MF9223
METAL FORMING PROCESSES

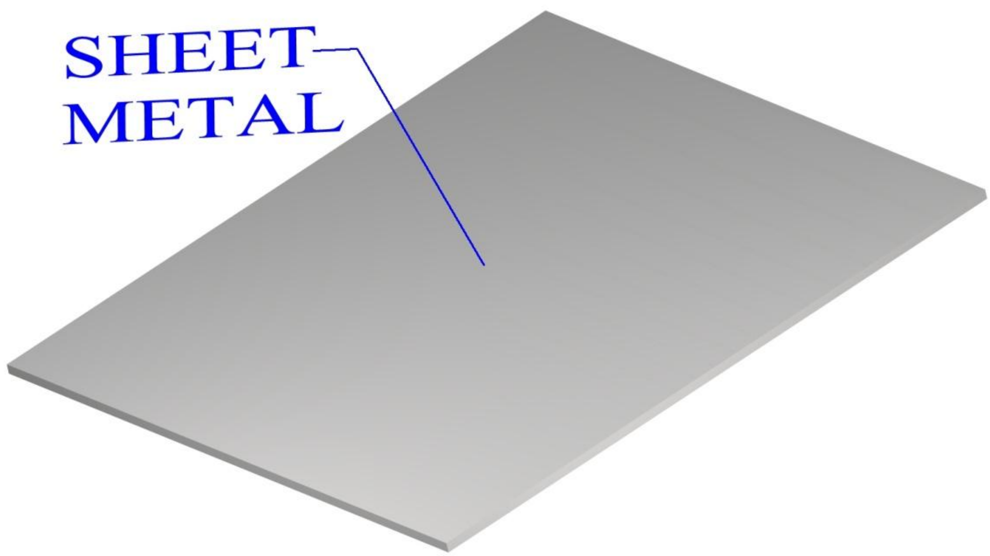
UNIT III SHEET METAL FORMING

Formability studies – Conventional processes – H E R F techniques – Superplastic forming techniques – Hydro forming – Stretch forming – Water hammer forming – Principles and process parameters – Advantage, Limitations and application.

FORMABILITY STUDIES

Sheet Metal Basics

Sheet metal forming involves a wide range of processes that manufacture parts for a vast amount of purposes, both seen and unseen. Sheet metal refers to metal that has a high surface area to volume ratio. Sheet metal work stock, used for sheet metal processes, is usually formed by rolling and comes in coils.



A distinction needs to be made between sheet metal and plate metal. Sheet metal is a 1/4 inch or less in thickness, while plate is over 1/4 inch in thickness. Sheet and plate have different applications. Plate is generally used for larger structural parts like boilers, turbines, bridges, and ships. Sheet metal is used in the manufacture of cars, trains, aircraft, farm equipment, office equipment, furniture, house appliances, computers, machine components, and beverage cans to name a few. Some of the sheet metal manufacturing processes may be applicable to plate metal as well, even though the work piece is referenced only as sheet metal. However plate, particularly thicker plate will provided its own set of problems in processing. Therefore, some of the sheet metal operations discussed may not be applicable to plate.

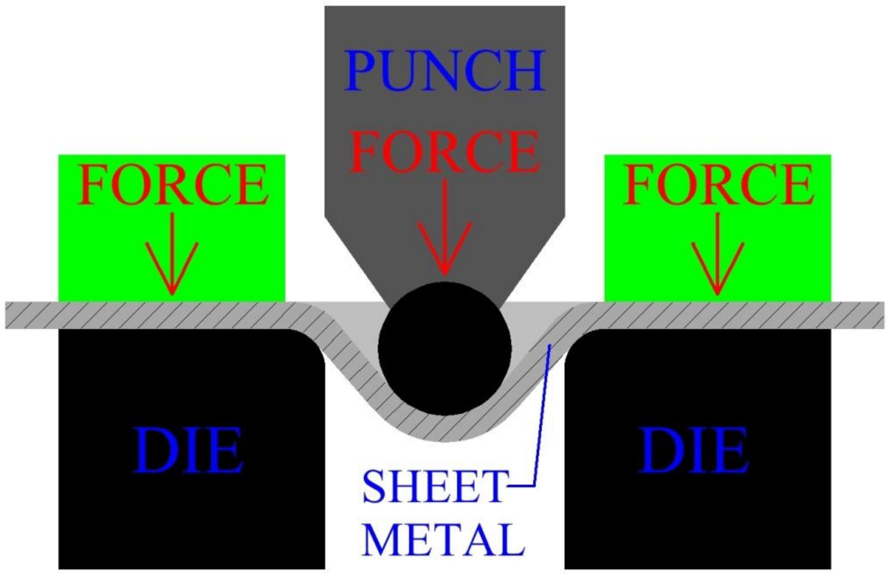
Sheet metal manufacture is mostly performed on a press, and parts are formed between two die. The top die is called a punch. Sometimes sheet metal parts are referenced to as stampings. Parts are usually economical and easy to mass produce. Sheet metal is usually formed cold, however warm or hot working of parts, (particularly plate), is possible. Generally for sheet metal applications there is essentially no change or negligible change in sheet thickness. For some processes like deep drawing, there is a slight and expected change in thickness, but this may also be neglected in most cases. Sheet metal products typically have high strength, good surface, and accurate tolerances.

Sheet Metal Mechanics And Testing Methods

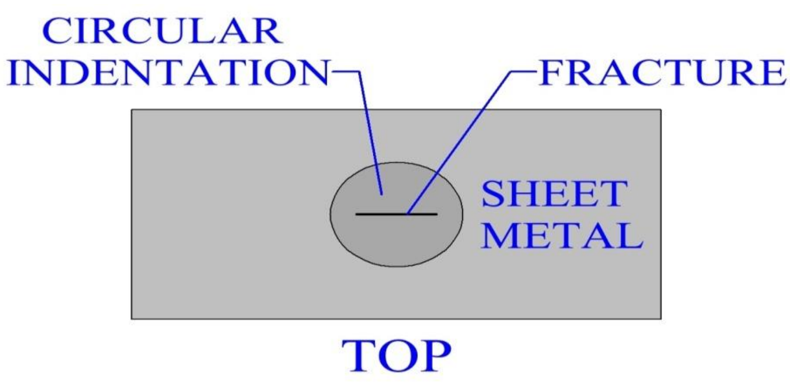
Mechanical behavior of metal is important to understand when manufacturing sheet metal products. The metal forming basics section provides information on this topic. Generally a desirable property for metals is a large plastic deformation before necking. When necking of the metal occurs, diffuse necking is preferred over localized necking. A high total elongation of the material before fracture is also desirable for sheet metal forming. Some metals such as low carbon steels and aluminum-magnesium alloys may experience yield point elongation. This uneven yielding of the material may produce stretcher strains or Lueder's bands. These lines are actually small depressions in the material. Lueder's bands may not be acceptable in situations where surface finish matters. Grain size, structure and orientation are also important in a sheet metal work piece. Grains will effect the properties of the metal as well as surface finish.

In addition to the standard tests for materials, (such as tension tests), there are tests that are used specifically to determine the formability of sheet metal. One common test is the cupping test. A specimen is secured over a round die cavity and a steel ball is pushed into the specimen until fracture of the material occurs. The greater the distance that the sheet metal can plastically deform before fracture, the greater the sheet's formability.

CUPPING TEST

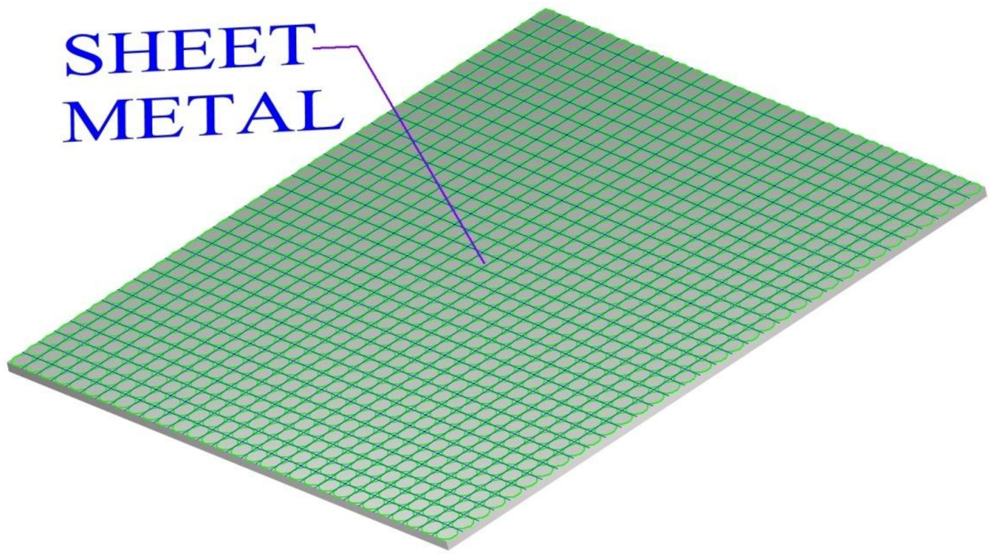


Anisotropy is an important factor in sheet metal forming. Anisotropy is the directional variation of mechanical properties. In other words, the material will react differently to stress applied in one direction than it would to the same stress applied in a different direction. If a sheet is isotropic, then its properties are the same in any direction. Cupping tests can be used to determine anisotropy. If the fracture occurring due to the applied force through the round ball is circular, then the sheet is isotropic. If a straight fracture occurs, this means that the sheet is anisotropic.



SHEET IS ANISOTROPIC

Many sheet metal operations will create a complex distribution of forces. Material elements experience different amounts and proportions of bi-axle stress and strain depending upon their location within the work. Sometimes a sheet metal is tested over a range of different bi-axle forces. A grid with inscribed circles is printed on the specimen. The grid and circles will deform with the metal.



Tests can then be performed to determine the metal's reaction to different combinations of bi-axle strain. Failure and safe zones for combinations of major and minor, (the two directions), strain can be established. Forming limit diagrams can then be created to display this information graphically. The forming limit diagram is a useful reference for sheet metal manufacturers.

Sheet Metal Classification

There are 3 major classes of processes of sheet metal working.

Cutting: Cutting is the use of shearing forces to remove material from a work piece. Technically not a metal forming process, but of extreme industrial importance.

Bending: Bending is the forming of a sheet metal work about an axis.

Deep Drawing: Deep drawing is the forming of a cup or box with a flat base and straight walls, from a sheet metal blank.

Other Processes: Other sheet metal working processes such as ironing, spinning, rubber forming, and high energy rate forming are also discussed in latter sections.

