BULK DEFORMATION PROCESSES

EXTRUSION

- Extrusion is a compression process in which the work metal is forced to flow through a die opening to produce a desired cross-sectional shape.
- The process can be likened to squeezing toothpaste out of a toothpaste tube.

Advantages:

(1) a variety of shapes are possible, especially with hot extrusion;

(2) grain structure and strength properties are enhanced in cold and warm extrusion;

(3) fairly close tolerances are possible, especially in cold extrusion;

(4) little or no wasted material is created in some extrusion operations

There are two types of extrusion:

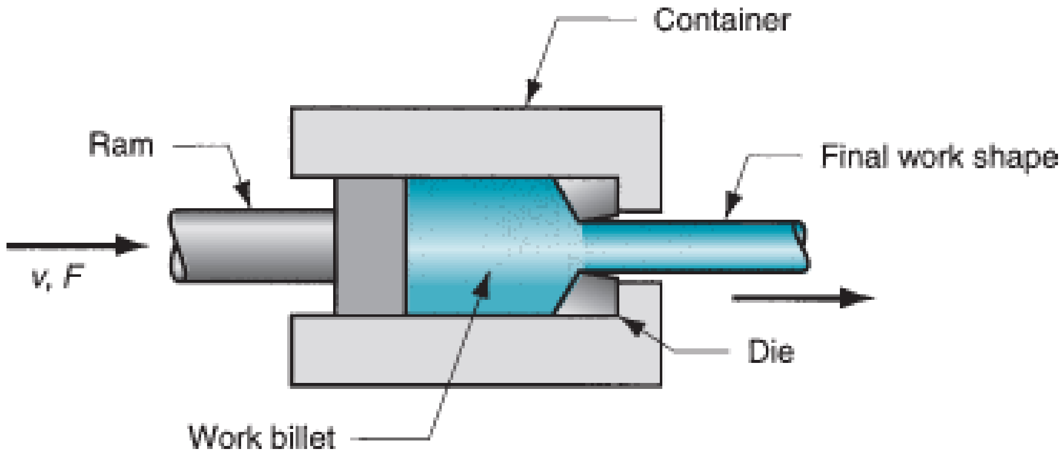
❖ Direct and indirect.

BULK DEFORMATION PROCESSES

EXTRUSION

Direct extrusion

- A metal billet is loaded into a container, and a ram compresses the material, forcing it to flow through one or more openings in a die at the opposite end of the container.
- As the ram approaches the die, a small portion of the billet remains that cannot be forced through the die opening. This extra portion, called the butt, is separated from the product by cutting it just beyond the exit of the die.



Direct extrusion

BULK DEFORMATION PROCESSES

EXTRUSION

Direct extrusion

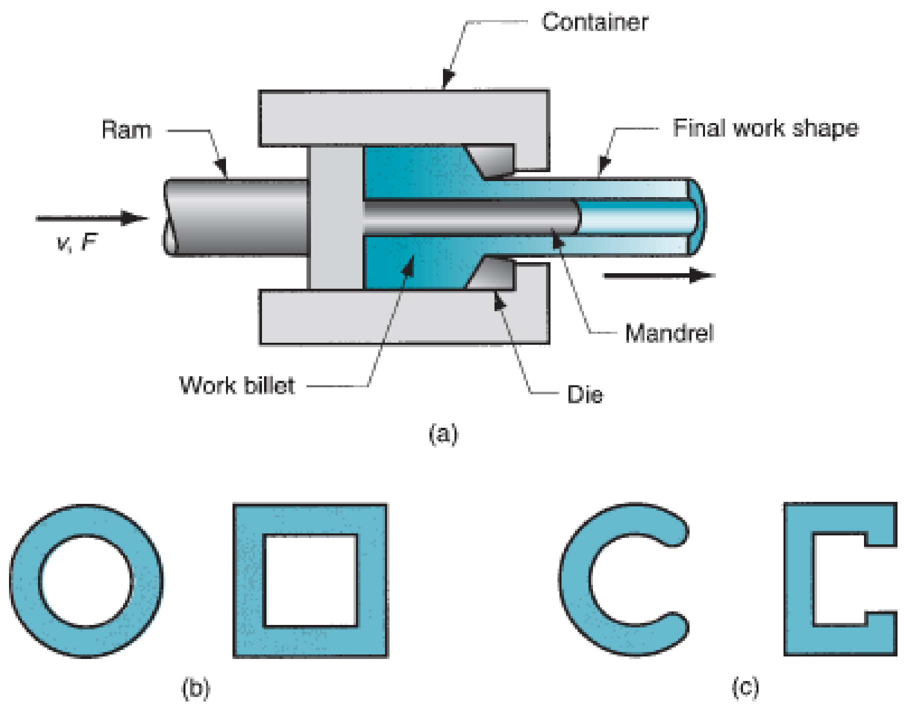
- The starting billet in direct extrusion is usually round in cross section, but the final shape is determined by the shape of the die opening.
- The largest dimension of the die opening must be smaller than the diameter of the billet.
- One of the problems in direct extrusion is the significant friction that exists between the work surface and the walls of the container as the billet is forced to slide toward the die opening.
- This friction causes a substantial increase in the ram force required in direct extrusion.

BULK DEFORMATION PROCESSES

EXTRUSION

Direct extrusion

- Hollow sections (e.g., tubes) are possible in direct extrusion
- The starting billet is prepared with a hole parallel to its axis. This allows passage of a mandrel that is attached to the dummy block. As the billet is compressed, the material is forced to flow through the clearance between the mandrel and the die opening. The resulting cross section is tubular. Semi-hollow cross-sectional shapes are usually extruded in the same way.



(a) Direct extrusion to produce a hollow or semi-hollow cross section; (b) hollow and (c) semi-hollow cross sections.

BULK DEFORMATION PROCESSES

EXTRUSION

Indirect extrusion

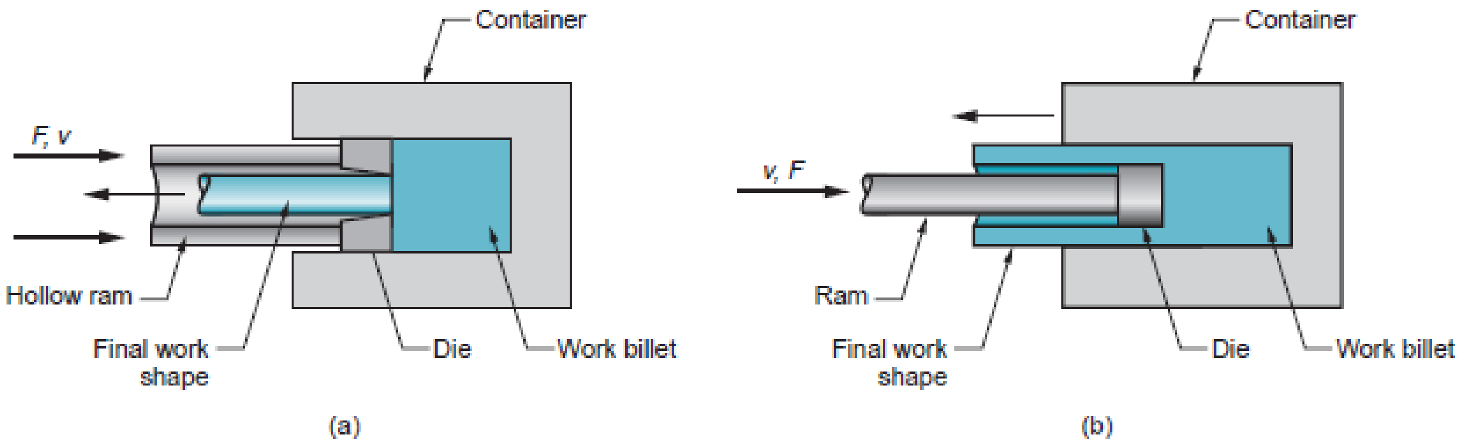
- The die is mounted to the ram rather than at the opposite end of the container.
- As the ram penetrates into the work, the metal is forced to flow through the clearance in a direction opposite to the motion of the ram.
- Since the billet is not forced to move relative to the container, there is no friction at the container walls, and the ram force is therefore lower than in direct extrusion.

