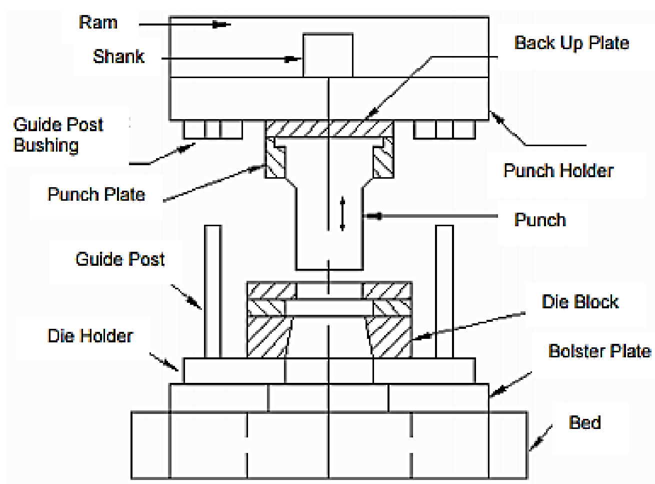
Die size = blank size + 2 x clearance

Clearance = k .t .

Types of dies

Simple die

A simple cutting die is shown in Figure



Simple Die

Description

Bed : The bed is lower part of press frame that serves as a table on which a bolster plate is mounted.

Bolster Plate : Bolster plate is a thick plate secured to the press bed, which is used for locating and supporting the die assembly. Its thickness is usually 5 to 12.5 cm.

Die set : Die set is unit assembly which incorporates a lower and upper shoe, two or more guide posts and guide post bushings.

Die : Die is the female part of a complete tool for producing work in a press. It is also referred to a complete tool consisting of pair of mating members for producing work in press.

Die Block : It is the block or a plate which contains the die cavity.

Lower Shoe : The lower shoe of a die set is generally mounted on the upper plate of a press. The die block is mounted on the lower shoe. The guide posts are also mounted in it.

Punch : Punch is the male component of the die assembly which is directly or indirectly moved by or fastened to the press ram or slide.

Upper Shoe : It is the upper part of the die set which contain die post bushings

Punch Plate : The punch plate or punch retainer fits closely over the body of the punch and holds it in proper relative position.

Back Up Plate : It is also called pressure plate. It is placed so that the intensity of pressure does not become excessive on punch holder. The plate distributes the pressure over a wide area and intensity of pressure on the punch holder is reduced to avoid crushing.

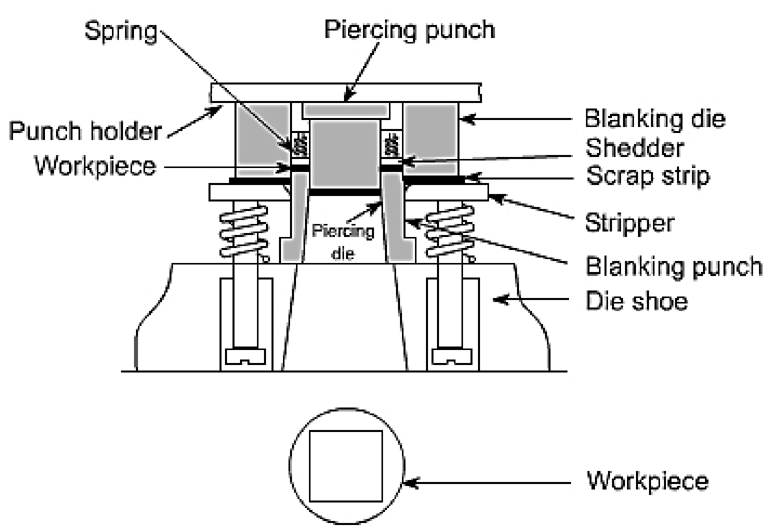
Stripper : Stripper is a plate which is used to strip the metal strip from a cutting or non-cutting punch or die. It may also guide the strip.

Knock Out : Knock out mechanism is used to remove the workpiece from a die. It is connected to and operated by the press ram.

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

Compound die

Compound die combines the principles of the conventional and inverted dies in one station. This type of die may produce a workpiece which is pierced and blanked in one operation at one station. The piercing punch is fastened in the conventional position to the punch holder. Its matching die opening for piercing is machined into the blanking punch. The blanking punch and blanking die opening are mounted in an inverted position. The blanking punch is fastened to the die shoe and the blanking die opening is



Compound Die

fastened to the punch holder.

It is used for producing washer which is piercing and blanked at one station in one operation.

Advantages

- Accuracy is more
- Large parts can be blanked in a smaller press
- Shorter length of strip material can be used.
- The cost of production is very less.

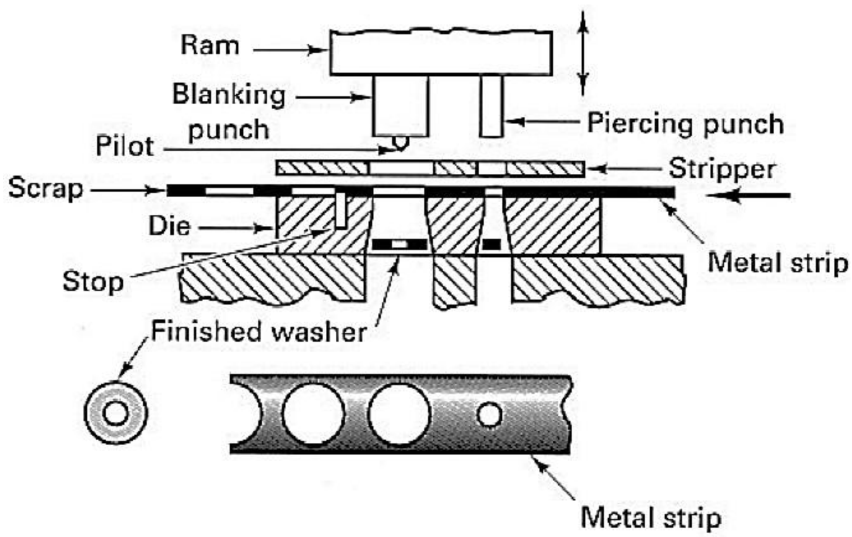
Disadvantages

- More expensive to construct and repair
- Slower in operation as compared with progressive die
- Heaviest construction.
- Complicated design.

Progressive die

It is also called a follow on die. The progressive die is shown in Figure. It performs two or more operations in one stroke of a ram at different stages. First operation is punching, which is followed by blanking. The metal strip is transferred to the next station in between the stroke to produce a complete workpiece.

When the piercing punch cuts a hole in the strip, the blanking punch draws out a portion of the metal strip in which a hole had been pierced at a previous station. The metal strip is fed into the die mechanically or manually. The primary stop is pushed in by hand and lead end is then made to contact with it. The press is now made to operate to pierce a hole at station 1.



Progressive die

As the primary stop is released, the strip is transferred to the station 2. The strip contacts with automatic button die stop at station 2.

During the next stroke, the pilot on blanking punch enters the previously pierced hole which ensures the exact alignment of the strip to be blanked next. The die stop activation pin pushes the die stop pin below the edge of the blank. Hence the strip is transferred to next station on return stroke of the ram. The button die stop pin returns to its normal position and holds the strip on the inside wall of the blanked hole. During the third stroke, another complete part is produced and thereafter parts are produced at each stroke of the ram. In a progressive die, force required is reduced to a large extent due to the staggering of punches. The disadvantage of progressive die is that it makes balancing of the punches difficult.