CONVENTIONAL PROCESSES

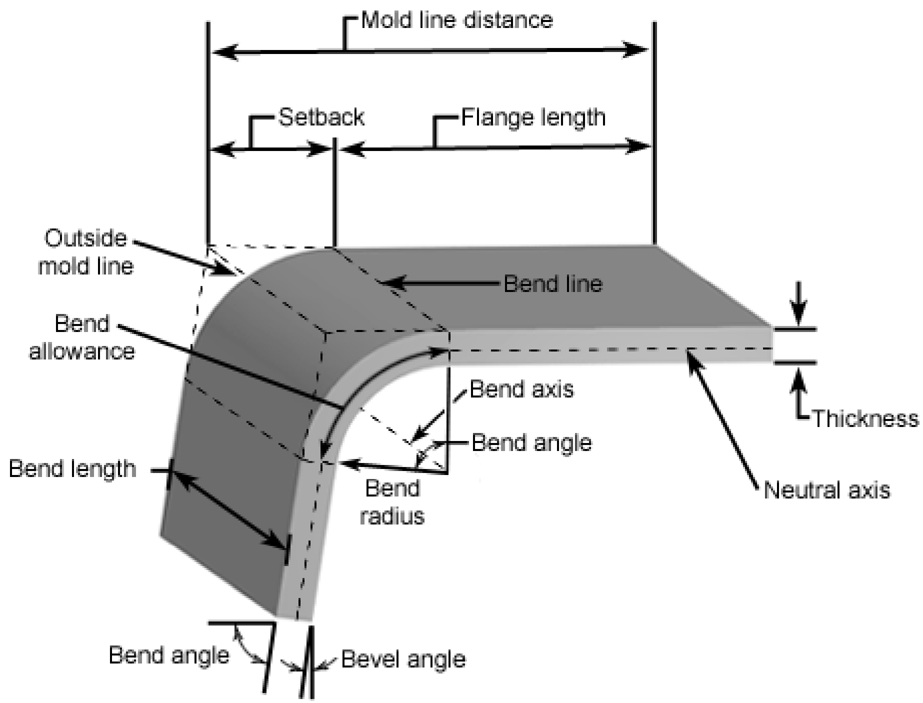
Sheet Metal Forming

Sheet metal forming processes are those in which force is applied to a piece of sheet metal to modify its geometry rather than remove any material. The applied force stresses the metal beyond its yield strength, causing the material to plastically deform, but not to fail. By doing so, the sheet can be bent or stretched into a variety of complex shapes. Sheet metal forming processes include the following:

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

Bending

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

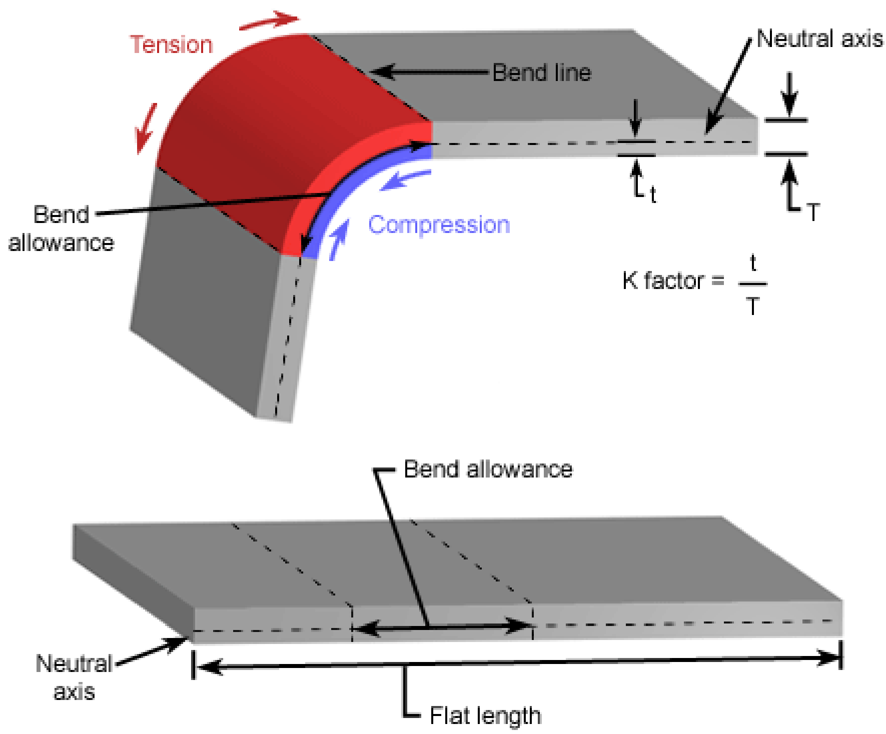


Bending Diagram

- *Bend line* - The straight line on the surface of the sheet, on either side of the bend, that defines the end of the level flange and the start of the bend.
- *Outside mold line* - The straight line where the outside surfaces of the two flanges would meet, were they to continue. This line defines the edge of a mold that would bound the bent sheet metal.
- *Flange length* - The length of either of the two flanges, extending from the edge of the sheet to the bend line.
- *Mold line distance* - The distance from either end of the sheet to the outside mold line.
- *Setback* - The distance from either bend line to the outside mold line. Also equal to the difference between the mold line distance and the flange length.
- *Bend axis* - The straight line that defines the center around which the sheet metal is bent.
- *Bend length* - The length of the bend, measured along the bend axis.
- *Bend radius* - The distance from the bend axis to the inside surface of the material, between the bend lines. Sometimes specified as the inside bend radius. The outside bend radius is equal to the inside bend radius plus the sheet thickness.

- Bend angle - The angle of the bend, measured between the bent flange and its original position, or as the included angle between perpendicular lines drawn from the bend lines.
- *Bevel angle* - The complimentary angle to the bend angle.

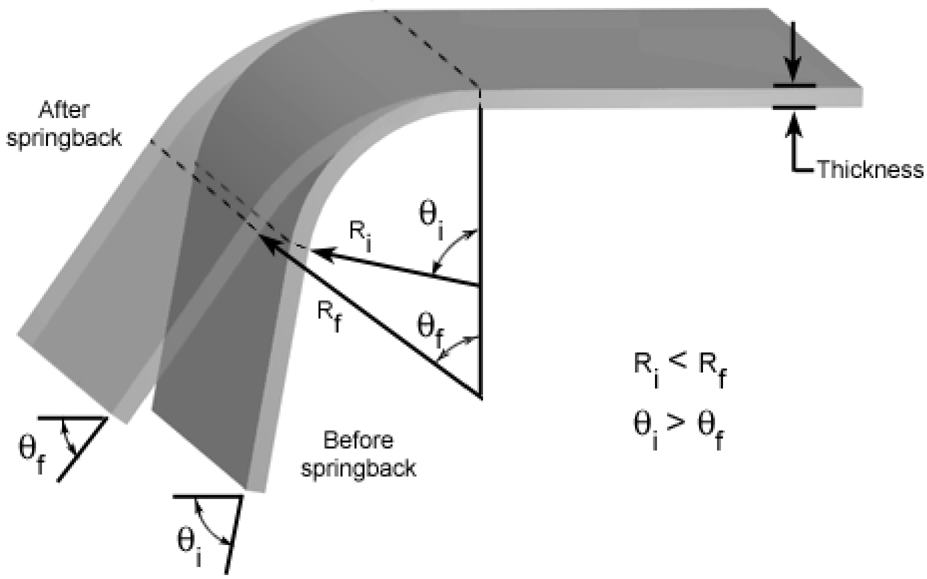
The act of bending results in both tension and compression in the sheet metal. The outside portion of the sheet will undergo tension and stretch to a greater length, while the inside portion experiences compression and shortens. The neutral axis is the boundary line inside the sheet metal, along which no tension or compression forces are present. As a result, the length of this axis remains constant. The changes in length to the outside and inside surfaces can be related to the original flat length by two parameters, the bend allowance and bend deduction, which are defined below.



Neutral Axis

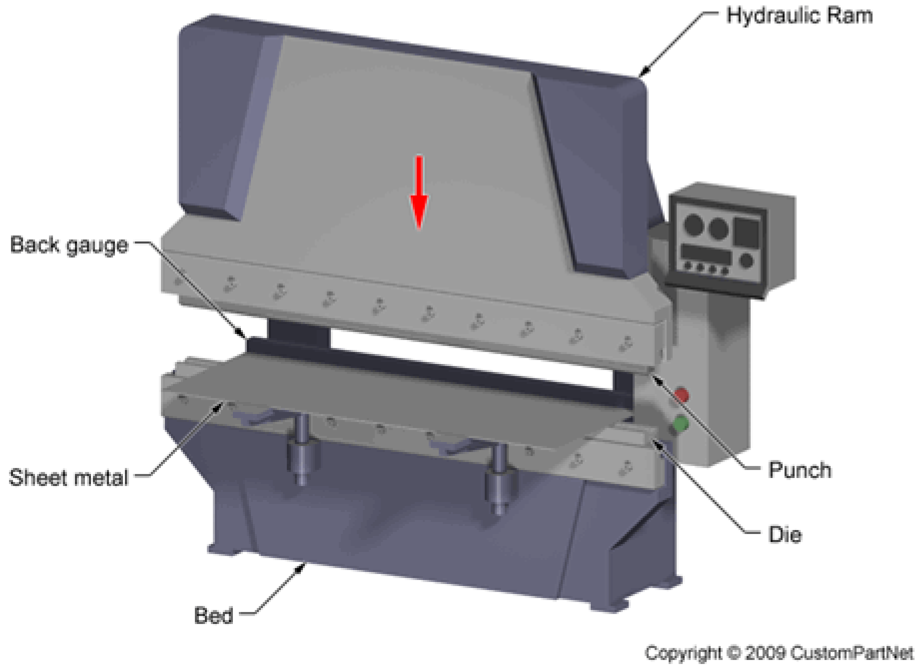
- *Neutral axis* - The location in the sheet that is neither stretched nor compressed, and therefore remains at a constant length.
- *K-factor* - The location of the neutral axis in the material, calculated as the ratio of the distance of the neutral axis (measured from the inside bend surface) to the material thickness. The K-factor is dependent upon several factors (material, bending operation, bend angle, etc.) and is typically greater than 0.25, but cannot exceed 0.50.
- *Bend allowance* - The length of the neutral axis between the bend lines, or in other words, the arc length of the bend. The bend allowance added to the flange lengths is equal to the total flat length.
- *Bend deduction* - Also called the bend compensation, the amount a piece of material has been stretched by bending. The value equals the difference between the mold line lengths and the total flat length.

When bending a piece of sheet metal, the residual stresses in the material will cause the sheet to springback slightly after the bending operation. Due to this elastic recovery, it is necessary to over-bend the sheet a precise amount to achieve the desired bend radius and bend angle. The final bend radius will be greater than initially formed and the final bend angle will be smaller. The ratio of the final bend angle to the initial bend angle is defined as the springback factor, K_S. The amount of springback depends upon several factors, including the material, bending operation, and the initial bend angle and bend radius.