BULK DEFORMATION PROCESSES

EXTRUSION

Indirect extrusion

- Indirect extrusion can produce hollow (tubular) cross sections.
- In this method, the ram is pressed into the billet, forcing the material to flow around the ram and take a cup shape.
- There are practical limitations on the length of the extruded part that can be made by this method. Support of the ram becomes a problem as work length increases.



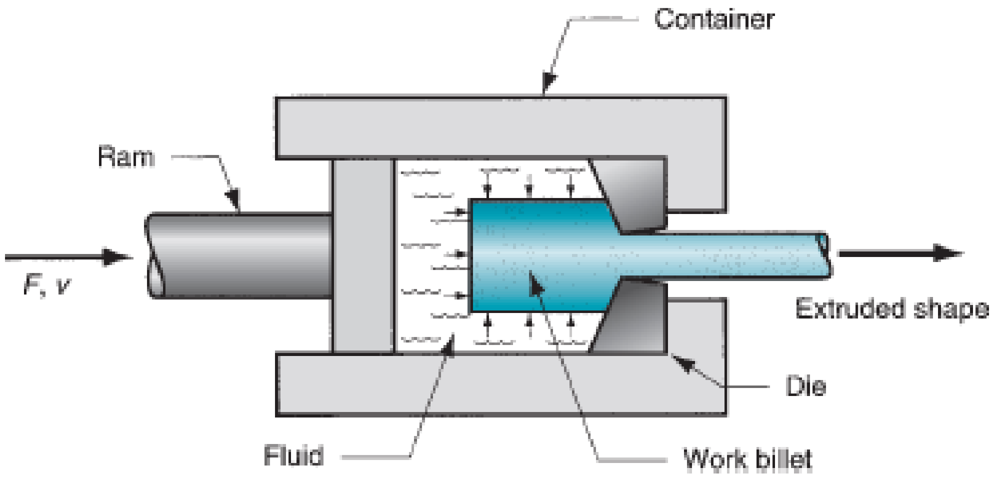
Indirect extrusion to produce (a) a solid cross section and (b) a hollow cross section

BULK DEFORMATION PROCESSES

EXTRUSION

Hydrostatic extrusion

- One of the problems in direct extrusion is friction along the billet– container interface.
- This problem can be addressed by surrounding the billet with fluid inside the container and pressurizing the fluid by the forward motion of the ram.
- No friction inside the container, and friction at the die opening is reduced.
- Consequently, ram force is significantly lower than in direct extrusion.
- Hydrostatic extrusion is an adaptation of direct extrusion.



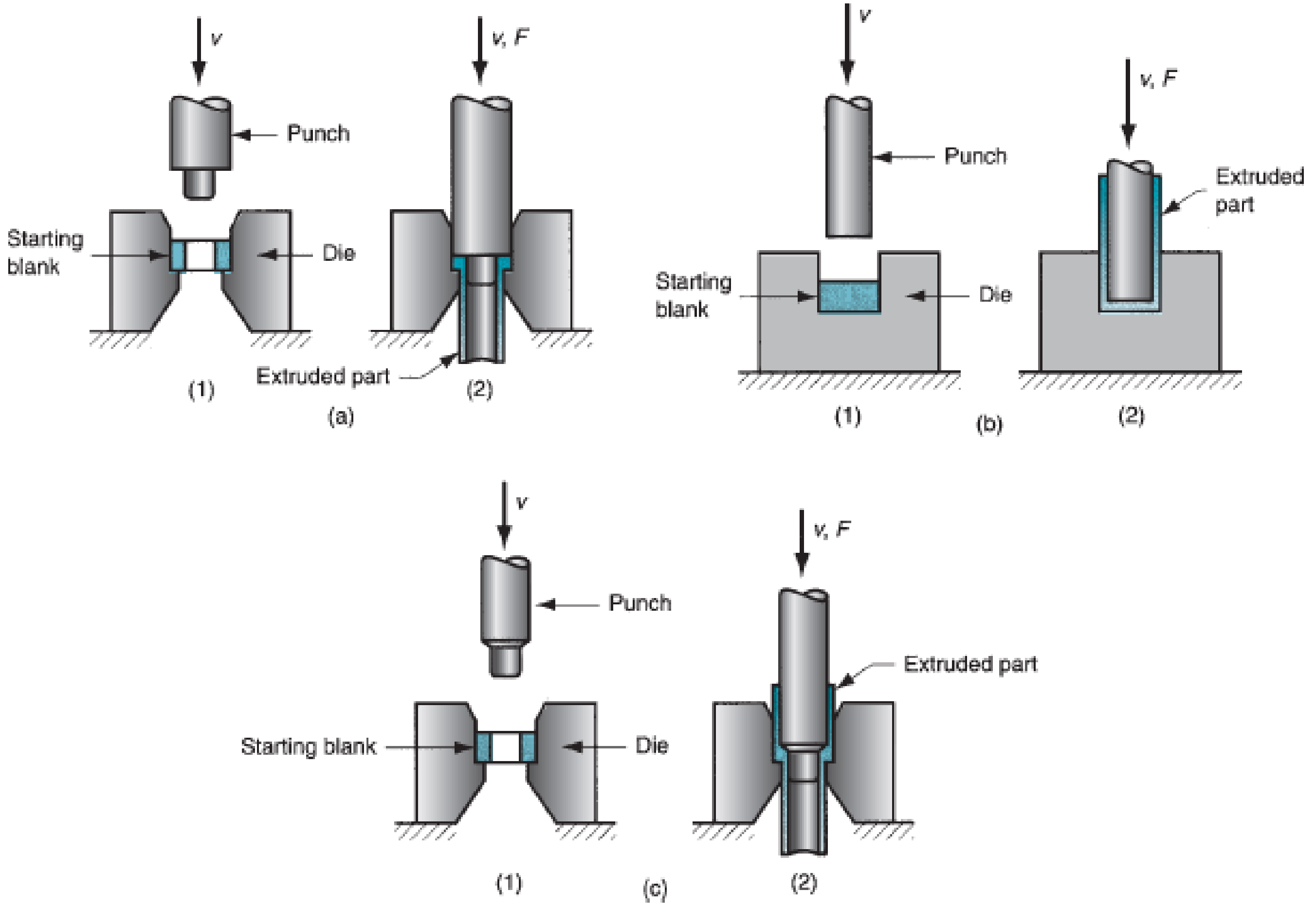
Hydrostatic extrusion

BULK DEFORMATION PROCESSES

EXTRUSION

Impact extrusion

- Impact extrusion is performed at higher speeds and shorter strokes than conventional extrusion.
- It is used to make individual components.
- The punch impacts the workpart rather than simply applying pressure to it



Several examples of impact extrusion: (a) forward, (b) backward, and (c) combination of forward and backward