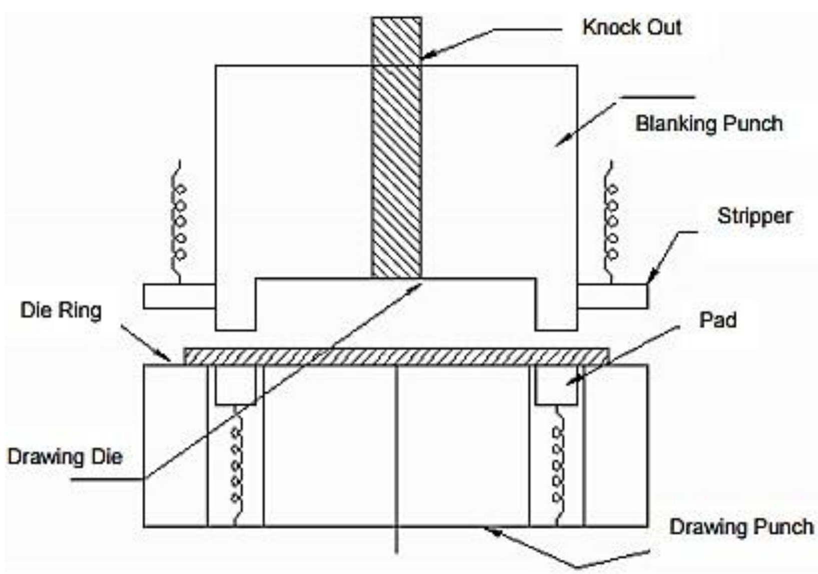
Transfer die

Transfers dies are same as progressive dies, the only difference being that the already cut blanks are fed manually or automatically from station to station. First operation is blanking, which is followed by piercing.

Combination Dies

In a combination die, cutting action is combined with non-cutting actions, i.e. forming. Non-cutting actions may be bending, drawing, extrusion or embossing. More than one operation is possible in one stroke at a single stage, but the die is more useful for two operations only.

The principle of working of a combination dies is shown in Figure



Combination die

The die ring is mounted on the die shoe. The die ring is counter bored at the bottom to allow the flange of a pad to travel up and down. This pad is held flush with the face of die by a spring. The drawing punch of required shape is attached to the die shoe. The blanking punch is placed in the punch holder. The stripper (spring operated) strips the skeleton from the blanking punch. As the workpiece comes in contact with the knock out bar during the return stroke, knock out removes the part attached to the punch. As the part is blanked, the blank holding comes down. Then the drawing punch contacts and forces the blank into the drawing die which is made into the blanking punch.

Bending

Bending is a manufacturing process; it is defined as the straining of the sheet metal around a straight edge. It produces a V-shape, U-shape, or channel shape along a straight axis in ductilematerials called sheet metal.

Bending induces plastic deformation in the material, so the part retains its shape after the bending force is released.

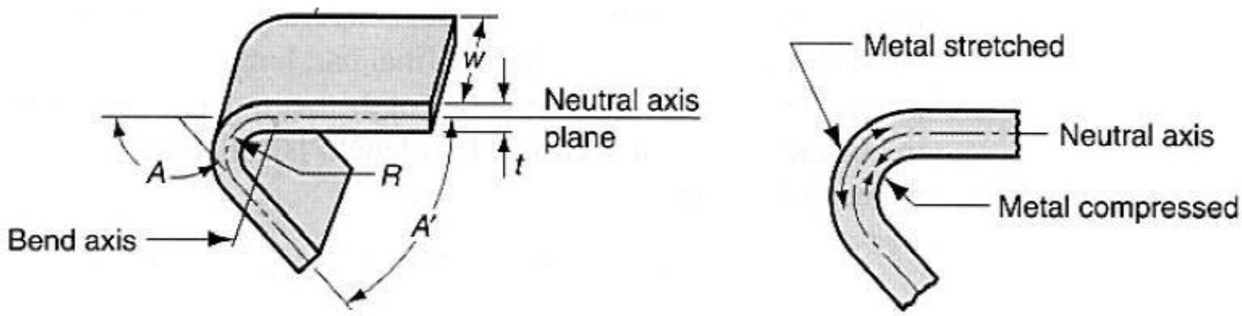


Figure (a) Bending of sheet metal

Figure (a) shows a simple bend on a rectangular blank. The top profile of the blank undergoes extension – a thin element along the top surface will be longer after the bending than the initial length; likewise, the bottom portion experiences compression. Thus, as we travel from the bottom to the top, there is some layer in the middle which retains its original length – this forms the neutral axis. The location of the neutral axis, and therefore its length, determines the length of the blank we must begin with, in order to get the final part with the correct geometry.

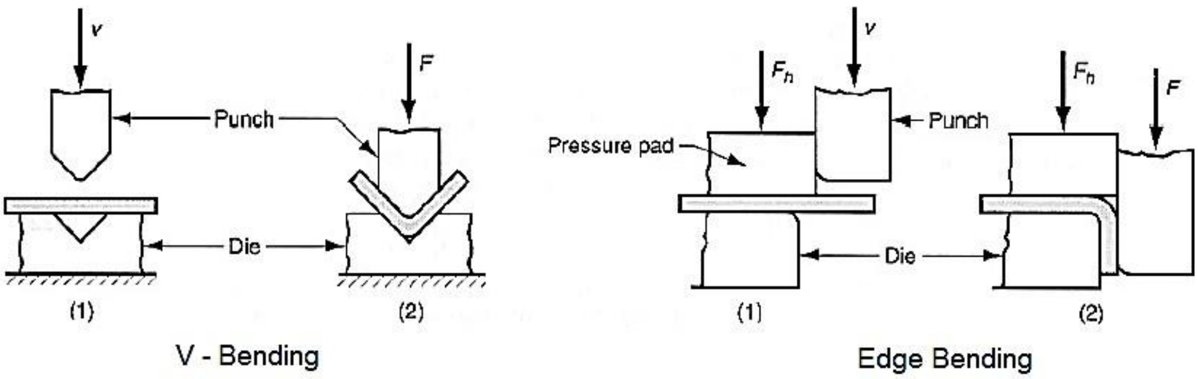
Types of bending

- V – Bending

  One of the most common types of sheet metal manufacturing processes is V bending. The V shaped punch forces the work into the V shaped die and hence bends it. This type of process can bend both very acute and very obtuse angles, also anything in between, including 90 .

- Edge Bending (wiping)

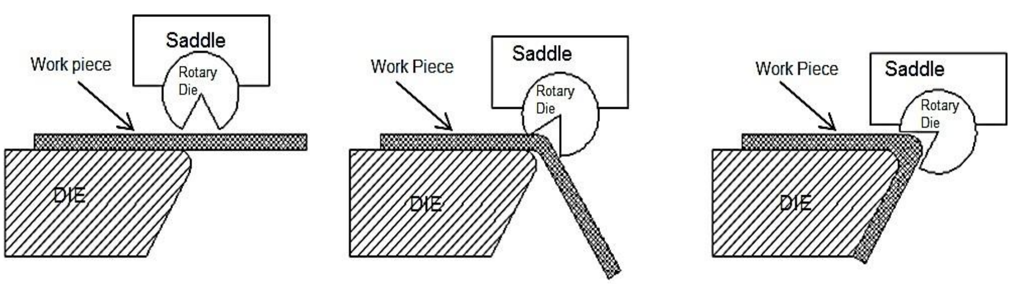
Edge bending is another very common sheet metal process and is performed with a wiping die. Edge bending gives a good mechanical advantage when forming a bend. However, angles greater than 90 degrees will require more complex equipment, capable of some horizontal force delivery.



(1) Before bending (2) After Bending

- Rotary bending

Rotary bending forms the work by a similar mechanism as edge bending. However, rotary bending uses a different design than the wiping die. A cylinder, with the desired angle cut out, serves as the punch. The cylinder can rotate about one axis and is securely constrained in all other degrees of motion by its attachment to the saddle. The sheet metal is placed cantilevered over the edge of the lower die, similar to the setup in edge bending.



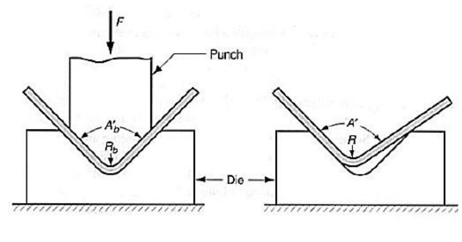
Rotary bending of sheet metal

Spring Back

At the end of the bending operation, when the pressure on the metal is released, there is an elastic recovery of the material. This cause a decrease in the bend angle and this phenomenon is called as spring back.