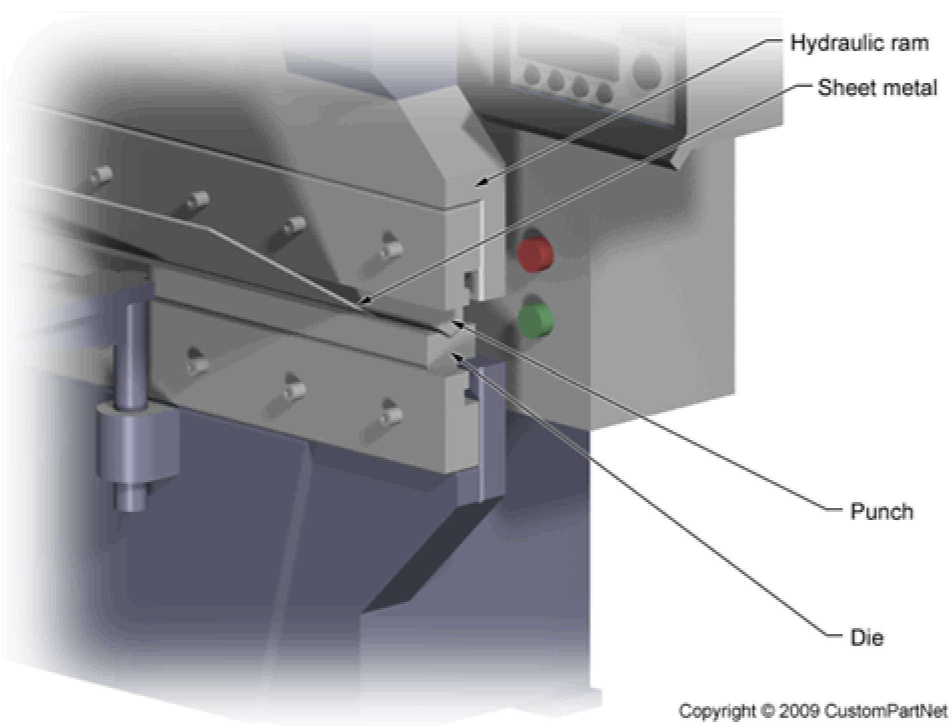


Springback

Bending is typically performed on a machine called a press brake, which can be manually or automatically operated. For this reason, the bending process is sometimes referred to as press brake forming. Press brakes are available in a range of sizes (commonly 20-200 tons) in order to best suit the given application. A press brake contains an upper tool called the punch and a lower tool called the die, between which the sheet metal is located. The sheet is carefully positioned over the die and held in place by the back gauge while the punch lowers and forces the sheet to bend. In an automatic machine, the punch is forced into the sheet under the power of a hydraulic ram. The bend angle achieved is determined by the depth to which the punch forces the sheet into the die. This depth is precisely controlled to achieve the desired bend. Standard tooling is often used for the punch and die, allowing a low initial cost and suitability for low volume production. Custom tooling can be used for specialized bending operations but will add to the cost. The tooling material is chosen based upon the production quantity, sheet metal material, and degree of bending. Naturally, a stronger tool is required to endure larger quantities, harder sheet metal, and severe bending operations. In order of increasing strength, some common tooling materials include hardwood, low carbon steel, tool steel, and carbide steel.

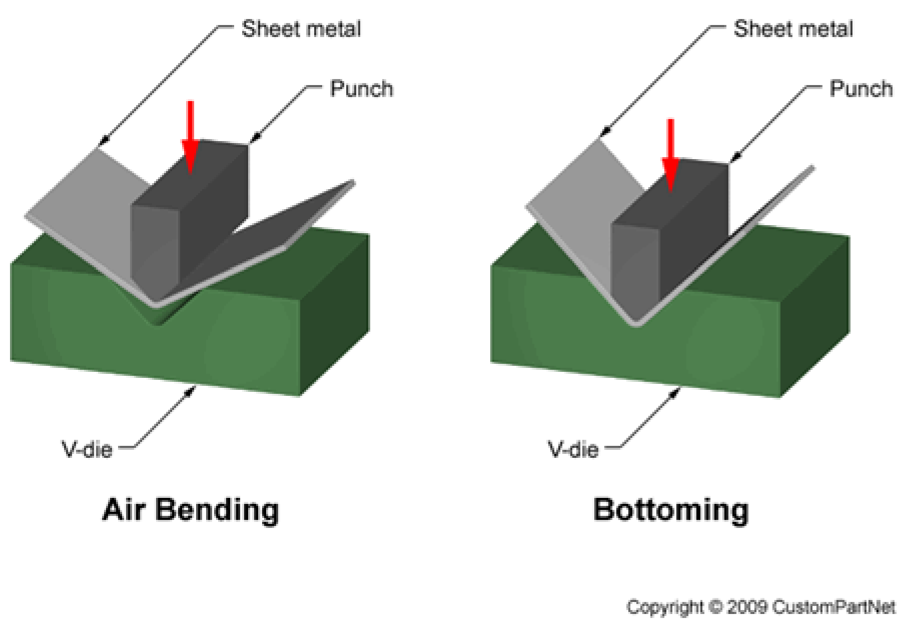


Press Brake (Open)



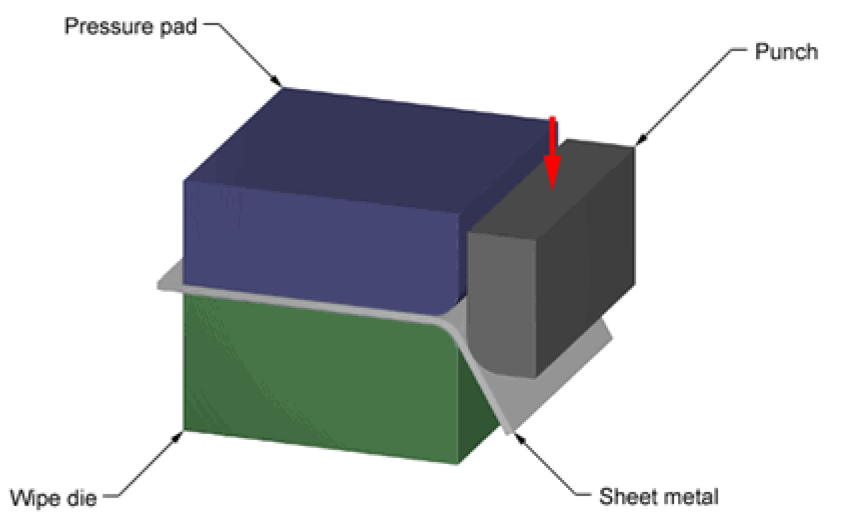
Press Brake (Closed)

While using a press brake and standard die sets, there are still a variety of techniques that can be used to bend the sheet. The most common method is known as V-bending, in which the punch and die are "V" shaped. The punch pushes the sheet into the "V" shaped groove in the V-die, causing it to bend. If the punch does not force the sheet to the bottom of the die cavity, leaving space or air underneath, it is called "air bending". As a result, the V-groove must have a sharper angle than the angle being formed in the sheet. If the punch forces the sheet to the bottom of the die cavity, it is called "bottoming". This technique allows for more control over the angle because there is less springback. However, a higher tonnage press is required. In both techniques, the width of the "V" shaped groove, or die opening, is typically 6 to 18 times the sheet thickness. This value is referred to as the die ratio and is equal to the die opening divided by the sheet thickness.



V Bending

In addition to V-bending, another common bending method is wipe bending, sometimes called edge bending. Wipe bending requires the sheet to be held against the wipe die by a pressure pad. The punch then presses against the edge of the sheet that extends beyond the die and pad. The sheet will bend against the radius of the edge of the wipe die.



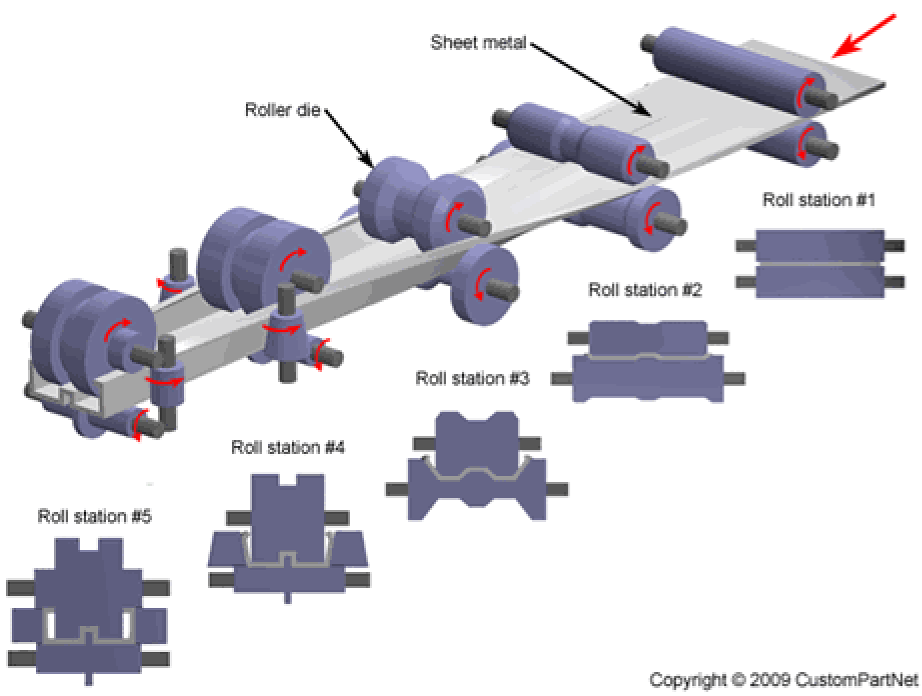
Wipe Bending

Design rules

- Bend location - A bend should be located where enough material is present, and preferably with straight edges, for the sheet to be secured without slipping. The width of this flange should be equal to at least 4 times the sheet thickness plus the bend radius.
- Bend radius
- Use a single bend radius for all bends to eliminate additional tooling or setups
- Inside bend radius should equal at least the sheet thickness
- Bend direction - Bending hard metals parallel to the rolling direction of the sheet may lead to fracture. Bending perpendicular to the rolling direction is recommended.
- Any features, such as holes or slots, located too close to a bend may be distorted. The distance of such features from the bend should be equal to at least 3 times the sheet thickness plus the bending radius.
- In the case of manual bending, if the design allows, a slot can be cut along the bend line to reduce the manual force required.