BULK DEFORMATION PROCESSES

ANALYSIS of EXTRUSION

Extrusion ratio (reduction ratio)

$$r_x = \frac{A_0}{A_f}$$

The ratio applies for both direct and indirect extrusion

r_x = extrusion ratio;

A_o = cross-sectional area of the starting billet, mm^2

A_f = final cross-sectional area of the extruded section, mm^2

$$\epsilon = \ln r_x = \ln \frac{A_o}{A_f}$$

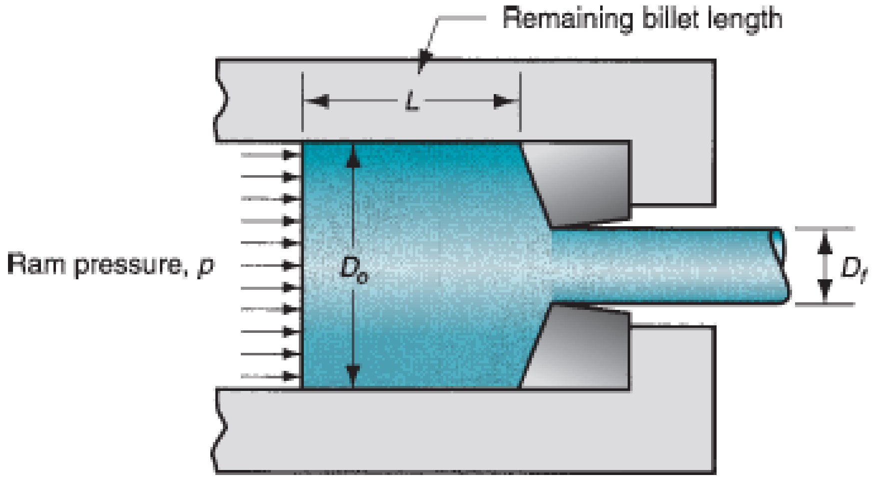
$$\overline{Y}_f = \frac{K\epsilon^n}{1+n}$$

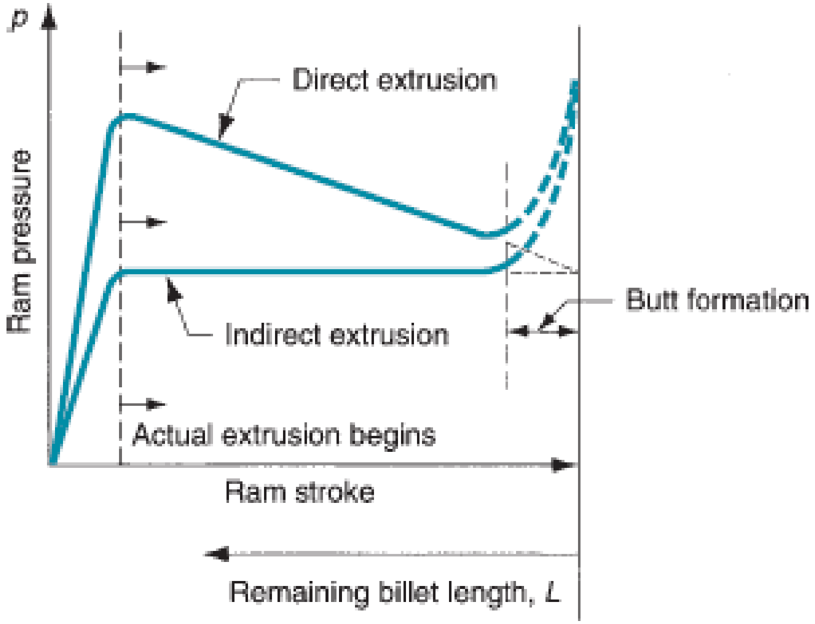
$$p = \overline{Y}_f \ln r_x$$

Extrusion is not a frictionless process, and the previous equations underestimate the strain and pressure in an extrusion operation

BULK DEFORMATION PROCESSES

ANALYSIS of EXTRUSION



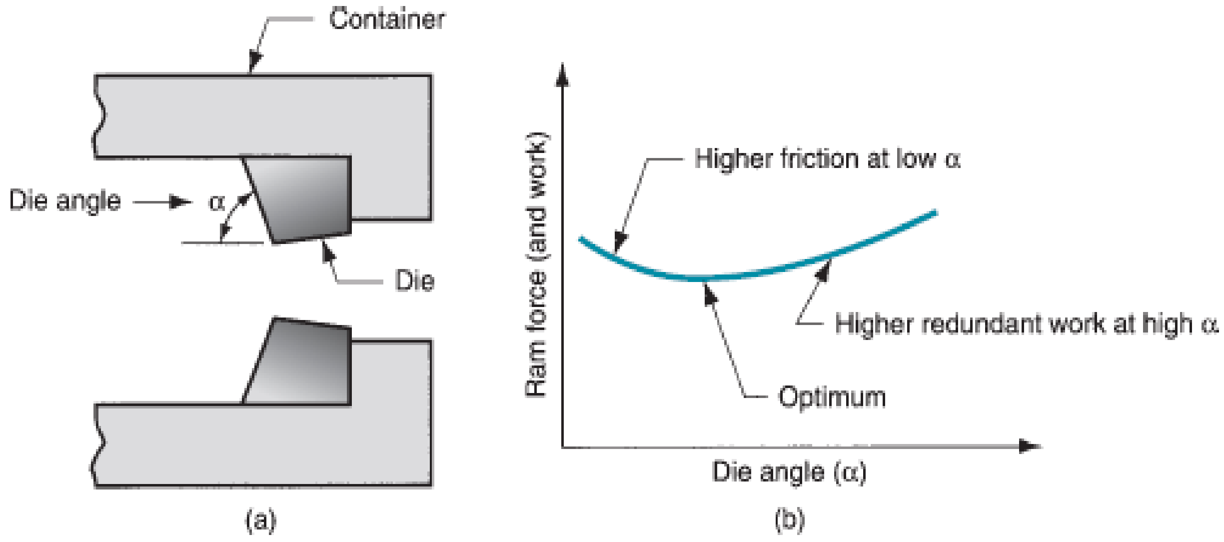


Typical plots of ram pressure versus ram stroke (and remaining billet length) for direct and indirect extrusion. The higher values in direct extrusion result from friction at the container wall. The shape of the initial pressure buildup at the beginning of the plot depends on die angle (higher die angles cause steeper pressure buildups). The pressure increase at the end of the stroke is related to formation of the butt.

BULK DEFORMATION PROCESSES

EXTRUSION DIES and PRESSES

- For low angles, surface area of the die is large, leading to increased friction at the die–billet interface. Higher friction results in larger ram force.
- On the other hand, a large die angle causes more turbulence in the metal flow during reduction, increasing the ram force required.
- The optimum angle depends on various factors (e.g., work material, billet temperature, and lubrication) and is therefore difficult to determine for a given extrusion job.

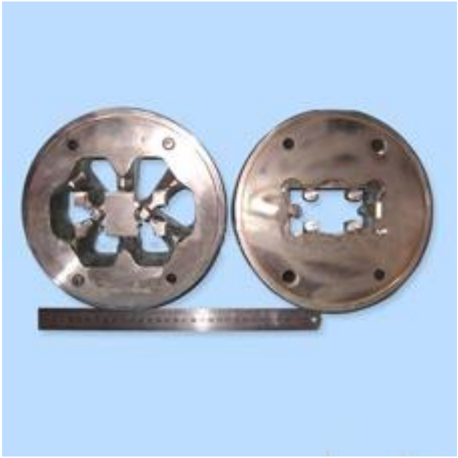


(a) Definition of die angle in direct extrusion;
(b) effect of die angle on ram force.