Table 4.1 Spring back value for various materials

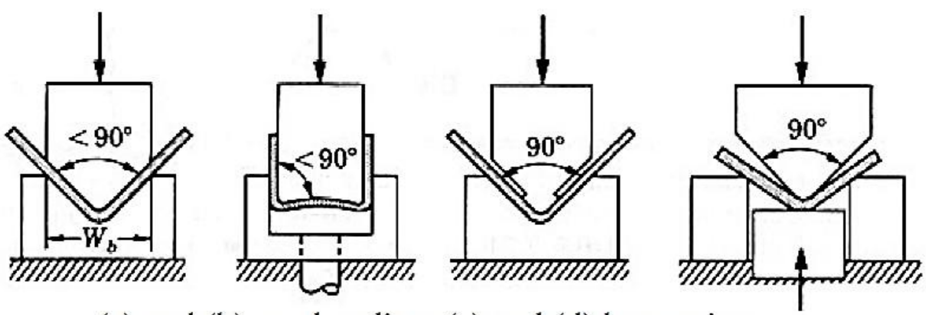
Material	Angle value
Low carbon steel	1° to 2°
Medium carbon steel	3° to 4°
Phosphor bronze and spring steel	10° to 15°



Springback in bending

To compensate for springback two methods are commonly used:

- Œ Over bending—the punch angle and radius are smaller than the final ones.
- • Bottoming—squeezing the part at the end of the stroke.

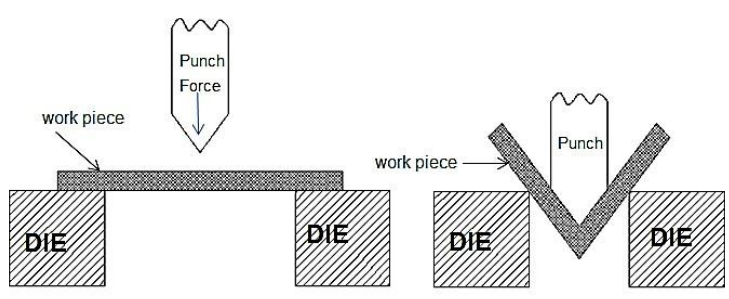


(a) and (b) overbending; (c) and (d) bottoming

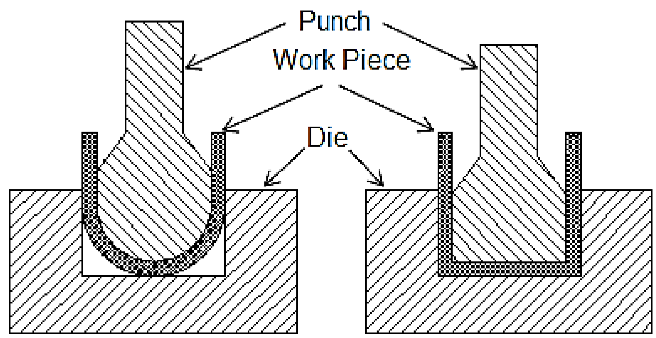
Other types of bending

- Air Bending

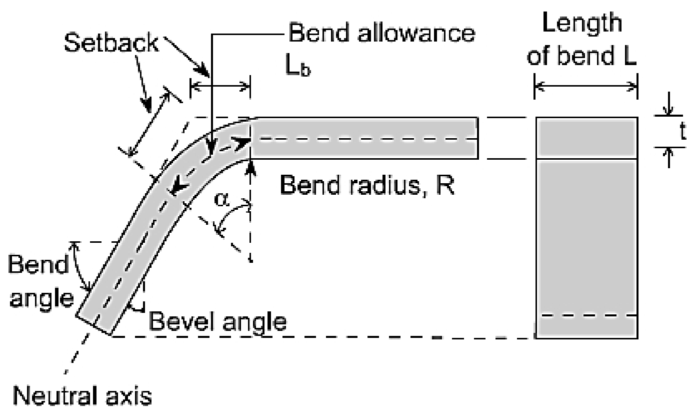
  Air Bending is the most common type of bending process used in sheet metal shops today. In this process the work piece is only in contact with the edge of the Die and the tip of the Punch. The punch is them forced the top of the die into the v-opening without coming into contact with the bottom of the V.



Air Bending



U - Bending   Channel Bending



Bending Terminology

BEND ALLOWANCE

This is the stretching length that occurs duringbending. It must be accounted to determine thelength of the blank

BA = (R + kt)

Where,

BA = bend allowance (mm)

= 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 600 at bend radius 10 mm. determine the bend allowance.

Solution.

Here, bend radius R = 10 mm   Sheet thickness t = 4 mm

Since R > 2t, k = 0.5

Bend allowance

Bending Force :

The bending force is required to perform bending depends on the geometry of the punch and die, strength, thickness and width of the sheet metal. The bending force can be estimated from the following simple relation.

Where

F = Bending force

TS = tensile strength of sheet metal

w = width of the part in the direction of the bend axis

t = thickness of sheet metal

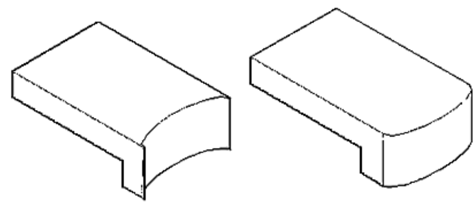
D = Die opening dimension

K_{bf} = bending factor 1.33 = V-Bending

Bending Operation

- Flanging

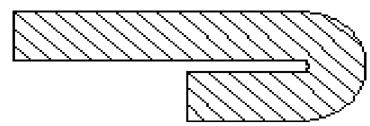
Flanging is one kind of bending operation in which the edge of the sheet metal part is bending at 90^o angle to form a rim or flange. It is often used to strengthen or stiffen the sheet metal part. There are three type of flanging, they are:



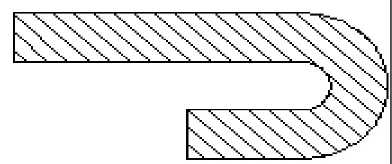
Stretch Flanging Shrink Flanging

  - Straight
  - Stretch
  - Shrink
- Hemming

Hemming involves bending the edge of the sheet over on itself, in more than one bending step. This is often done to eliminate the sharp edge of the piece, to increase stiffness and to improve appearance. There are two type of hemming, namely as:



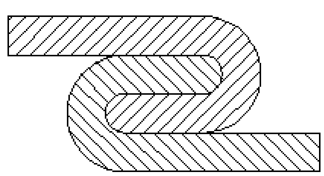
Flat Hemming



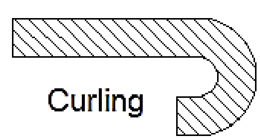
Open Hemming

  - Flat
  - Open

- Seaming – two sheet metal edges are assembled
- Curling – form the edges of the part in to a roll or curl as shown in figure

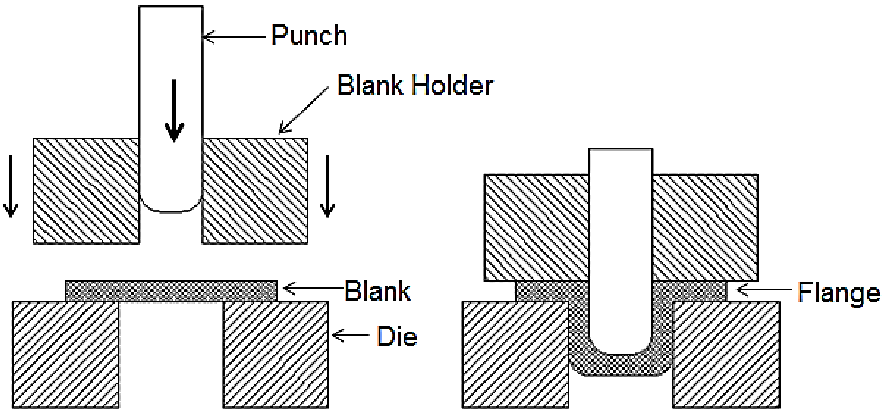


Seaming



Drawing

Drawing is sheet-metal forming operation used to make cup-shaped, box shaped or other more complex-curved, hollow shaped parts. It is performed by placing a sheet metal blank over die cavity and then pushing the metal into the opening with a punch, as shown in figure



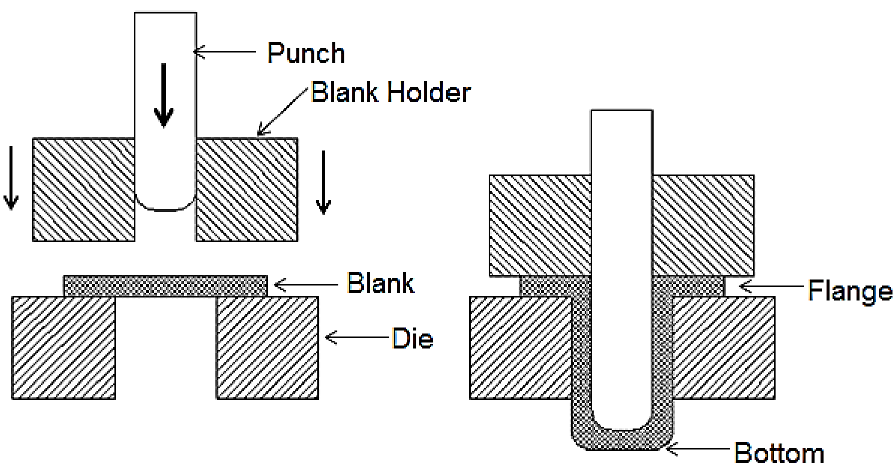
Drawing

The blank must usually be held down flat against the die by a blank holder.