Roll forming

Roll forming, sometimes spelled rollforming, is a metal forming process in which sheet metal is progressively shaped through a series of bending operations. The process is performed on a roll forming line in which the sheet metal stock is fed through a series of roll stations. Each station has a roller, referred to as a roller die, positioned on both sides of the sheet. The shape and size of the roller die may be unique to that station, or several identical roller dies may be used in different positions. The roller dies may be above and below the sheet, along the sides, at an angle, etc. As the sheet is forced through the roller dies in each roll station, it plastically deforms and bends. Each roll station performs one stage in the complete bending of the sheet to form the desired part. The roller dies are lubricated to reduce friction between the die and the sheet, thus reducing the tool wear. Also, lubricant can allow for a higher production rate, which will also depend on the material thickness, number of roll stations, and radius of each bend. The roll forming line can also include other sheet metal fabrication operations before or after the roll forming, such as punching or shearing.



Roll Forming Line

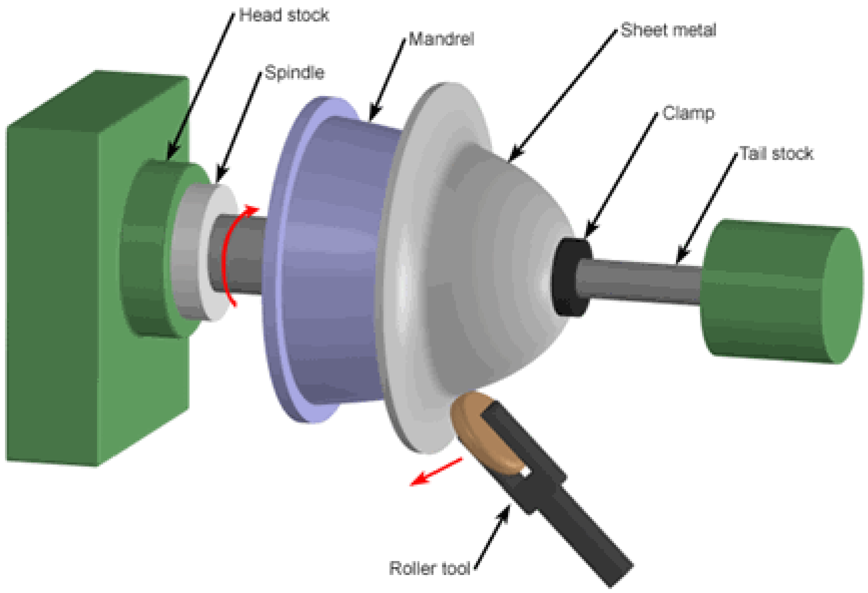
The roll forming process can be used to form a sheet into a wide variety of cross-section profiles. An open profile is most common, but a closed tube-like shape can be created as well. Because the final form is achieved through a series of bends, the part does not require a uniform or symmetric cross-section along its length. Roll forming is used to create very long sheet metal parts with typical widths of 1-20 inches and thicknesses of 0.004-0.125 inches. However wider and thicker sheets can be formed, some up to 5 ft.

wide and 0.25 inches thick. The roll forming process is capable of producing parts with tolerances as tight as ±0.005 inches. Typical roll formed parts include panels, tracks, shelving, etc. These parts are commonly used in industrial and commercial buildings for roofing, lighting, storage units, and HVAC applications.

Spinning

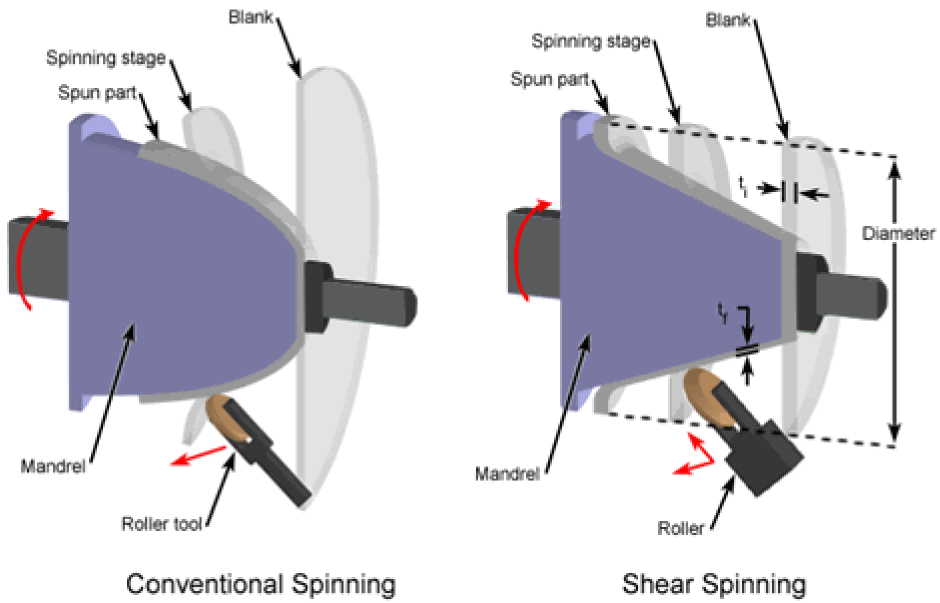
Spinning, sometimes called spin forming, is a metal forming process used to form cylindrical parts by rotating a piece of sheet metal while forces are applied to one side. A sheet metal disc is rotated at high speeds while rollers press the sheet against a tool, called a mandrel, to form the shape of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

Spinning is typically performed on a manual or CNC lathe and requires a blank, mandrel, and roller tool. The blank is the disc-shaped piece of sheet metal that is pre-cut from sheet stock and will be formed into the part. The mandrel is a solid form of the internal shape of the part, against which the blank will be pressed. For more complex parts, such as those with reentrant surfaces, multi-piece mandrels can be used. Because the mandrel does not experience much wear in this process, it can be made from wood or plastic. However, high volume production typically utilizes a metal mandrel. The mandrel and blank are clamped together and secured between the headstock and tailstock of the lathe to be rotated at high speeds by the spindle. While the blank and mandrel rotate, force is applied to the sheet by a tool, causing the sheet to bend and form around the mandrel. The tool may make several passes to complete the shaping of the sheet. This tool is usually a roller wheel attached to a lever. Rollers are available in different diameters and thicknesses and are usually made from steel or brass. The rollers are inexpensive and experience little wear allowing for low volume production of parts.



Spinning Lathe

There are two distinct spinning methods, referred to as conventional spinning and shear spinning. In conventional spinning, the roller tool pushes against the blank until it conforms to the contour of the mandrel. The resulting spun part will have a diameter smaller than the blank, but will maintain a constant thickness. In shear spinning, the roller not only bends the blank against the mandrel, it also applies a downward force while it moves, stretching the material over the mandrel. By doing so, the outer diameter of the spun part will remain equal to the original blank diameter, but the thickness of the part walls will be thinner.

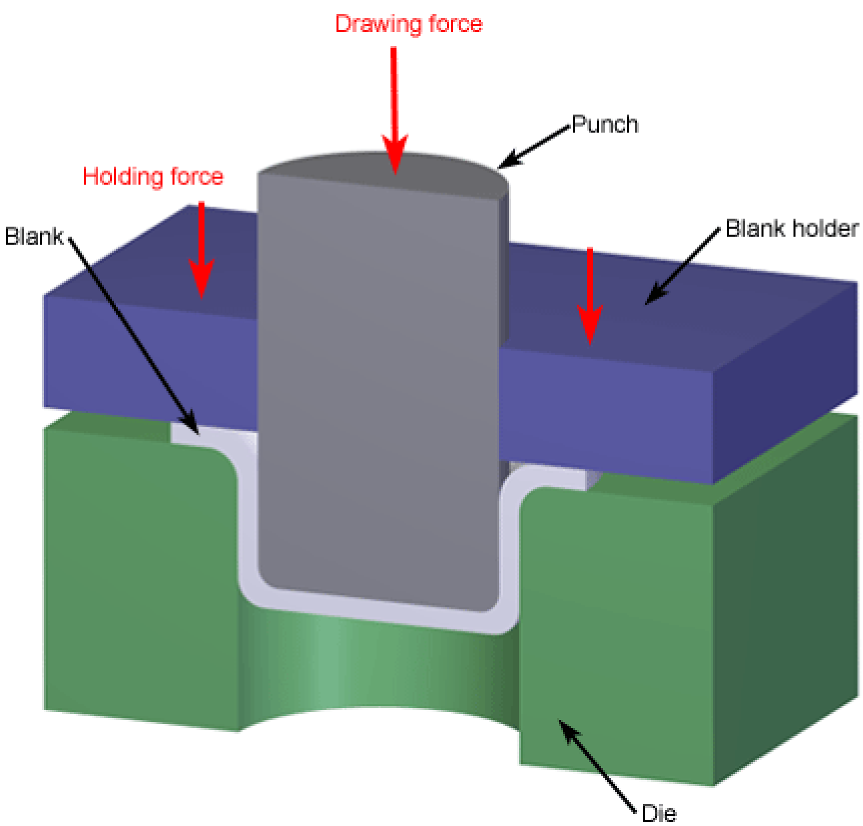


Conventional Spinning vs. Shear Spinning

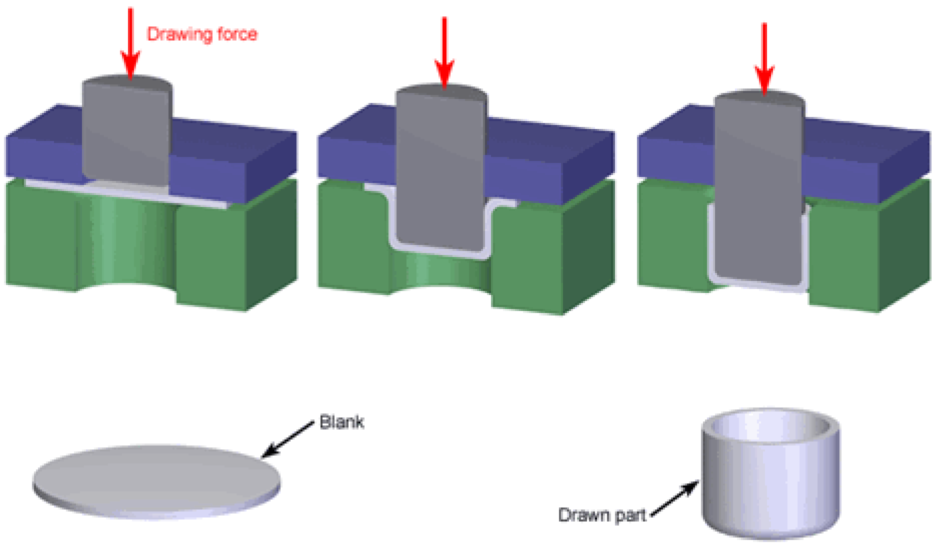
Deep Drawing

Deep drawing is a metal forming process in which sheet metal is stretched into the desired part shape. A tool pushes downward on the sheet metal, forcing it into a die cavity in the shape of the desired part. The tensile forces applied to the sheet cause it to plastically deform into a cup-shaped part. Deep drawn parts are characterized by a depth equal to more than half of the diameter of the part. These parts can have a variety of cross sections with straight, tapered, or even curved walls, but cylindrical or rectangular parts are most common. Deep drawing is most effective with ductile metals, such as aluminum, brass, copper, and mild steel. Examples of parts formed with deep drawing include automotive bodies and fuel tanks, cans, cups, kitchen sinks, and pots and pans.