BULK DEFORMATION PROCESSES

EXTRUSION DIES and PRESSES

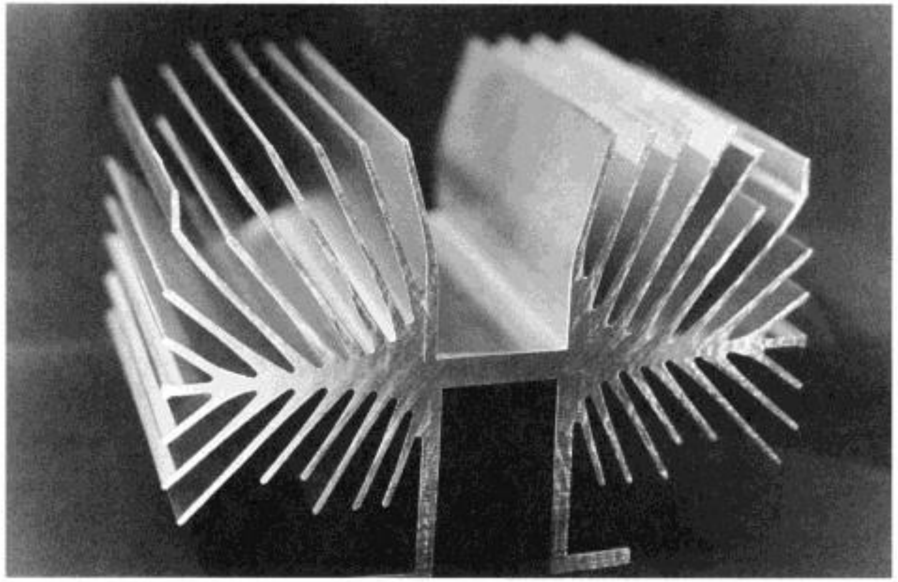
- Die materials used for hot extrusion include tool and alloy steels. Important properties of these die materials include high wear resistance, high hot hardness, and high thermal conductivity to remove heat from the process.
- Die materials for cold extrusion include tool steels and cemented carbides.



BULK DEFORMATION PROCESSES

EXTRUSION DIES and PRESSES

- Extrusion presses are either horizontal or vertical, depending on orientation of the work axis.
- Horizontal types are more common. Extrusion presses are *usually hydraulically driven*. This drive is especially suited to semi continuous production of long sections, as in direct extrusion.
- Mechanical drives are often used for cold extrusion of individual parts, such as in impact extrusion.



A complex extruded cross section for a heat sink

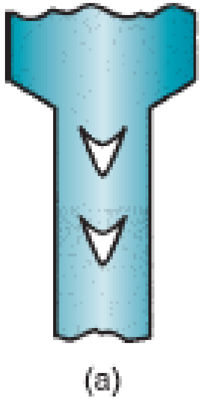
Various extruded parts

BULK DEFORMATION PROCESSES

DEFECTS in EXTRUDED PRODUCTS

Centerburst (Chevron cracks)

- This defect is an internal crack that develops as a result of tensile stresses along the centerline of the work part during extrusion.
- The significant material movement in these outer regions stretches the material along the center of the work. If stresses are great enough, bursting occurs.
- Conditions that promote center burst are *high die angles*, *low extrusion ratios*, and *impurities in the work metal* that serve as starting points for crack defects.
- The difficult aspect of center burst is its detection. It is an internal defect that is usually not noticeable by visual observation.



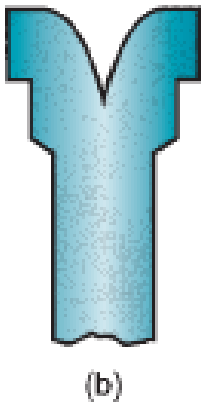
Some common defects in extrusion: (a) centerburst

BULK DEFORMATION PROCESSES

DEFECTS in EXTRUDED PRODUCTS

Piping (Tailpipe)

- Piping is a defect associated with direct extrusion.
- It is the formation of a sink hole in the end of the billet. The use of a dummy block whose diameter is slightly less than that of the billet helps to avoid piping.



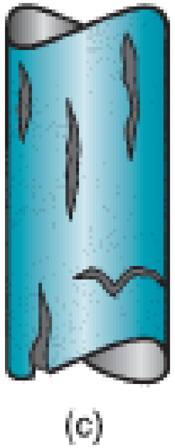
Some common defects in extrusion: (b) piping

BULK DEFORMATION PROCESSES

DEFECTS in EXTRUDED PRODUCTS

Surface cracking

- This defect results from high workpart temperatures that cause cracks to develop at the surface.
- They often occur when *extrusion speed is too high*, leading to high strain rates and associated heat generation.
- Other factors contributing to surface cracking are *high friction* and *surface chilling of high temperature billets in hot extrusion*.

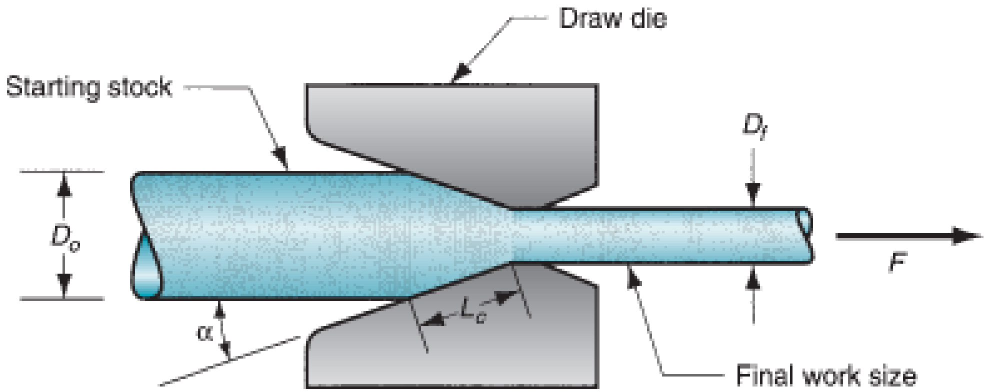


Some common defects in extrusion: (c) surface cracking.

BULK DEFORMATION PROCESSES

WIRE and BAR DRAWING

- Drawing is an operation in which the cross section of a bar, rod, or wire is reduced by pulling it through a die opening.
- The general features of the process are similar to those of extrusion. The difference is that the work is pulled through the die in drawing, whereas it is pushed through the die in extrusion.
- Although the presence of tensile stresses is obvious in drawing, compression also plays a significant role because the metal is squeezed down as it passes through the die opening. For this reason, the deformation that occurs in drawing is sometimes referred to as indirect compression.