Applications: beverage cans, cooking pots and automobile body panels.

DEEP DRAWING

Deep drawing is a sheet metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch. The process is considered "deep" drawing when the depth of the drawn part exceeds its diameter. This is achieved by redrawing the part through a series of dies. The flange region (sheet metal in the die shoulder



Deep Drawing

area) experiences a radial drawing stress and a tangential compressive stress due to the material retention property. These compressive stresses (hoop stresses) result in flange wrinkles (wrinkles of the first order). Wrinkles can be prevented by using a blank holder, the function of which is to facilitate controlled material flow into the die radius.

Deep drawing is always accompanied by other forming techniques within the press. These other forming methods include:

- Beading: Material is displaced to create a larger, or smaller, diameter ring of material beyond the original body diameter of a part, often used to create O-ring seats.
- Bottom Piercing: A round or shaped portion of metal is cut from the drawn part.
- Bulging: In the bulging process a portion of the part's diameter is forced to protrude from the surrounding geometry.
- Coining: Material is displaced to form specific shapes in the part. Typically coining should not exceed a depth of 30% of the material thickness.
- Curling: Metal is rolled under a curling die to create a rolled edge.
- Extruding: After a pilot hole is pierced, a larger diameter punch is pushed through, causing the metal to expand and grow in length.
- Ironing / Wall Thinning: Ironing is a process to reduce the wall thickness of parts. Typically ironing should not exceed a depth of 30% of the material thickness.
- Necking: A portion of the part is reduced in diameter to less than the major diameter.
- Rib Forming: Rib forming involves creating an inward or outward protruding rib during the drawing process.
- Stamping / Marking: This process is typically used to put identification on a part, such as a part number or supplier identification.
- Threading: Using a wheel and arbor, threads are formed into a part. In this way threaded parts can be produced within the stamping press.

FORMABILITY OF SHEET METAL

Formability may be defined as the ease with which material may be forced into a permanent change of shape.

The formability of a material depends on several factors. The important one concerns the properties of material like yield strength, strain hardening rate, and ductility. These are greatly temperature - dependent. As the temperature of material is increased, the yield strength and rate of strain hardening progressively reduce and ductility increases. The hot working of metal, therefore, permits relatively very large amount of deformation before cracking.

There are several methods of predicting formability. A brief description of some important methods follows.

Cup or Radial Drawing:

Cup drawing test uses a circular blank from the metal to be tested. It is inserted in a die, and the severity of the draw it is able to withstand without tearing called the drawing ratio, is noted. The drawing ratio is the ratio of the cup diameter to the blank diameter.

$$R_d = \frac{D - d}{D}$$

Where R_d = drawing ratio

D = blank diameter

d = punch diameter

A drawing ratio of 50 % is considered excellent. As shown in Fig 4.1(a), either a flat bottom punch with lubricated blank may be used to draw the cup, or as shown in Fig 4.1(b) a blank may be drawn by a lubricated hemi – spherical punch. In the first case, the action is principally that of drawing in which cylindrical stretching of material takes place. In the second case, there will be bi – axial stretching of the material. For drawing, the clamping force is just sufficient to prevent buckling of the material at the draw radius as it enters the die. The deformation takes place in the flange and over the draw radius.

Fukui Conical – Cup Test:

It utilizes a hemispherical, smoothly polished punch. No blank holder is required. In each test, a drawing ratio which will result in a broken cup is determined. Formation of wrinkles is avoided by using a fixed ratio between the thickness of the sheet, the size of the blank, and the punch and die diameters. Under these conditions, the test produces a known amount of stretching, drawing, and bending under tension.

Normal Anisotropy Coefficient:

The material is subjected to uni-axial tensile test. The anisotropy coefficient is derived from the ratio of the plastic width strain e_W to the thickness strain e_t . A material with a high plastic anisotropy also has a greater —thinning resistance.‖ In general, the higher the anisotropy coefficient the better the material deforms in drawing operations.

Strain-Hardening Coefficient:

Strain hardening refers to the fact that as a metal deforms in some area, dislocations occur in the microstructure. As these dislocations pile up, they tend to strengthen the metal against further deformation in that area. Thus the strain is spread throughout the sheet. However, at some point in the deformations, the strain suddenly localizes and necking, or localized thinning, develops. When this occurs, little further overall deformation of the sheet can be obtained without it fracturing in the necked region.

The strain – hardening coefficient therefore reflects how well the metal distributes the strain throughout the sheet, avoiding or delaying localized necking. The higher the strain – hardening coefficient, the move the material will harden as it is being stretched and the greater will be the resistance to localized necking. Necks in the metal harm surface appearance and affect structural integrity.

For many stamping operations, stretching of the metal is the critical factor and is dependent on the strain – hardening coefficient. Therefore, stampings that need much drawing should be made from metal having high average strain – hardening coefficients. Yield strength should be low to avoid wrinkles or buckling

Forming Limit Curve:

The forming – limit curve is a good index of determining the formability of sheet metal. Essentially, it requires to draw a curve that shows a boundary line between acceptable strain levels in forming and those that may cause failure, Fig 4.2.

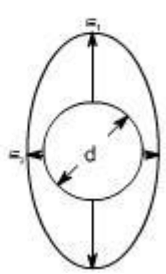
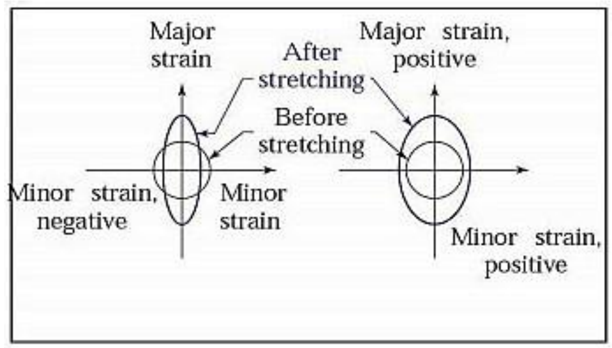


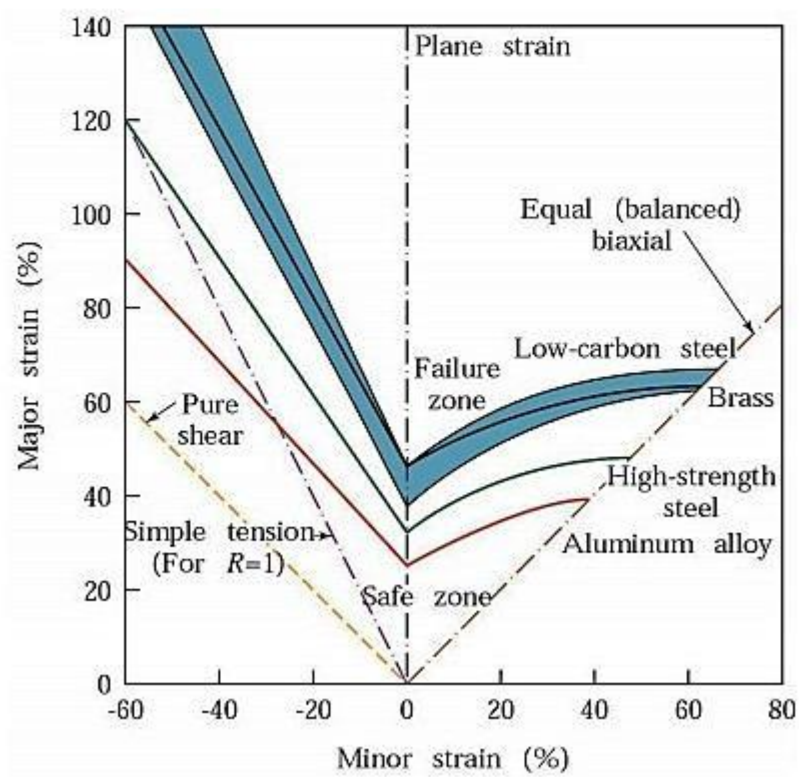
Fig 4.2 The relationship of major, e_1 , and minor, e_2 , strains is established by measurement after forming.