The deep drawing process requires a blank, blank holder, punch, and die. The blank is a piece of sheet metal, typically a disc or rectangle, which is pre-cut from stock material and will be formed into the part. The blank is clamped down by the blank holder over the die, which has a cavity in the external shape of the part. A tool called a punch moves downward into the blank and draws, or stretches, the material into the die cavity. The movement of the punch is usually hydraulically powered to apply enough force to the blank. Both the die and punch experience wear from the forces applied to the sheet metal and are therefore made from tool steel or carbon steel. The process of drawing the part sometimes occurs in a series of operations, called draw reductions. In each step, a punch forces the part into a different die, stretching the part to a greater depth each time. After a part is completely drawn, the punch and blank holder can be raised and the part removed from the die. The portion of the sheet metal that was clamped under the blank holder may form a flange around the part that can be trimmed off.



Deep Drawing



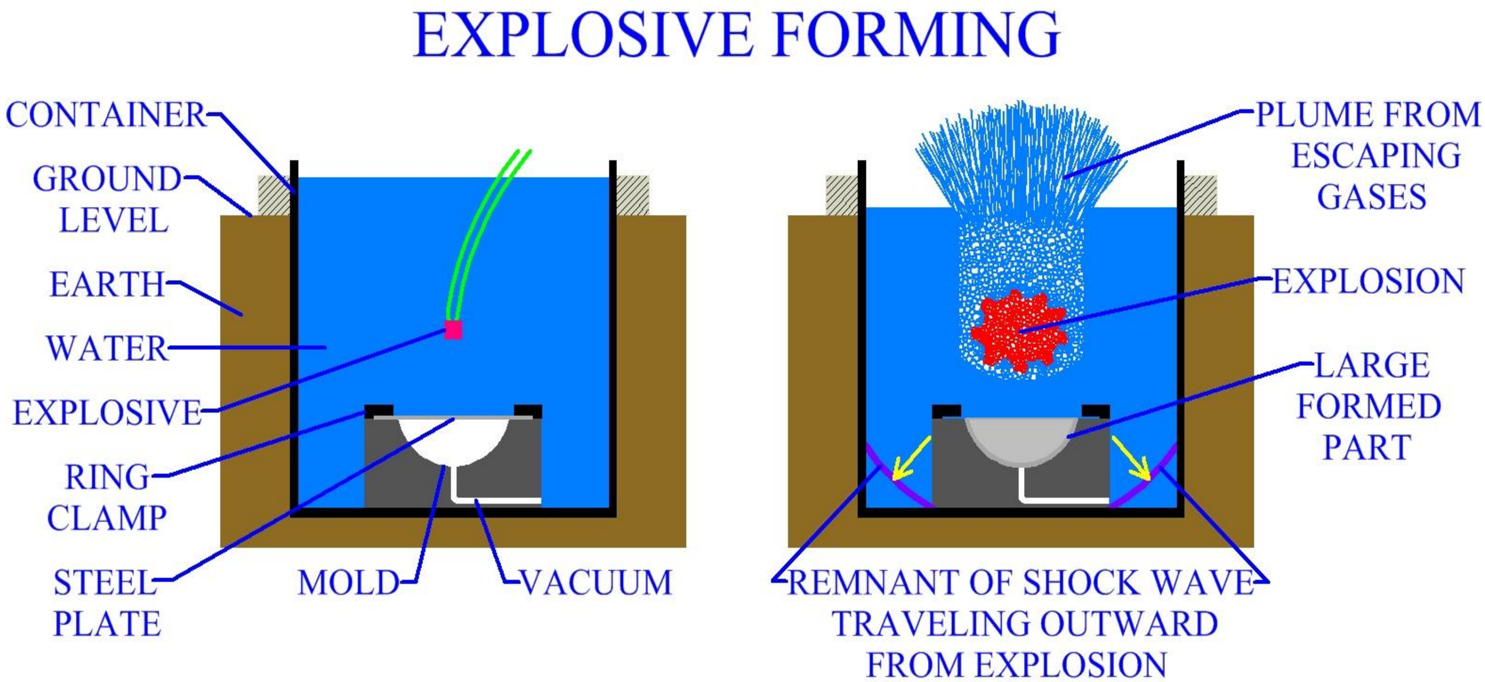
Deep Drawing Sequence

HIGH ENERGY RATE FORMING (HERF TECHNIQUES)

High energy rate forming is the forming of sheet metal by a high energy surge, delivered over a very short time. Since the forming of the metal occurs so quickly, desirable materials for (HERF) will be ductile at high deformation speeds.

Explosive Forming

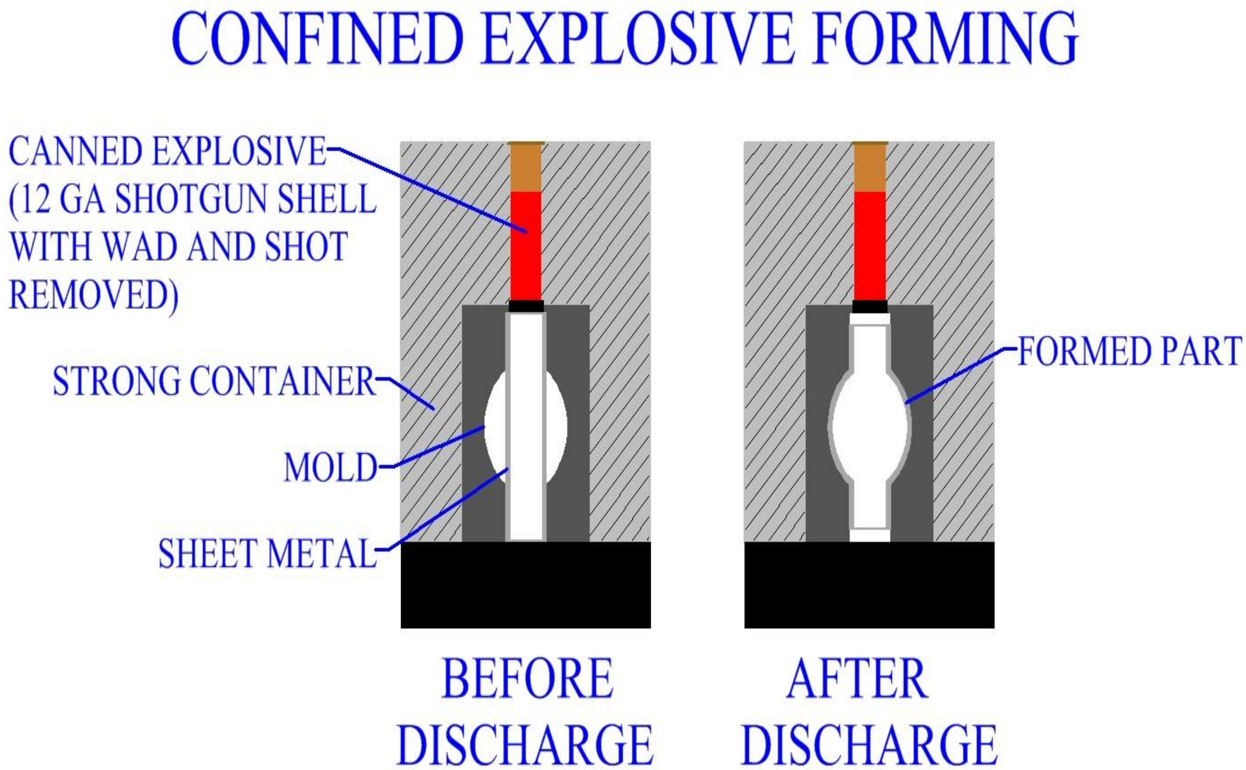
Explosives can deliver a huge amount of power. Although most explosive detonations are destructive, the power from an explosive charge can be used to manufacture parts. An explosive forming process commonly used for the production of large parts is called a standoff system. Typically the mold and work piece are submerged in water. The sheet metal is secured over the mold by a ring clamp. Air is drawn out, creating a vacuum in the die cavity. An explosive is placed between the die cavity and the work, a certain distance from the work. This distance is called the standoff distance. Standoff distance depends on the size of the work, for larger parts it is usually about half the diameter of the blank. The explosive itself is also deeply submersed in water. Upon detonation, the shock wave travels through the water and delivers great energy to the



work, forming it to the die cavity near instantaneously. This high energy rate forming process can be used to form big thick plates.

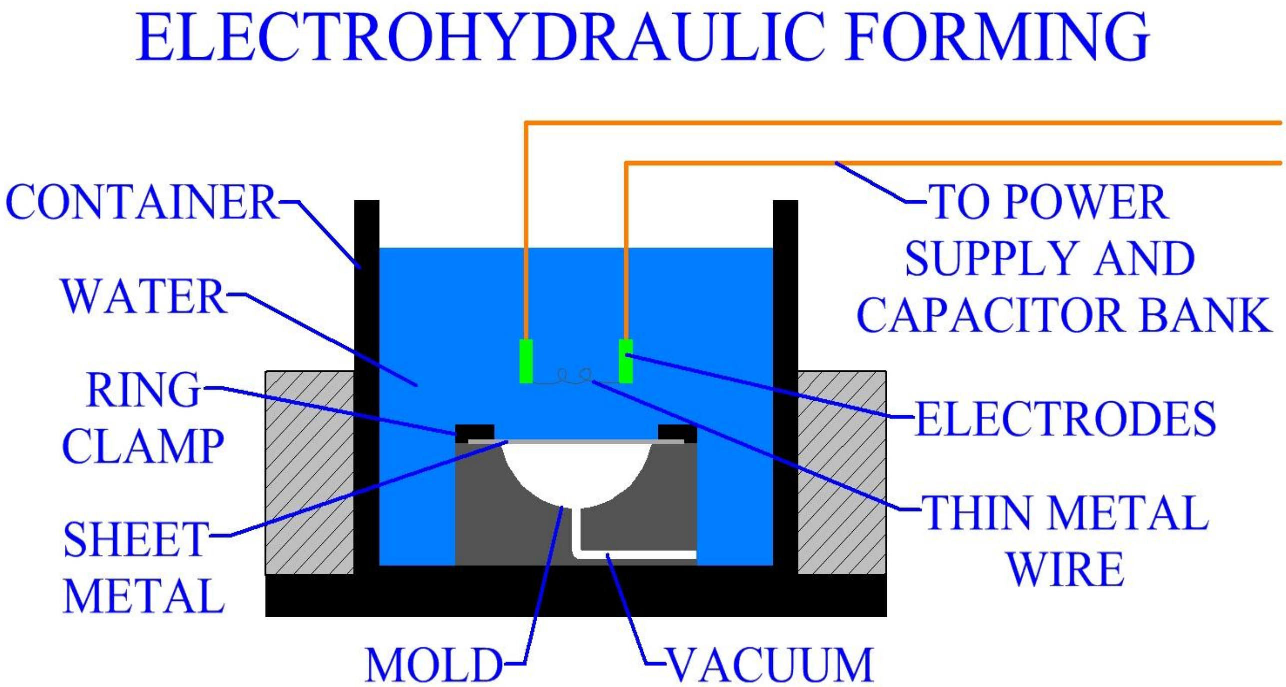
Explosive forming has a long cycle time, and is suitable for low quantity production of large, unique parts. Mechanical properties imparted to the material as a result of the explosive forming process are similar to mechanical properties imparted to work manufactured by other forming processes. Molds can be made out of inexpensive or easy to shape materials, or molds can be made more permanent. Materials for molds include aluminum, wood, concrete, plastic, iron, and steel. If a mold is manufactured from a material such as plastic, the low modulus of elasticity will greatly reduce springback resulting in higher accuracy.