BULK DEFORMATION PROCESSES

WIRE and BAR DRAWING

- The basic difference between bar drawing and wire drawing is the stock size that is processed. Bar drawing is the term used for large diameter bar and rod stock, while wire drawing applies to small diameter stock.
- Wire sizes down to 0.03 mm are possible in wire drawing.

$$r = \frac{A_o - A_f}{A_o}$$

r = area reduction in drawing

A_o = original area of work, mm^2

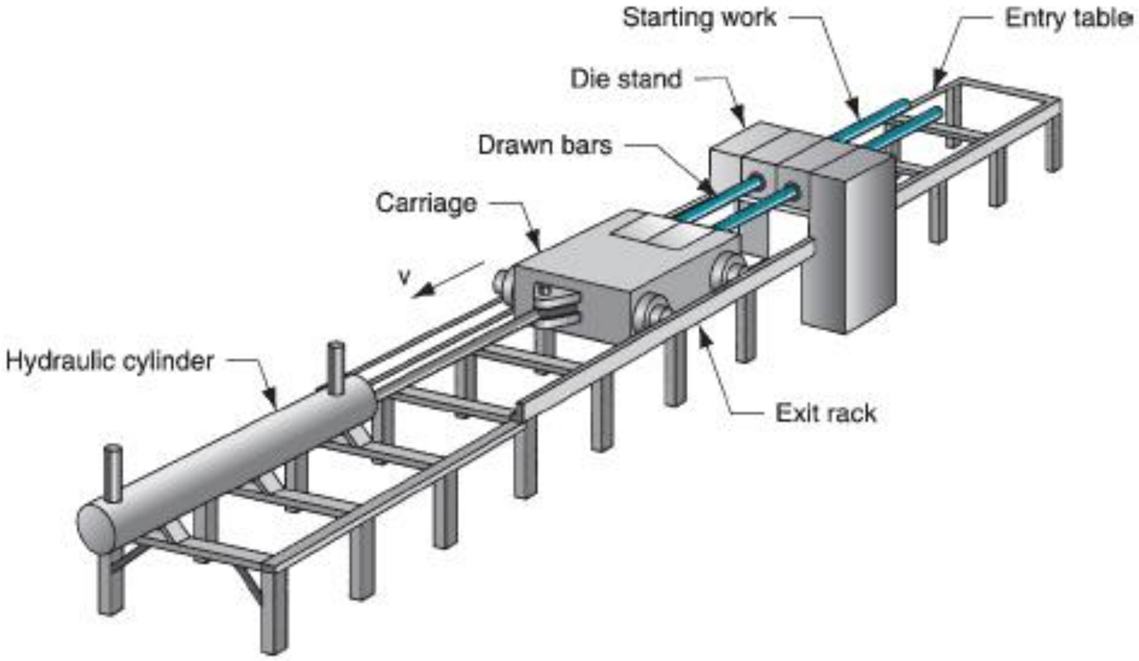
A_f = final area, mm^2

The ***draft*** is simply the difference between original and final stock diameters

$$d = D_o - D_f$$

BULK DEFORMATION PROCESSES

BAR DRAWING

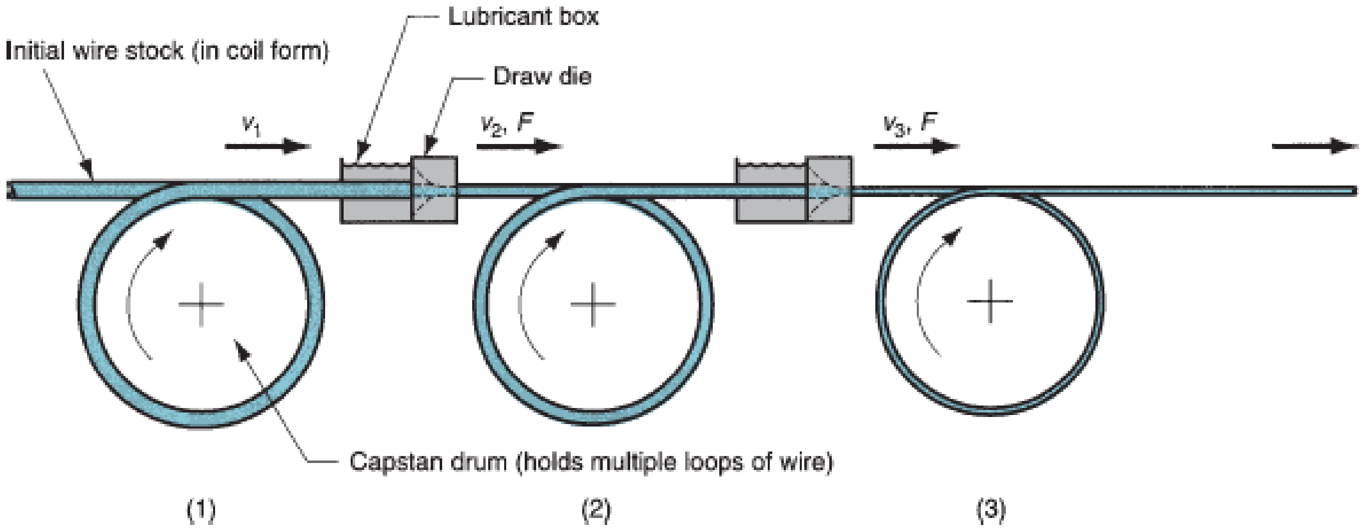


Hydraulically operated draw bench for drawing metal bars

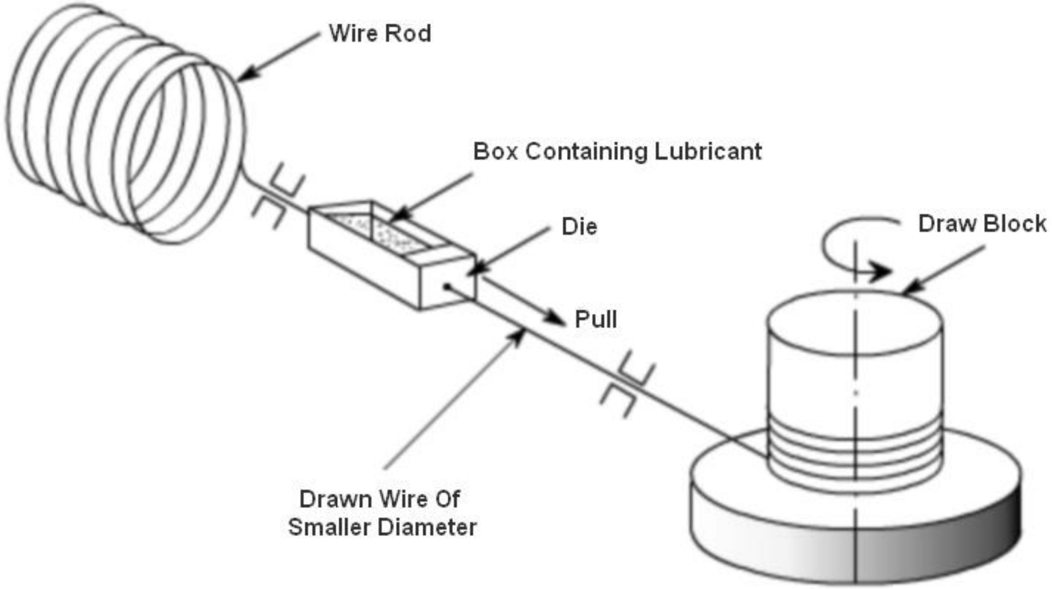
BULK DEFORMATION PROCESSES

WIRE DRAWING

- Wire drawing is done on continuous drawing machines that consist of multiple draw dies, separated by accumulating drums between the dies.
- Each drum, called a capstan, is motor driven to provide the proper pull force to draw the wire stock through the upstream die.
- Each die provides a certain amount of reduction in the wire, so that the *desired total reduction is achieved by the series*. Depending on the metal to be processed and the total reduction, *annealing of the wire is sometimes required* between groups of dies in the series.