The curve indicates the relation between major and minor strains that are perpendicular to the plane of the sheet. To determine these strains, a grid of circles is marked on the sheet metal, say by an electrolytic stencil – etching process. After the metal is deformed, the circles are measured to obtain the major strain e1 and the minor strain e2 , as shown in Fig 4.2 Typically, ten to fifteen data points are obtained from a test specimen in the region of fracture. Ellipses lying both in the failed region and just outside of it are measured. The forming – limit curve is then drawn to fall below the strains in the necked and fractured zones, and above the strains found just outside these zones (Fig 4.3)



With controlled variation in specimen size it is possible to plot an entire forming – limit curve from one test setup. A reasonably accurate forming limit curve may be obtained with four specimens while a precision curve may be obtained with eight specimens.

In may be noted that –local‖ ductility varies for different metals, so no universal forming – limit curve can be developed. For example, two metals may have peak local ductilities of 20% and 50% at a given minor strain. The metal with the 20 % local ductility (high strain – hardening coefficient) may turn out to be the best choice because the strain will then have a better distribution throughout, allowing the entire sheet to be stretched 20%. If the other sheet showed little strain hardening, it might stretch by 50% in local area, but leave the rest of the sheet relatively unstrained.

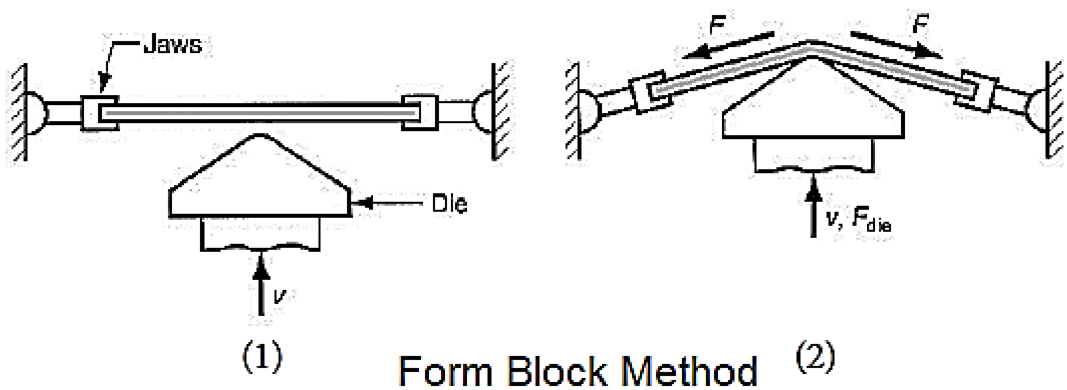


Through the use of formability – prediction techniques. Designers and fabricators are able to make a wider choice of metals and obtain date quickly on newer metals. The essential data can be obtained before the die is designed. Also metal suppliers will be able to establish whether a material possesses required formability before it is shipped from the plant.

Stretch forming

Stretch forming is a very accurate and precise method for forming metal shapes, economically. The level of precision is so high that even intricate multi-components and snap-together curtainwall components can be formed without loss of section properties or original design function. Stretch forming capabilities include portions of circles, ellipses, parabolas and arched shapes. These shapes can be formed with straight leg sections at one or both ends of the curve. This eliminates several conventional fabrication steps and welding.

The stretch forming process involves stretch forming a metal piece over a male stretch form block (STFB) using a pneumatic and hydraulic stretch press. Stretch forming is widely used in producing automotive body panels. Unlike deep drawing, the sheet is gripped by a blank holder to prevent it from being drawn into the die. It is important that the sheet can deform by elongation and uniform thinning.



Form Block Method

The variety of shapes and cross sections that can be stretch formed is almost unlimited. Window systems, skylights, store fronts, signs, flashings, curtainwalls, walkway enclosures, and hand railings can be accurately and precisely formed to the desired profiles.

Benefits

- Close and consistent tolerances,
- No surface defacing,
- No distortion or ripples,

- No surface misalignment of complex profiles
- smooth and even surface results

This process is ideally suited for the manufacture of large parts made from aluminum, but does just as well with stainless steel and commercially pure titanium. It is quick, efficient, and has a high degree of repeatability.

Stretch forming method

- Form block Method
- Mating Die Method

Hydroforming

Hydroforming, sometimes referred to as fluid forming or rubber diaphragm forming, was developed during the late 1940's and early 1950's in response to a need for a lower cost method of producing relatively small quantities of deep drawn parts.

Hydroforming, in simple terms, replaces the punch in traditional stamping with liquid--usually water--to provide shaping force. Hydroforming refers to the manufacture, via fluid pressure, of hollow parts with complex geometries. Hydroforming can be used to shape tubes or extrusions—where it finds its greatest use--or to shape sheet blanks.

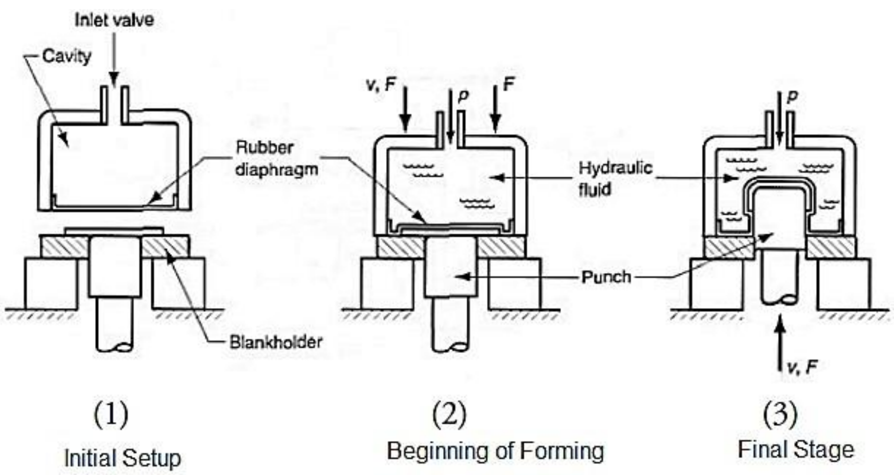
In tube and extrusion hydroforming, the workpiece is inflated by introducing fluid into the cavity while the tube undergoes axial or radial compression. The tube then expands where permitted by the tooling to the die wall. Such hydroforming in many cases is preceded by forming steps such as bending the tube to distribute where it’s needed—corner radii, usually--for final hydroforming, or bent in order to fit into the die. Hydroforming dies used for tubes or extrusions consist of upper and lower blocks and plates as well as axial units used for sealing and end-feeding of the part.

A sheet blank can be formed via fluid applied directly or through a bladder system to force the sheet to assume the shape of the die wall or punch end. Here, the punch may provide additional pressure to assist in the process.

The hydroforming process requires specialized presses—or specially fitted hydraulic presses--and tooling as well as fluid delivery, storage, disposal and reclamation capability. Fluid pressure can range from the about 3,000 to nearly 100,000 psi.

Competitive processes

Deep-draw stamping, tube bending, fabrication.



Hydro Forming

Applications -

In automotive, the process delivers hollow parts such as radiator frames, engine cradles, exhaust manifolds, roof and frame rails and instrument-panel supports. Various rails, manifolds and supports find use in aircraft and appliance applications. Parts made through sheet hydroforming, currently a low-volume specialty process, include automotive deep-drawn fuel-tank trays and body panels as well as appliance parts such as panels and sink basins. The process also works well with smaller parts such as fittings and fuel filler necks

Benefits -

- Lighterweight parts in applications where it has replaced traditional stamping, fabrication and assembly methods.
- One-piecehydro formed parts can replace assemblies, thus increasing structural integrity while saving on material costs and reducing scrap.
- Hydroforming is better suited in producing parts from high-strength steel and aluminum than competing processes.