The amount of explosive depends upon the type of system used and the amount of pressure needed to form the part. The shock wave generated by the explosive travels along an expanding spherical front. Much of the energy from the shock wave is not absorbed by the work piece. A modified setup of the standoff system uses reflectors to focus the energy surge. This provides a more effective use of power and a smaller explosive can be used to form the same part. Another system called a confined system, uses a canned explosive or cartridge. This is usually used for relatively smaller parts than the standoff system. All of the energy is directed into a closed container, the walls of which contain the die cavity. The energy from the canned explosive forces the sheet metal into the walls of the mold forming the part. Safety is always a consideration when manufacturing by explosive forming, particularly with the confined system, where die failure is a significant concern.



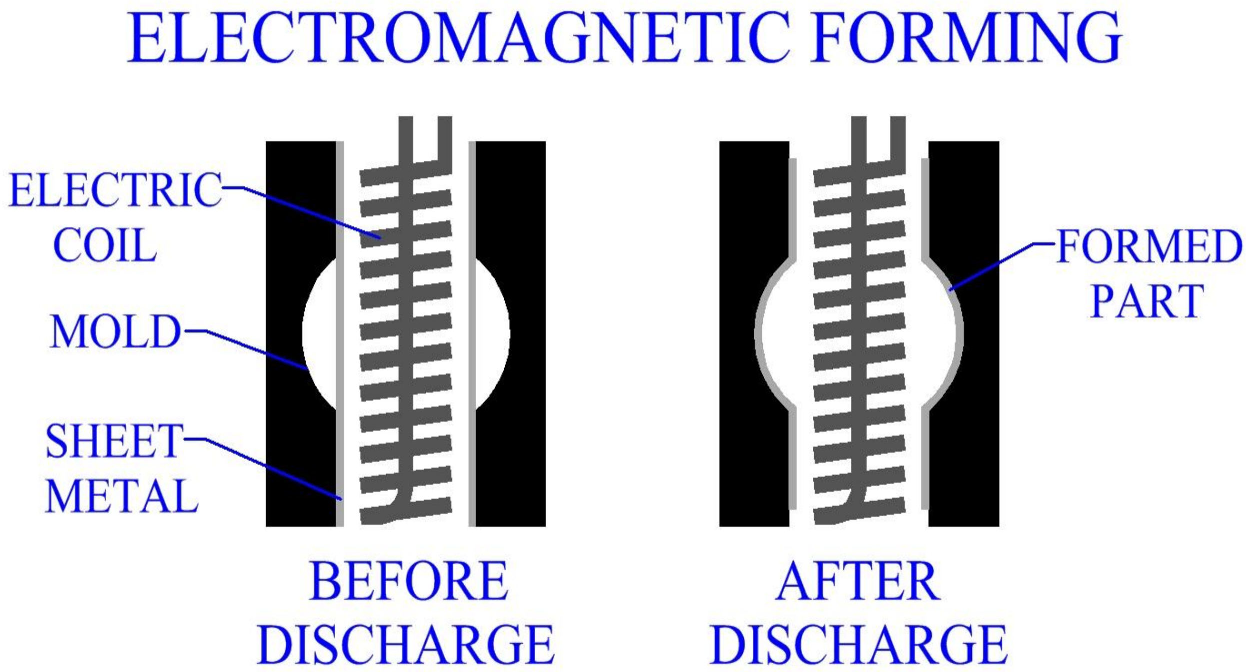
Electrohydraulic Forming

Electrohydraulic forming, also called electric discharge forming is a unique high energy forming process. This process uses the energy from the combustion of a thin metal wire. Two electrodes, with a wire connecting them, are submersed in liquid. The work is set up similar to the standoff system described above, however this process is applicable to relatively smaller parts. A sheet metal blank is secured on top of the mold with a ring clamp, and a vacuum is created in the die cavity under the blank. Electrical energy is stored in a capacitor bank. The electricity is discharged through the electrodes and the wire, instantly vaporizing the wire, creating a shock wave that travels through the water. This shock wave forms the sheet metal to the mold cavity. Electrohydraulic forming produces a shock wave of relatively low magnitude, and is best suited for thinner work. The wire needs to be replaced after every operation. Electrohydraulic forming may be considered to have a low production rate.



Electromagnetic Forming

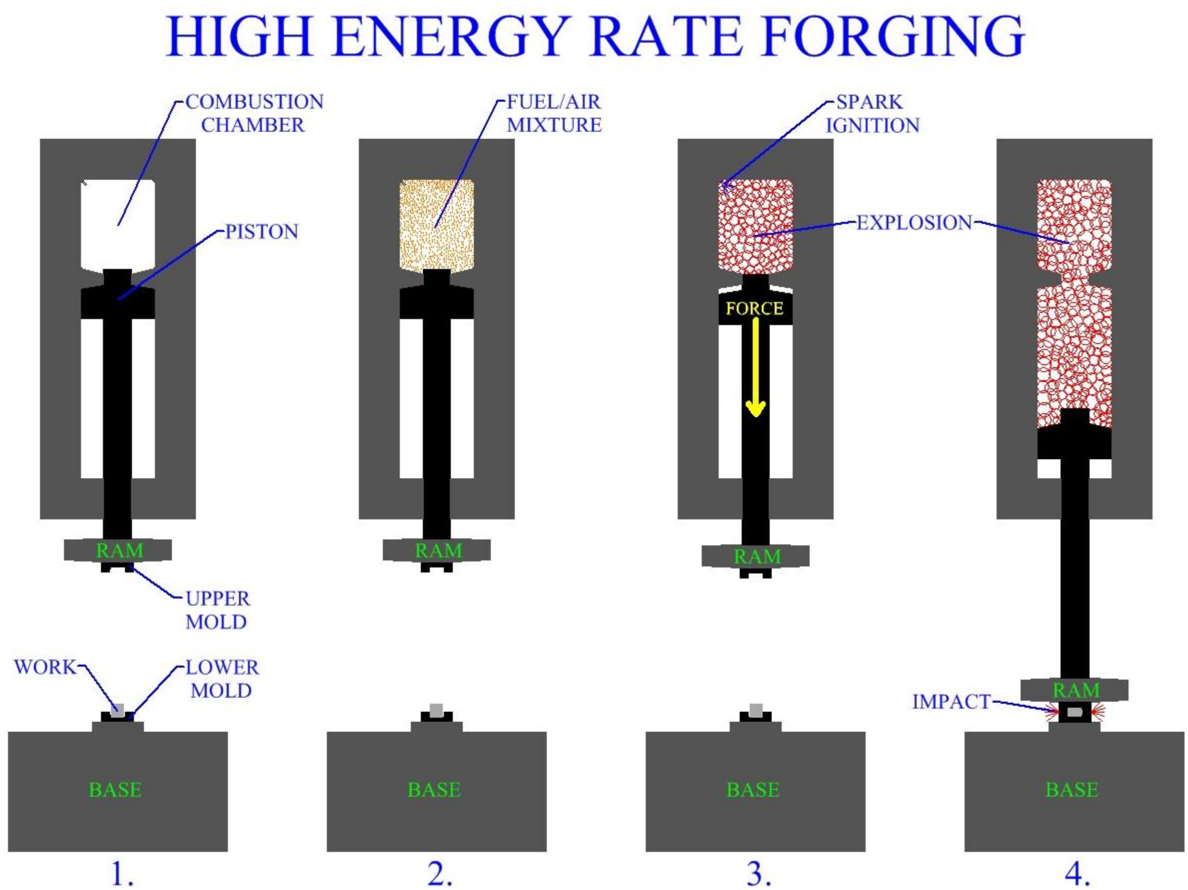
Electromagnetic forming is a popular high energy rate forming process that uses a magnetic surge to form a sheet metal part. In the electromagnetic process, also called magnetic pulse forming, an electric coil is placed near a metal work piece. A capacitor bank is charged up, and a large electrical surge is sent through the coil. The current creates a magnetic field. When a conductive material disrupts a magnetic field it produces a current in that material, this is called an eddy current. Due to the close proximity of the conductive sheet metal to the coil, the coils magnetic field is disrupted, and eddy currents are generated in the work piece. These currents in the sheet metal produce their own magnetic field that opposes the original magnetic field of the coil. The opposing forces push these fields apart and form the work. The coil may be placed inside or over the work depending upon the desired effect. Many electromagnetic forming operations are used to bulge tubes, or form tubes over other parts such as rods and cables. Electromagnetic forming is used for relatively thinner sheet metal parts.



High energy rate forming, (HERF), is a forging process in which the actual forming of the work occurs in a few thousandths of a second. This type of operation is very useful for hard to forge materials. As discussed in isothermal forging, there may be reasons that the cooling of a part during the forging process may create problems. Such as, mechanical properties of some metals can vary considerably over a short temperature range, some metals are difficult to form at lower temperatures, or parts may have thin, complex sections. Isothermal forging was developed specifically to deal with the problems associated with cooling of the material at the work-mold interface. High energy rate forming also solves that same problem, but by a different method. Since the part is forged so fast, there is no time for cooling to occur during the forming of the work. With high energy rate forming, hard to form materials, and thin complicated parts can be forged with a single stroke.