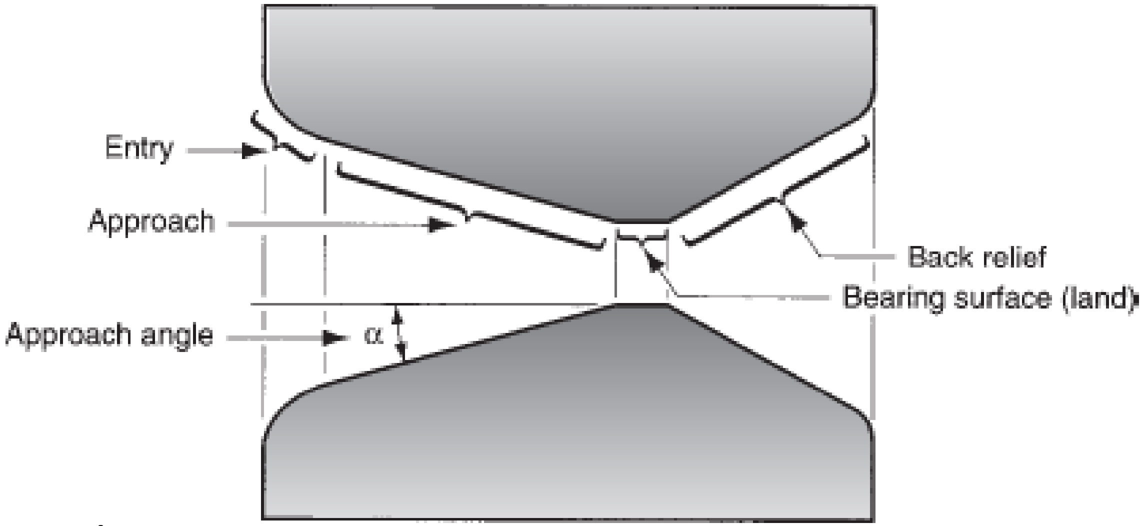
Continuous drawing of wire



BULK DEFORMATION PROCESSES

DRAW DIES

Four regions of the die can be distinguished: (1) entry, (2) approach angle, (3) bearing surface (land), and (4) back relief.



- The *entry region* is usually a bell-shaped mouth that does not contact the work. Its purpose is to funnel the lubricant into the die and prevent scoring of work and die surfaces.
- The *approach* is where the drawing process occurs. It is cone-shaped with an angle (halfangle) normally ranging from about 6° to 20°.
- The *bearing surface*, or land, determines the size of the final drawn stock.
- Finally, the *back relief* is the exit zone.

BULK DEFORMATION PROCESSES

PREPARATION of the WORK in WIRE DRAWING

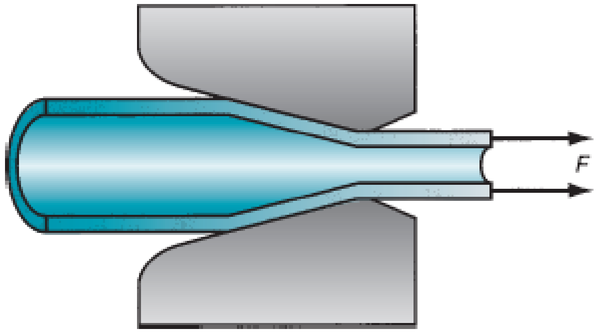
This involves three steps: (1) annealing, (2) cleaning, and (3) pointing.

- The purpose of ***annealing*** is to increase the ductility of the stock to accept deformation during drawing. Annealing is sometimes needed between steps in continuous drawing.
- ***Cleaning*** of the stock is required to prevent damage of the work surface and draw die. It involves removal of surface contaminants (e.g., scale and rust) by means of chemical pickling or shot blasting.
- ***Pointing*** involves the reduction in diameter of the starting end of the stock so that it can be inserted through the draw die to start the process.

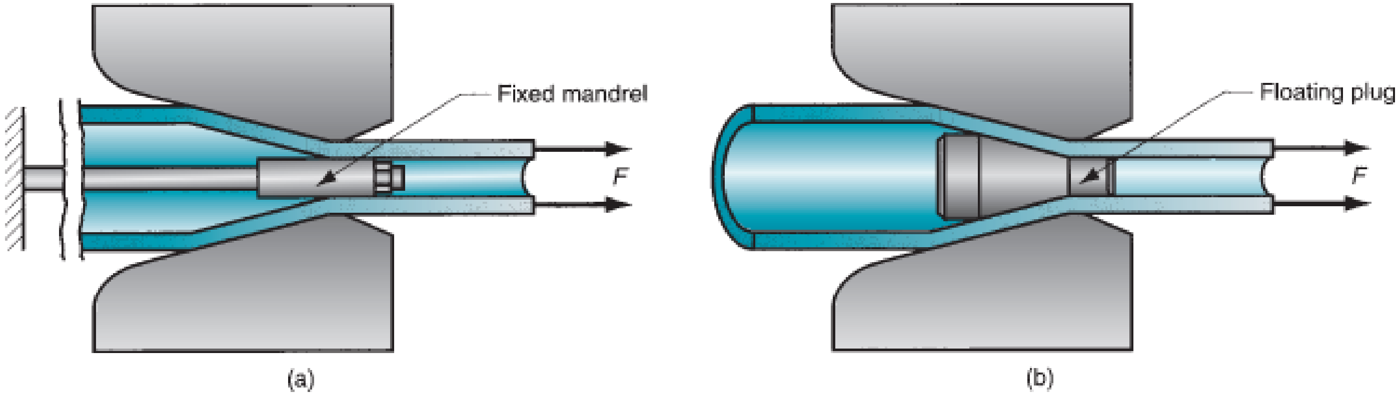
BULK DEFORMATION PROCESSES

TUBE DRAWING

Drawing can be used to reduce the diameter or wall thickness of seamless tubes and pipes, after the initial tubing has been produced by some other process such as extrusion.



Tube drawing with no mandrel (tube sinking)



Tube drawing with mandrels: (a) fixed mandrel, (b) floating plug

SHEET METALWORKING

- Sheet metalworking includes cutting and forming operations performed on relatively thin sheets of metal. Typical *sheet-metal thicknesses* are between *0.4 mm and 6 mm*.
- When thickness exceeds about 6 mm, the stock is usually referred to as plate rather than sheet.
- The sheet or plate stock used in sheet metalworking is produced by *flat rolling*.
- The most commonly used sheet metal is low carbon steel (0.06%–0.15% C typical).

Industrial Products of Sheet or Plate Metal Parts:

  - ❖ Automobile and truck bodies, airplanes, railway cars, locomotives, farm and construction equipment, appliances, office furniture

- Sheet-metal processing is usually performed at room temperature (cold working).

SHEET METALWORKING

- Most sheet-metal operations are performed on machine tools called presses.
- The term ***stamping press*** is used to distinguish these presses from forging and extrusion presses.
- The ***tooling*** that performs sheet metalwork is called a ***punch-and-die***; the term stamping die is also used.
- The sheet-metal products are called stampings.

The three major categories of sheet-metal processes:

(1) cutting, (2) bending, and (3) drawing.