Recently, technology has allowed inclusion of operations such as piercing during hydroforming.

Capacities:

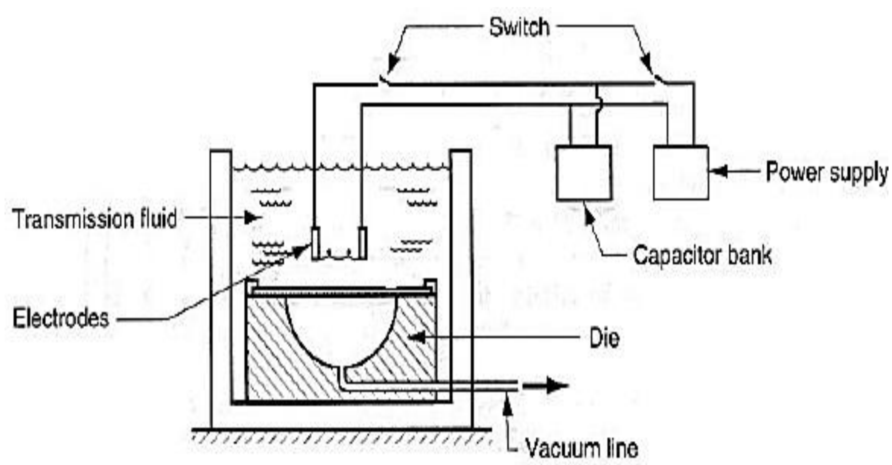
Part size is dependent on press size. Currently, the largest hydroforming press available can churn out parts to nearly 20 ft. long, but typical parts are less than half that size, and can be produced in sizes down to a few inches. Cycle times are slower than traditional stamping methods.

Materials:

High-strength steel and aluminum are the materials of choice in hydroforming parts for automotive use. But any sheet material that can be cold formed is a candidate for hydroforming.

Electrohydraulic Forming

In electrohydraulic forming, an electric arc discharge is used to convert electrical energy to mechanical energy. A capacitor bank delivers a pulse of high current across two electrodes, which are positioned a short distance apart while submerged in a fluid (water or oil). The electric arc discharge rapidly vaporizes the surrounding fluid creating a shock wave. The workpiece, which is kept in contact with the fluid, is deformed into an evacuated die.



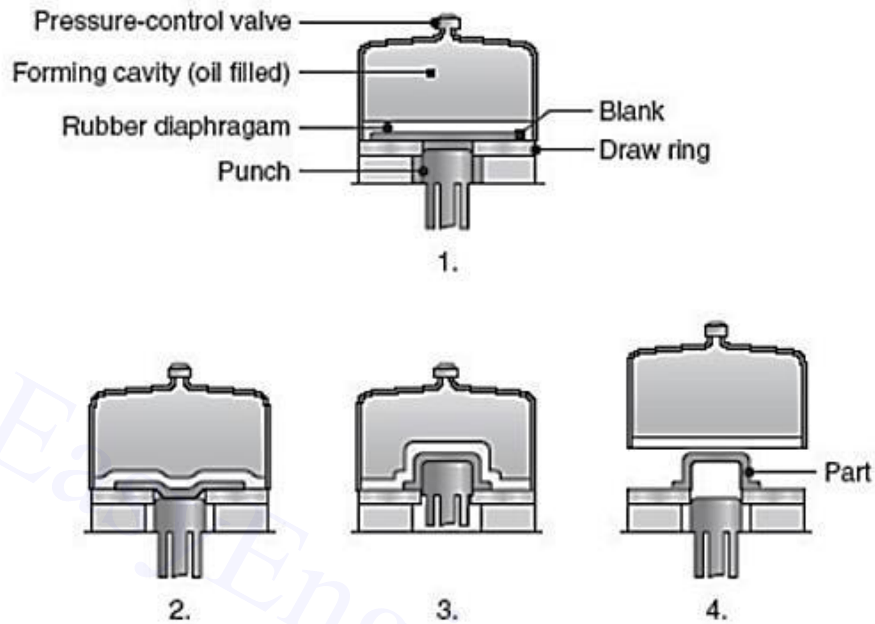
Electro Hydraulic forming

The potential forming capabilities of submerged arc discharge processes were recognized as early as the middle of 1940s. During the 1950s and early 1960s, the basic process was developed into production systems. This work principally was by and for the aerospace industries. By 1970, forming machines based on submerged arc discharge, were available from machine tool builders. A few of the larger aerospace fabricators built machines of their own design to meet specific part fabrication requirements.

Electrohydraulic forming is a variation of the older, more general, explosive forming method. The only fundamental difference between these two techniques is the energy source, and subsequently, the practical size of the forming event.

Very large capacitor banks are needed to produce the same amount of energy as a modest mass of high explosives. This makes electrohydraulic forming very capital intensive for large parts. On the other hand, the electrohydraulic method was seen as better suited to automation because of the fine control of multiple, sequential energy discharges and the relative compactness of the electrode-media containment system.

RUBBER PAD FORMING



Rubber Pad Forming

The name of rubber pad forming is also called as Guerin Process.

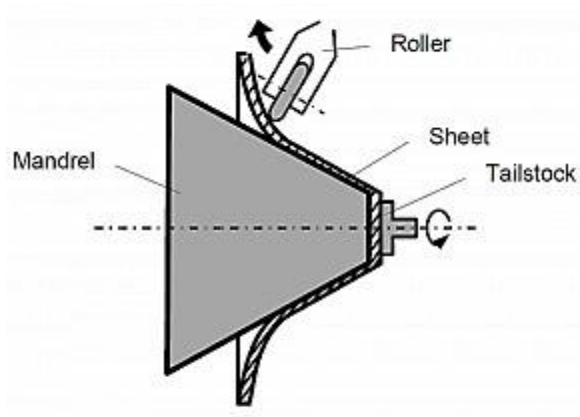
Rubber pad forming (RPF) is a metalworking process where sheet metal is pressed between a die and a rubber block, made of polyurethane. Under pressure, the rubber and sheet metal are driven into the die and conform to its shape, forming the part. The rubber pads can have a general purpose shape, like a membrane. Alternatively, they can be machined in the shape of die or punch.

Rubber pad forming has been used in production lines for many years. Up to 60% of all sheet metal parts in the aerospace industry are fabricated using this process. The most relevant applications are indeed in the aerospace field.It is frequently used in prototyping shops and for the production of kitchenware.

METAL SPINNING PROCESS

The metal spinning process starts with special machinery that produces rotationally symmetrical (i.e. cone-shaped) hollow parts; usually from circular blanks. Shear forming, a related process where parts are formed over a rotating conical mandrel, can be used to produce not only cone-shaped parts but also elliptical or other concave or convex parts. Often, shear forming is used in conjunction with metal spinning. Metal spinning is used as a replacement for the stamping and deep drawing processes.

The metal spinning process starts with a sheet metal blank which rotates on a lathe. The metal disc is pressed against a tool (called a mandrel or a chuck) with a tailstock. The metal disc, tailstock and tool rotate in a circular motion and a roller presses against the metal to form the metal over the tool through a series of passes by the roller. The resulting part is a piece that duplicates the exterior portion of the tool it was formed on. The basic shapes in metal spinning are cones, flanged covers, hemispheres, cylindrical shells, venturis and parabolic nose shapes.



Metal Spinning

Metal spinning yields pots and pans, vases, lamp shades, musical-instrument parts and trophies. Automotive parts include wheel discs, rims, hubcaps and clutch drums. Other examples include radar reflectors, parabolic dishes, hoppers, concrete-mixer bodies, drums, pressure bottles, tank ends, compensator and centrifuge parts, pulleys, hydraulic cylinders, engine inlet rings and a variety of jet-engine and missile parts.

Some of the advantages of metal spinning include -

- Low capital-investment
- Low tooling and energy costs
- Short setup times
- Quick and inexpensive adaptation of tooling and methods to accommodate design changes
- Ability to carry out other operations such as beading, profiling, trimming and turning in the same production cycle with one setup.