The petro forge is a machine designed to perform high energy rate forming operations. The petro forge bears some similarities to the engine in a car, in that it does employ an internal combustion chamber for its working energy. The upper die of the mold is attached to the ram that is a part of a piston that is located under a combustion chamber. Basically, the combustion chamber is filled with a fuel-air mixture. The mixture is then ignited by a spark plug, creating an explosion in the chamber. This explosion forces the piston, ram, and upper die downward with tremendous power. The upper apparatus accelerates towards the work, striking it with a great velocity, forging the part in a few milliseconds. Back pressure is then used to raise the apparatus, returning it to position, this also occurs rapidly. In industrial high energy rate forming manufacture, forging die can strike the work a velocities of 750 feet per second. The power and velocity employed during this process raises many concerns with regard to safety.

Figure:207



In high-energy rate forming (HERF), parts are shaped by the extremely rapid application of high pressures. Pressures as high its 13,600 MPa and speeds as high as 914 m/s may be used.

The principal advantages of HERF are as follows:

1. Parts can be formed that cannot be formed by conventional methods.

2. Exotic metals, which do not readily lend themselves to conventional forming processes, may be formed over a wide range of sizes and configurations.

3. The method is excellent for restrike operations.

4. Springback after forming is reduced to a minimum.

5. Dimensional tolerances are generally excellent.

6. Variations from part to part are held to a minimum.

7. Scrap rate is low.

8. Less equipment and fewer dies cut down on production lead time.

SUPERPLASTIC FORMING

Introduction

Manufacturing of complex lightweight automotive structures that meet cost and product goals is a competitive challenge facing industry. Superplastic forming (SPF) is a valuable tool for the fabrication of complex parts used in the aircraft and automobile industries. Superplastic forming (SPF) of sheet metal has been used to produce very complex shapes and integrated structures that are often lighter and stronger than the assemblies they replace. Superplasticity in metals is defined by very high tensile elongations, ranging from two hundred to several thousand percent. Superplasticity is the ability of certain materials to undergo extreme elongation at the proper temperature and strain rate.

The process typically conducted at high temperature and under controlled strain rate, can give a ten-fold increase in elongation compared to conventional room temperature processes. Components are formed by applying gas pressure between one or more sheets and a die surface, causing the sheets to stretch and fill the die cavity. The evolution of pressures must be closely controlled during the process since the alloys of interest only exhibits Superplastic behaviour for certain temperature dependent range of strain rates. Specific alloys of titanium, stainless steel, and aluminum are commercially available with the fine-grained microstructure and strain rate sensitivity of flow stress that are necessary for Superplastic deformation.

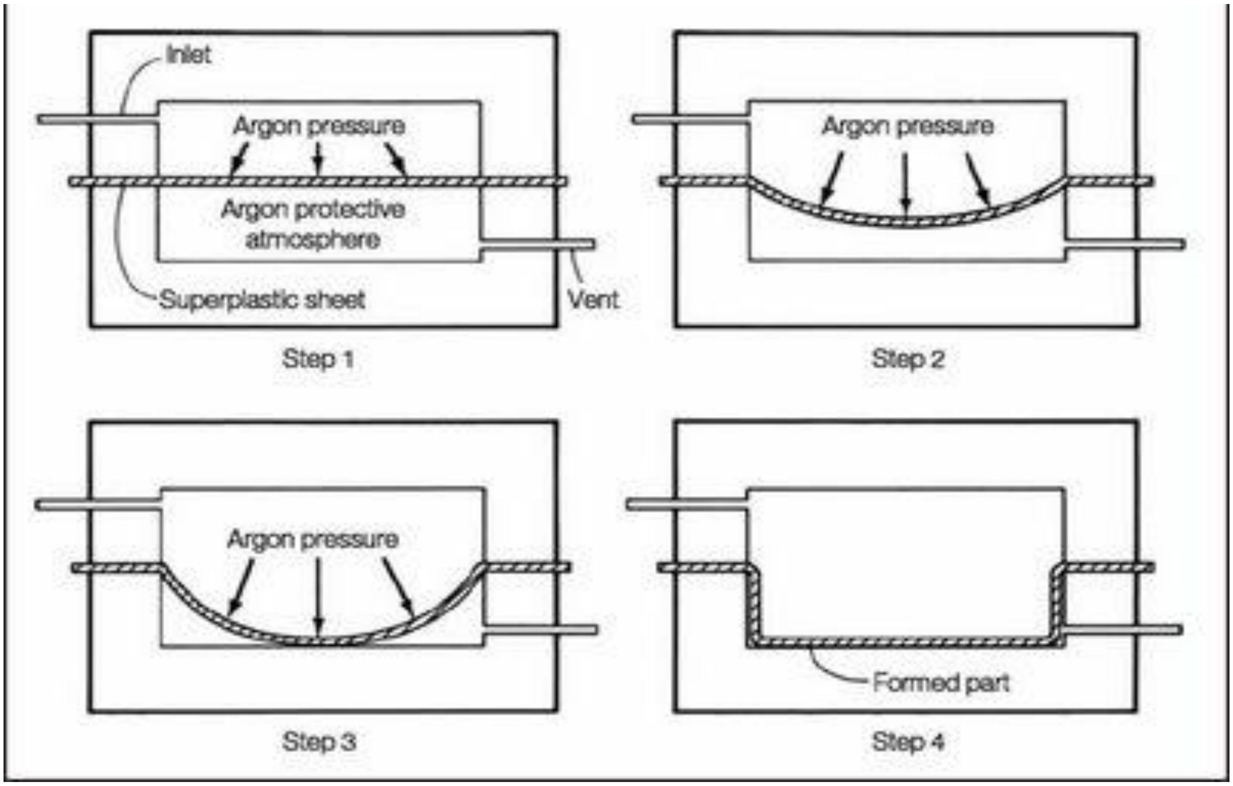
The Process

SPF can produce parts that are impossible to form using conventional techniques. During the SPF process, the material is heated to the SPF temperature within a sealed die. Inert gas pressure is then applied, at a controlled rate forcing the material to take the shape of the die pattern. The flow stress of the material during deformation increases rapidly with increasing strain rate. Superplastic alloys can be stretched at higher temperatures by several times of their initial length without breaking.

Vacuum forming is a superplastic forming process in which a gas pressure differential is imposed on the superplastic diaphragm, causing the material to form into the die configuration. Sometimes called stretch forming, the applied pressure is limited to atmospheric pressure (that is, 100 kPa, or 15 psi), and the forming rate and capability are therefore limited.

The rate of pressurization in blow forming is normally established such that the induced strain rates in the forming sheet are maintained in the superplastic range. The rate of pressurization is determined by trial and error, or by the application of analytical modeling methods. This pressure is generally applied slowly rather than abruptly to prevent too rapid a strain rate and consequent rupturing of the material. This information

With blow forming, additional pressure is applied from a gas pressure reservoir, and the only limitations are related to the pressure rating of the system and the pressure of the gas source. A maximum pressure of 690 to 3400 kPa (100 to 500 psi) is typically used in this process. The blow forming method is illustrated in the diagram, which shows a cross section of the dies and forming diaphragm. In this process, the dies and sheet material are normally maintained at the forming temperature, and the gas pressure is imposed over the sheet, causing the sheet to form into the lower die; the gas within the lower die chamber is simply vented to the atmosphere. The lower die chamber can also be held under vacuum, or a back pressure can be imposed to suppress cavitation if necessary.



Some of the materials developed for super plastic forming are:

1. Bismuth-tin (200% elongation)
2. Zinc-aluminum
3. Titanium (Ti-6Al-V)
4. Aluminum (2004, 2419, 7475)
5. Aluminum-lithium alloys (2090, 2091, 8090

Advantages of SPF Process

Superplastic forming technology offers the potential to reduce the weight and cost of automotive structural components for advance vehicle applications.

The main advantages of this process are:

1. It is a one step process.
2. The process can be used to form complex components in shapes that are very near the final dimension.
3. Higher material elongations.

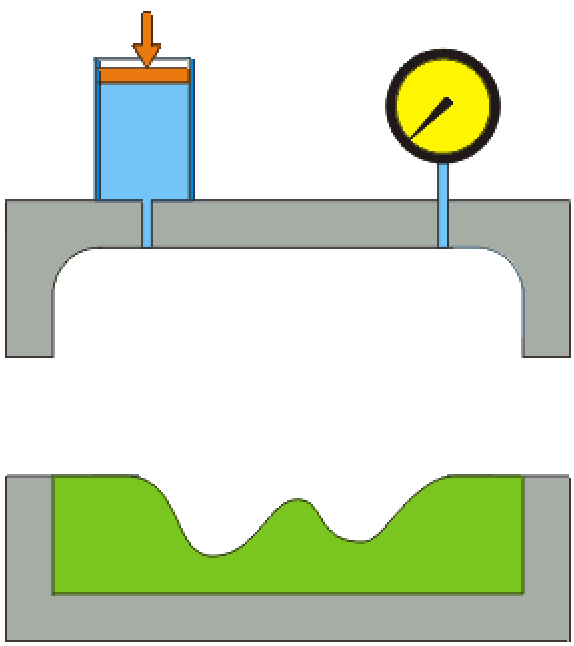
4. Elimination of unnecessary joints and rivets.
5. Reduction of subsequent machining.
6. Minimizes the amount of scrap produced.

Applications

The process is increasingly being applied in the aerospace industry as a way of manufacturing very complex geometries.

- In automotive body panels.
- In forming of aircraft frames and skins.
- Diaphragm forming of plastics.
- Complex shape parts – window frames, seat structures.

HYDROFORMING



Hydroforming is a cost-effective way of shaping ductile metals such as aluminum, brass, low alloy steels, stainless steel into lightweight, structurally stiff and strong pieces. One of the largest applications of hydroforming is the automotive industry, which makes use of the complex shapes possible by hydroforming to produce stronger, lighter, and more rigid unibody structures for vehicles. This technique is particularly popular with the high-end sports car industry and is also frequently employed in the shaping of aluminium tubes for bicycle frames. Hydroforming is a specialized type of die forming that uses a high pressure hydraulic fluid to press room temperature working material into a die. To hydroform aluminum into a vehicle's frame rail, a hollow tube of aluminum is placed inside a negative mold that has the shape of the desired result. High pressure hydraulic pumps then inject fluid at very high pressure inside the aluminum which causes it to expand until it matches the mold. The hydroformed aluminum is then removed from the mold. Hydroforming allows complex shapes with concavities to be formed, which would be difficult or impossible with standard solid die stamping. Hydroformed parts can often be made with a higher stiffness-to-weight ratio and at a lower per unit cost than traditional stamped or stamped and welded parts. Virtually all metals capable of cold forming can be hydroformed, including aluminum, brass, carbon and stainless steel, copper, and high strength alloys.