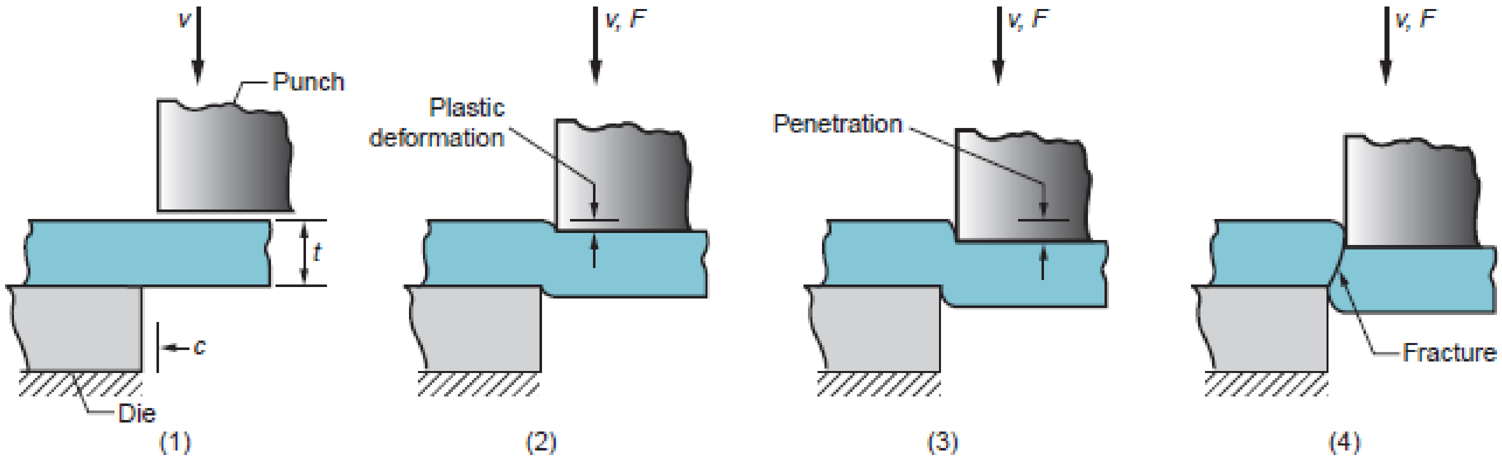
SHEET METALWORKING

CUTTING OPERATIONS

- Cutting of sheet metal is accomplished by a shearing action between two sharp cutting edges.
- As the punch begins to push into the work, plastic deformation occurs in the surfaces of the sheet.
- As the punch moves downward, penetration occurs in which the punch compresses the sheet and cuts into the metal. This penetration zone is generally about one-third the thickness of the sheet.
- As the punch continues to travel into the work, fracture is initiated in the work at the two cutting edges.

SHEET METALWORKING

CUTTING OPERATIONS



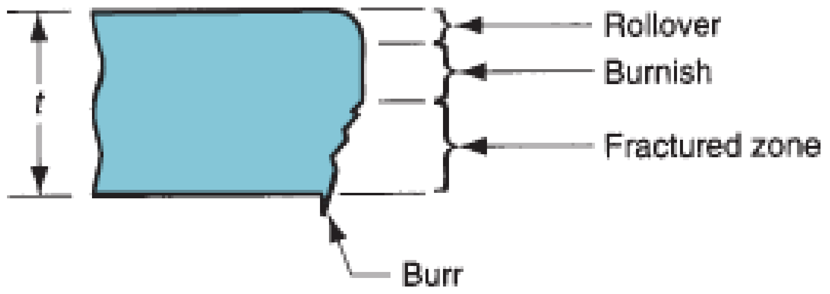
Shearing of sheet metal between two cutting edges: (1) just before the punch contacts work; (2) punch begins to push into work, causing plastic deformation; (3) punch compresses and penetrates into work causing a smooth cut surface; and (4) fracture is initiated at the opposing cutting edges that separate the sheet.
Symbols v and F indicate motion and applied force, respectively, t = stock thickness, c = clearance

SHEET METALWORKING

CUTTING OPERATIONS

The sheared edges of the sheet have characteristic features.

- At the top of the cut surface is a region called the *rollover*. This corresponds to the *depression made by the punch in the work prior to cutting*. It is where initial plastic deformation occurred in the work.
- Just below the rollover is a relatively *smooth region* called the *burnish*. This results from penetration of the punch into the work before fracture began.
- Beneath the burnish is the *fractured zone*, a *relatively rough surface of the cut edge* where continued downward movement of the punch caused fracture of the metal.
- Finally, at the bottom of the edge is a *burr*, a *sharp corner on the edge caused by elongation of the metal during final separation* of the two pieces.

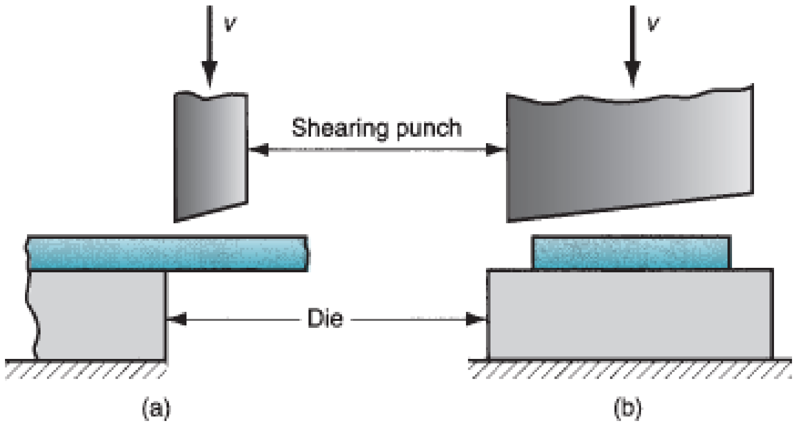


SHEET METALWORKING

CUTTING OPERATIONS

SHEARING, BLANKING, AND PUNCHING

- ***Shearing*** is a sheet-metal cutting operation along a straight line between two cutting edges.
- Shearing is typically used to cut large sheets into smaller sections for subsequent pressworking operations. It is performed on a machine called a power shears, or squaring shears.
- The upper blade of the power shears is often inclined.



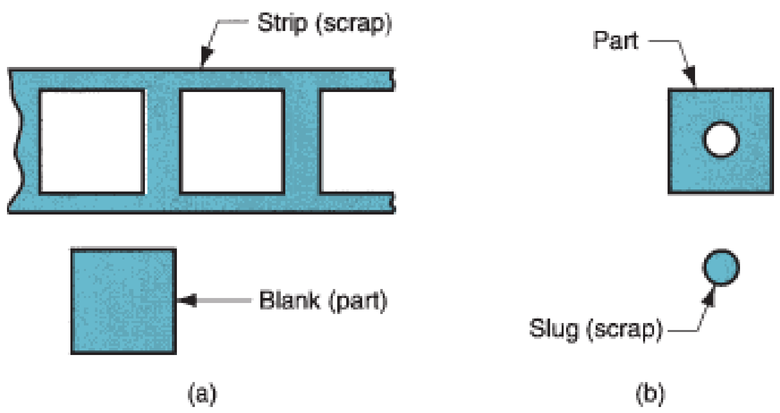
Shearing operation: (a) side view of the shearing operation; (b) front view of power shears equipped with inclined upper cutting blade. Symbol v indicates motion.

SHEET METALWORKING

CUTTING OPERATIONS

SHEARING, BLANKING, AND PUNCHING

- ***Blanking*** involves cutting of the sheet metal along a closed outline in a single step to separate the piece from the surrounding stock. The part that is cut out is the desired product in the operation and is called the blank.
- ***Punching*** is similar to blanking except that it produces a hole, and the separated piece is scrap, called the slug. The remaining stock is the desired part.