- Forming forces are appreciably lower than competing processes due to localized working.
- Economical for one-off parts; prototypes; and small, medium and high volumes.
- Any sheet material that can be cold formed for metal spinning including - cold rolled steel, hot rolled steel, aluminum, stainless steel, brass, copper and exotic metals such as titanium, Inconel, and haste alloy.

Tooling for spinning is relatively inexpensive and simple to employ, translating to a short lead time for parts. Tight tolerancing requirements may require secondary operations, but the advent of automated spinning machines allows more precise forming than with manual spinning machines, with less reliance on operator skill.

Explosive Forming

Explosive forming has evolved as one of the most dramatic of the new metalworking techniques. Explosive forming is employed in aerospace and aircraft industries and has been successfully employed in the production of automotive-related components. Explosive Forming or HERF (High Energy Rate Forming) can be utilized to form a wide variety of metals, from aluminum to high strength alloys. In this process the punch is replaced by an explosive charge. The process derives its name from the fact that the energy liberated due to the detonation of an explosive is used to form the desired configuration. The charge used is very small, but is capable of exerting tremendous forces on the workpiece. In Explosive Forming chemical energy from the explosives is used to generate shock waves through a medium (mostly water), which are directed to deform the workpiece at very high velocities.

Methods of Explosive Forming

Explosive Forming Operations can be divided into two groups, depending on the position of the explosive charge relative to the workpiece.

Standoff Method

In this method, the explosive charge is located at some predetermined distance from the workpiece and the energy is transmitted through an intervening medium like air, oil, or water. Peak pressure at the workpiece may range from a few thousand psi to several hundred thousand psi depending on the parameters of the operation.

Contact Method

In this method, the explosive charge is held in direct contact with the workpiece while the detonation is initiated. The detonation produces interface pressures on the surface of the metal up to several million psi (35000 MPa).

The system used for Standoff Method consists of following parts: -

1) An explosive charge
2) An energy transmitted medium
3) A die assembly
4) The workpiece.

The die assembly is put together on the bottom of a tank. Workpiece is placed on the die and blankholder placed above. A vacuum is then created in the die cavity. The explosive charge is placed in position over the centre of the workpiece. The explosive charge is suspended over the blank at a predetermined distance. The complete assembly is immersed in a tank of water.

After the detonation of explosive, a pressure pulse of high intensity is produced. A gas bubble is also produced which expands spherically and then collapses until it vents at the surface of the water. When the pressure pulse impinges against the workpiece, the metal is displaced into the die cavity.

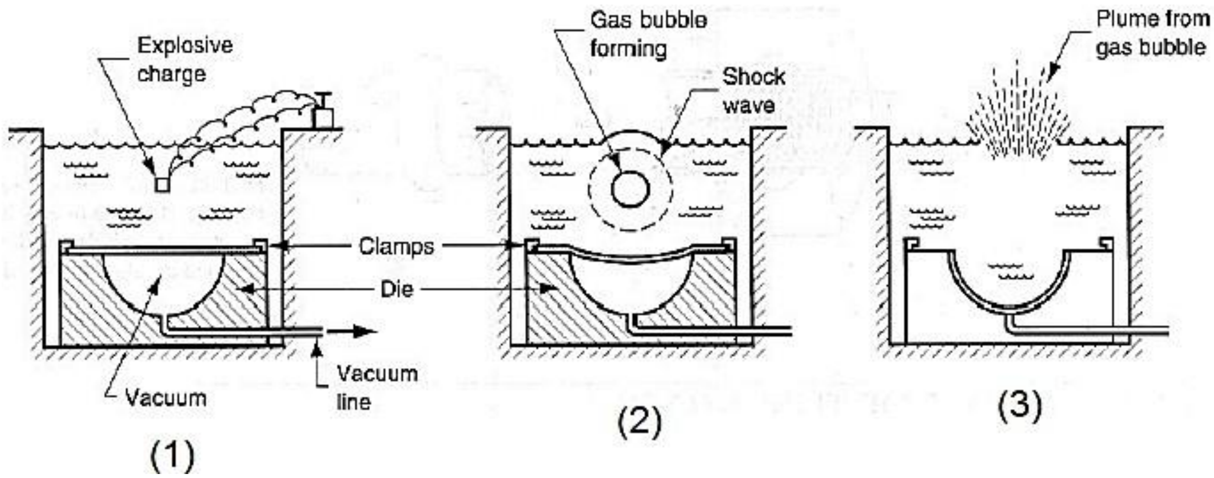
Explosives

Explosives are substances that undergo rapid chemical reaction during which heat and large quantities of gaseous products are evolved. Explosives can be solid (TNT-trinitro toluene), liquid (Nitroglycerine), or Gaseous (oxygen and acetylene mixtures). Explosives are divide into two classes; Low Explosives in which the ammunition burns rapidly rather than exploding, hence pressure build up is not large, and High Explosive which have a high rate of reaction with a large pressure build up. Low explosives are generally used as propellants in guns and in rockets for the propelling of missiles.

Advantages of Explosion Forming

1. Maintains precise tolerances
2. Eliminates costly welds.
3. Controls smoothness of contours.
4. Reduces tooling costs.

5. Less expensive alternative to super-plastic forming.



Die Materials

Different materials are used for the manufacture of dies for explosive working, for instance high strength tool steels, plastics, concrete. Relatively low strength dies are used for short run items and for parts where close tolerances are not critical, while for longer runs higher strength die materials are required. Kirksite and plastic faced dies are employed for light forming operations; tool steels, cast steels, and ductile iron for medium requirements.

Material of Die	Application Area
Kirksite	Low pressure and few parts
Fiberglass and Kirksite	Low pressure and few parts
Fiberglass and Concrete	Low pressure and large parts
Epoxy and Concrete	Low pressure and large parts
Ductile Iron	High pressure and many parts
Concrete	Medium pressure and large parts

Characteristics of Explosive Forming Process

- Very large sheets with relatively complex shapes, although usually axisymmetric.
- Low tooling costs, but high labor cost.
- Suitable for low-quantity production.
- Long cycle times.

Transmission Medium

Energy released by the explosive is transmitted through medium like air, water, oil, gelatin, liquid salts. Water is one of the best media for explosive forming since it is available readily, inexpensive and produces excellent results. The transmission medium is important regarding pressure magnitude at the workpiece. Water is more desirable medium than air for producing high peak pressures to the workpiece.

ADVANTAGE

1. It can simulate a variety of other conventional metal forming techniques such as stamp- or press-forming and spin-forming in a single operation.
2. Explosive hydro-forming can efficiently form large parts – up to 4’ square or 10’ in diameter.
3. It is particularly suitable for short production runs of a large parts such as occurs in aerospace applications.
4. It maintains precise tolerances and Eliminates costly welds.

DISADVANTAGES

1. Low tooling costs, but high labor cost.
2. Suitable for low-quantity production.
3. Due to shock waves and spillage of water it is not suitable to carry out indoor.
4. It should be done in open air.

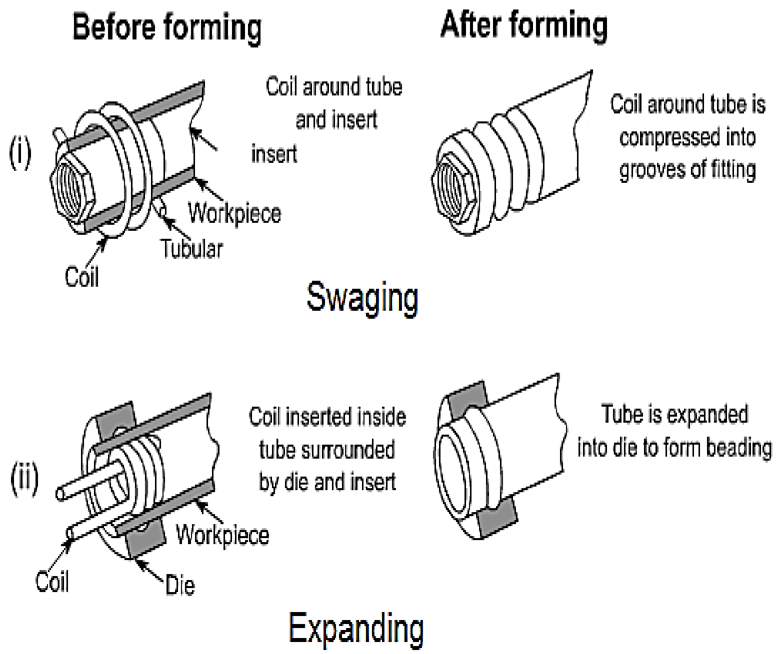
Electro Magnetic Forming

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, (Refer figure). 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.