TYPES

EXPLOSIVE HYDROFORMING FORMING

Hydroforming

SOURIAU PA&E's Bonded Metals Division, formally known as Northwest Technical Industries (NTI), specializes in **Explosive hydro-forming**, a metal forming technique that uses the energy generated by an explosive detonation to form the metal work piece. This process can deliver a great deal of flexibility in the metal-forming process.

Since **explosive forming** transmits the explosively-generated energy through water, it can simulate a variety of other conventional metal forming techniques. With flat-plate designs, explosive hydro-forming is very comparable to stamp- or press-forming. Where **cylindrical work pieces** need to be formed, it can simulate spin-forming. Additionally, explosive hydro-forming openly competes with conventional hydro-forming and hot-stretch forming. In fact, where each of these metal-forming techniques come up short, **explosive hydro-forming still has more to offer**. Explosive hydro-forming can simulate a variety of these forming techniques in a **single forming operation**.

Explosive Hydro-forming

Explosive hydro-forming has been an accepted **metal-forming technique** for almost 50 years. It has been used in a wide variety of applications in the automotive, **aerospace**, and maritime industries. SOURIAU PA&E has extensive experience using this technique to form a wide variety of metals. Typical forming projects yield very close tolerances and very high degrees of repeatability.

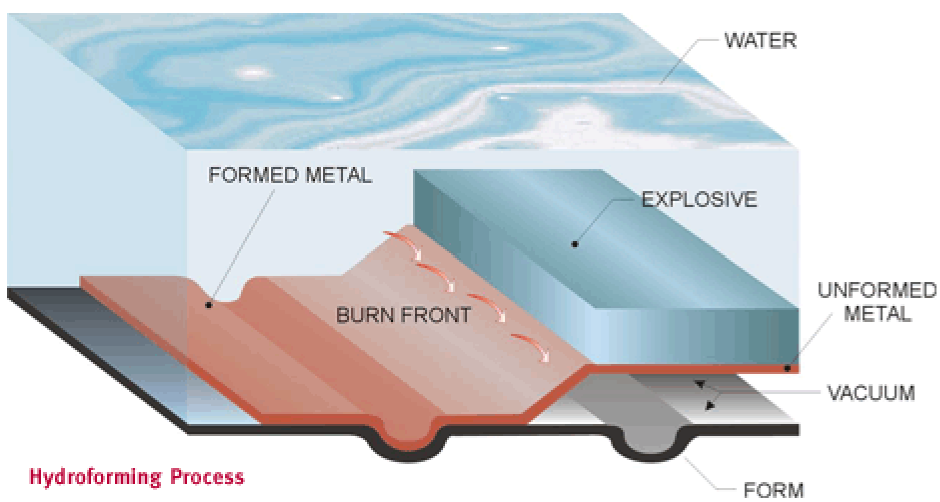
Explosive hydro-forming can offer significant **cost savings** on short-run parts because it often only requires a one-sided tooling die. In the **explosive hydro-forming process**, the water slug applies force evenly over the surface of the work piece, as it forms into the cavity of the forming die.

Explosive hydro-forming can also efficiently **form large parts**. Since the power generation comes from an explosive charge, you don't need larger machinery to form large parts, you simply apply a larger charge. Current explosively hydro-formed parts range up to 6 feet.

Benefits of Explosive Forming

Explosive-forming has many benefits. It employs lower tooling costsn and uses stamping type applications which only require a **one-sided tooling die**. Explosive energy can be transmitted differently across the part, in order to concentrate force onto specific forming features. It has a large size capability and is **suited to difficult configurations**.

Explosively-formed parts can range **up to 6 feet** and have very few limitations. Explosive-forming can simulate many aspects of all other conventional forming methods, without their respective limitations.

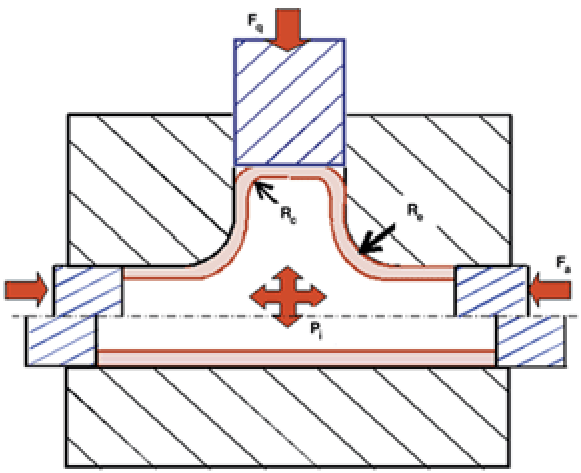


Tubular hydroforming

Many factors come into play when attempting to execute a production hydroforming operation, among them material selection, friction and lubricants, tube bending and preforming, and equipment. Many companies in the automotive sector are experiencing great success with the process, which can reduce weight, overall costs, and the number of parts per vehicle.

Tube hydroforming has been well-known since the 1950s. However, with recent advancements in computer controls and high-pressure hydraulic systems, the process has become a viable method for mass production, especially with the use of internal pressures of up to 6,000 pounds per square inch (PSI).

Modern machines have independent control of axial feeding, internal pressure, and counterpressure (see **Figure 1**), which increases the material-shaping capability of the process tremendously over other, more traditional forming methods.



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Numerous applications of hydroforming can be seen in exhaust manifolds made of stainless steel tubes. The BMW 5 series features a hydroformed aluminum rear axle. Seam welded tubes from 5000 series aluminum alloys were selected for this product because of the complications and distortions that resulted from annealing of 6000 series alloys.

In addition, Volvo Car Corp. has selected the front end of the Volvo 850 to conduct a research and development project with hydroform-intensive aluminum-based frame construction. Volvo has reported 50 percent less weight, 45 percent fewer parts, 45 percent fewer weld seams, and tighter tolerances compared to its conventional body-inwhite designs.

The process sequence for a typical hydroforming operation follows the progression illustrated in **Figure 3**. Fluid pressure within the tube is increased after the die closes to force the material into the deformation zone. During this process, axial feeding and internal pressure are controlled simultaneously to improve the process's material-shaping capabilities.

When hydroforming extruded aluminum profiles, stretching a tube's cross section beyond its yield point (2 to 3 percent elongation) is required to prevent springback and achieve tight tolerances. Having flanges and webs in the extruded tube makes the die geometry and sealing more complicated. In many cases, a large amount of axial feeding is not possible.

Advantages and Disadvantages of Hydroforming

Tube hydroforming allows engineers to optimize their designs through cross sectional reshaping and perimeter expansion. Combined with the ability to inexpensively create the holes that are required for vehicle subsystem interfaces, hydroforming has become a critical technology for structural components in mass-produced vehicles.

Hydroforming tubular components offers several advantages, including:

1. Part consolidation.
2. Weight reduction through more efficient section design and tailoring of the wall thickness.
3. Improved structural strength and stiffness.
4. Lower tooling cost as a result of fewer parts.

5. Fewer secondary operations.
6. Tight dimensional tolerances and low springback.
7. Reduced scrap.

Hydroforming also has some drawbacks, including:

1. Slow cycle time.
2. Expensive equipment.
3. Lack of extensive knowledge base for process and tool design.

Therefore, the feasibility of hydroforming has to be investigated from both an economic and mechanical standpoint for each individual part. To reduce cycle times, secondary operations, such as piercing, need to be integrated with the hydroforming process. Computer simulation of the hydroforming process also can and should be used to evaluate the limits of deformation

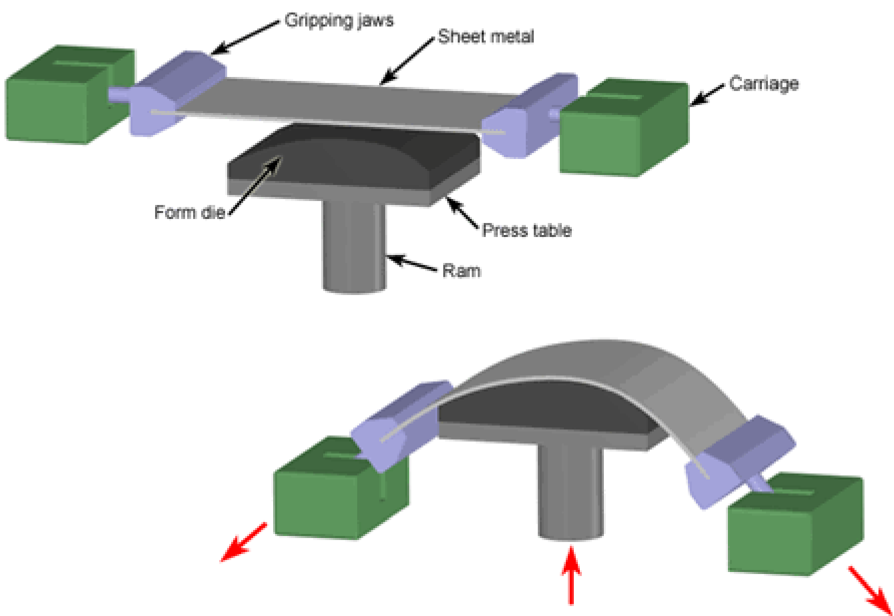
Factors Affecting the Tube Hydroforming Process

As hydroforming becomes more widely used, several issues must be addressed to increase the implementation of this technology in the stamping industry. These issues include:

1. Preparation of tubes, which involves material selection and quality of the incoming tube.
2. Preform design and production method.
3. Part design for hydroforming.
4. Welding and assembly of hydroformed components - - that is, fixturing and joining.
5. Crush performance and joint stiffness.
6. Selection of a lubricant that does not break down at high pressures.
7. Rapid process development.

STRETCH FORMING

Stretch forming is a metal forming process in which a piece of sheet metal is stretched and bent simultaneously over a die in order to form large contoured parts. Stretch forming is performed on a stretch press, in which a piece of sheet metal is securely gripped along its edges by gripping jaws. The gripping jaws are each attached to a carriage that is pulled by pneumatic or hydraulic force to stretch the sheet. The tooling used in this process is a stretch form block, called a form die, which is a solid contoured piece against which the sheet metal will be pressed. The most common stretch presses are oriented vertically, in which the form die rests on a press table that can be raised into the sheet by a hydraulic ram. As the form die is driven into the sheet, which is gripped tightly at its edges, the tensile forces increase and the sheet plastically deforms into a new shape. Horizontal stretch presses mount the form die sideways on a stationary press table, while the gripping jaws pull the sheet horizontally around the form die.



Stretch Forming

Stretch formed parts are typically large and possess large radius bends. The shapes that can be produced vary from a simple curved surface to complex non-uniform cross sections. Stretch forming is capable of shaping parts with very high accuracy and smooth surfaces. Ductile materials are preferable, the most commonly used being aluminum, steel, and titanium. Typical stretch formed parts are large curved panels such as door panels in cars or wing panels on aircraft. Other stretch formed parts can be found in window frames and enclosures.

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