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 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 in Fig. (a)), 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 in Fig. (b). The magnetic coil is placed inside the tube – like part, so that when energized would expand the material of the part into the collar.

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 riveting.

Peen Forming

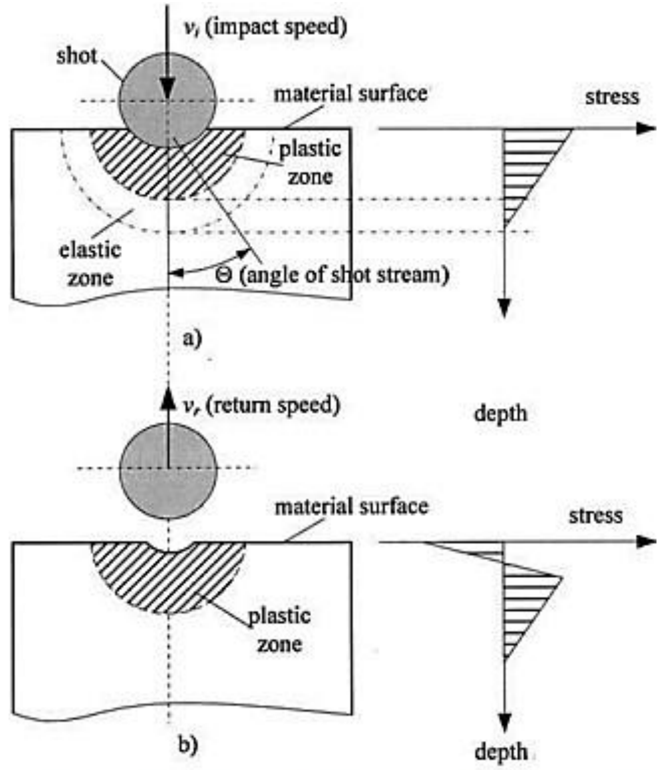
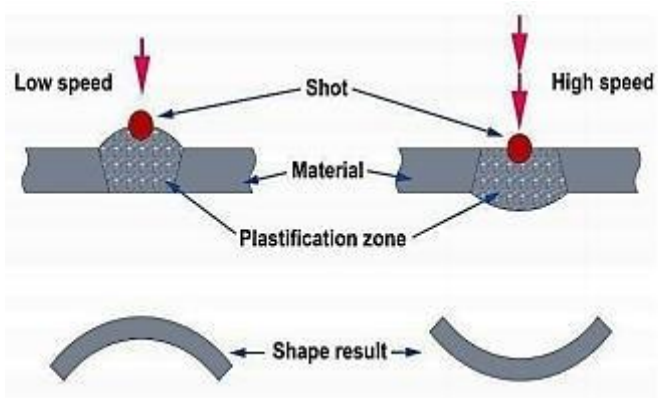


Figure 3 **The effect of shot impact on stress distribution: a) at the moment of impact; b) immediately after impact**

Shot peen forming is a dieless process performed at room temperature, whereby small round steel shot impact the surface of the work piece. Every piece of shot acts as a tiny peening hammer, producing elastic stretching of the upper surface and local plastic deformation that manifests itself as a residual compressive stress. The combination of elastic stretching and compressive stress generation causes the material to develop a compound, convex curvature on the peened side.

The shot peen forming process is ideal for forming large panel shapes where the bend radii are reasonably large and without abrupt changes in contour. Shot peen forming is best suited for forming curvatures where radii are within the metal's elastic range. Although no dies are required for shot peen forming, for severe forming applications, stress peen fixtures are sometimes used. Shot peen forming is effective on all metals, even honeycomb skins and ISO grid panels.



Mechanism of Peen forming

Shot peen forming is often more effective in developing curvatures than rolling, stretching or twisting of metal. Saddle-back shapes also are achievable. Because it is a dieless process, shot peen forming reduces material allowance from trimming and eliminates costly development and manufacturing time to fabricate hard dies. The shot peen forming process also is flexible to design changes, which may occur after initial design. Metal Improvement Company can make curvature changes by adjusting the shot peen forming process.

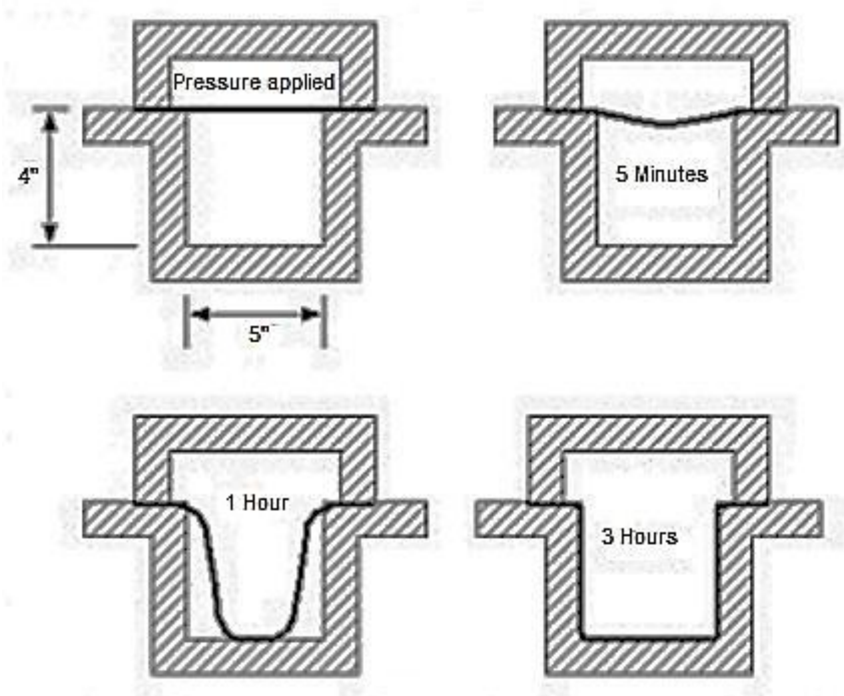
Parts formed by shot peen forming exhibit increased resistance to flexural bending fatigue. Unlike most other forming methods, all surface stresses generated by shot peen forming are of a compressive nature. Although shot peen formed pieces usually require shot peening on one side only, the result causes both sides to have compressive stress. These compressive stresses serve to inhibit stress corrosion cracking and to improve fatigue resistance. Some work pieces should be shot peened all over prior to or after shot peen forming to further improve fatigue and stress corrosion cracking resistance.

Shot peening of parts that have been cold formed by other processes overcomes the harmful surface tensile stresses set up by these other forming processes.

SUPERPLASTIC FORMING

The superplastic forming (SPF) operation is based on the fact that some alloys can be slowly stretched well beyond their normal limitations at elevated temperatures. The higher temperatures mean the flow stress of the sheet material is much lower than at normal temps. This characteristic allows very deep forming methods to be used that would normally rupture parts. Superplastic alloys can be stretched at higher temperatures by several times of their initial length without breaking. Superplastic forming can produce complex shapes with stiffening rims and other structural features as well.

The process begins by placing the sheet to be formed in an appropriate SPF die, which can have a simple to complex geometry, representative of the final part to be produced. The sheet and tooling are heated and then a gas pressure is applied, which plastically deforms the sheet into the shape of the die cavity.



Super Plastic Forming

Process Advantages --

- Reduced weight for high fuel efficiency
- Improved structural performance
- Increased metal formability and part complexity
- Near net shape forming of complex shapes reduces part count
- Cost/weight savings
- Low-cost tooling
- Low environmental impacts - non-lead die lubes, low noise

Materials used -

1) Titanium alloys
2) Aluminum alloys
3) Bismuth-tin alloys
4) Zinc-aluminum alloys
5) Stainless steel
6) Aluminum-lithium alloys