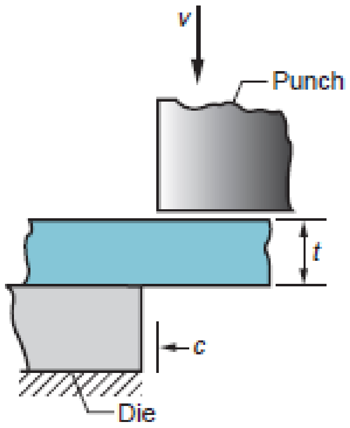
(a) Blanking and (b) punching.

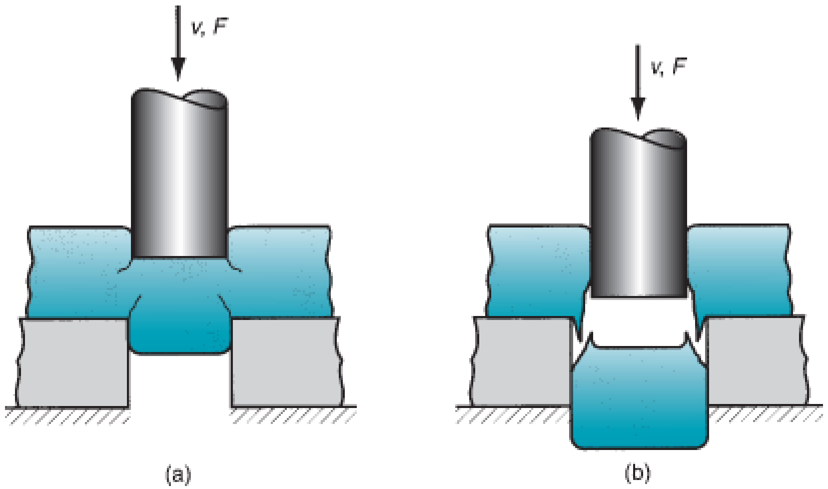
SHEET METALWORKING

CUTTING OPERATIONS

CLEARANCE in SHEET METAL CUTTING

- The clearance ‘c’ in a shearing operation is the distance between the punch and die. Sheet thickness is ‘t’. Typical clearances in conventional pressworking range between 4% and 8% of the sheet-metal thickness t.
- If the clearance is too small, then the fracture lines tend to pass each other, causing a double burnishing and larger cutting forces. If the clearance is too large, the metal becomes pinched between the cutting edges and an excessive burr results.





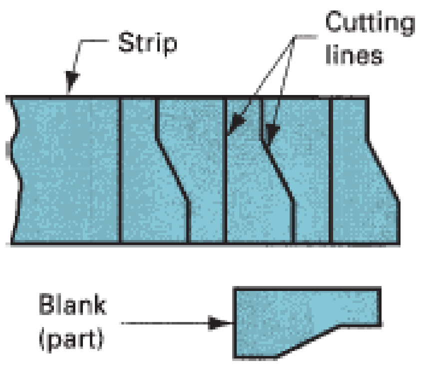
Effect of clearance: (a) clearance too small causes less-than optimal fracture and excessive forces; and (b) clearance too large causes oversized burr. Symbols v and F indicate motion and applied force, respectively.

SHEET METALWORKING

OTHER SHEET METAL CUTTING OPERATIONS

Cutoff and Parting

- ***Cutoff*** is a shearing operation in which blanks are separated from a sheet-metal strip by cutting the opposite sides of the part in sequence. With each cut, a new part is produced.
- The features of a cutoff operation that distinguish it from a conventional shearing operation are (1) the cut edges are not necessarily straight, and (2) the blanks can be nested on the strip in such a way that scrap is avoided.



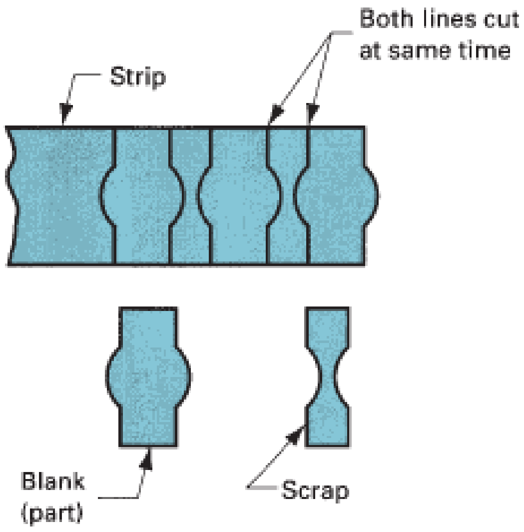
Cutoff

SHEET METALWORKING

OTHER SHEET METAL CUTTING OPERATIONS

Cutoff and Parting

- ***Parting*** involves cutting a sheet-metal strip by a punch with two cutting edges that match the opposite sides of the blank. This might be required because the part outline has an irregular shape that precludes perfect nesting of the blanks on the strip. Parting is less efficient than cutoff in the sense that it results in some wasted material.



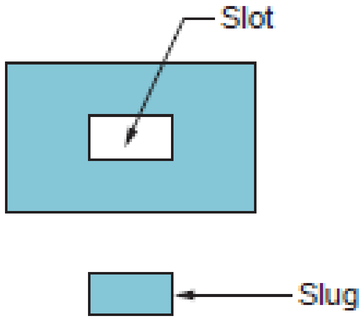
Parting

SHEET METALWORKING

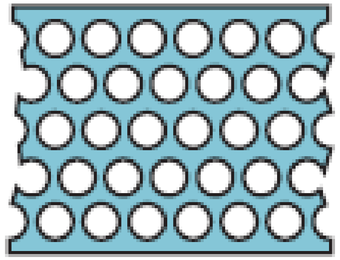
OTHER SHEET METAL CUTTING OPERATIONS

Slotting, Perforating, and Notching

- *Slotting* is the term sometimes used for a punching operation that cuts out an elongated or rectangular hole.
- *Perforating* involves the simultaneous punching of a pattern of holes in sheet metal. The hole pattern is usually for decorative purposes, or to allow passage of light, gas, or fluid.



Slotting



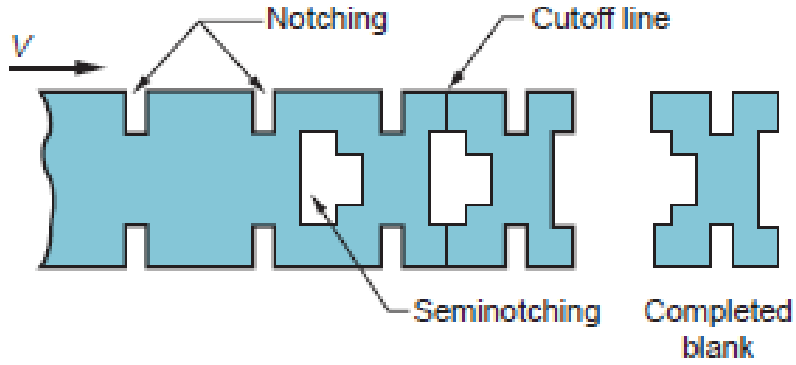
Perforating

SHEET METALWORKING

OTHER SHEET METAL CUTTING OPERATIONS

Slotting, Perforating, and Notching

- To obtain the desired outline of a blank, portions of the sheet metal are often removed by notching and seminotching.
- ***Notching*** involves cutting out a portion of metal from the side of the sheet or strip.
- ***Seminotching*** removes a portion of metal from the interior of the sheet.



Notching and seminotching

SHEET METALWORKING

OTHER SHEET METAL CUTTING OPERATIONS

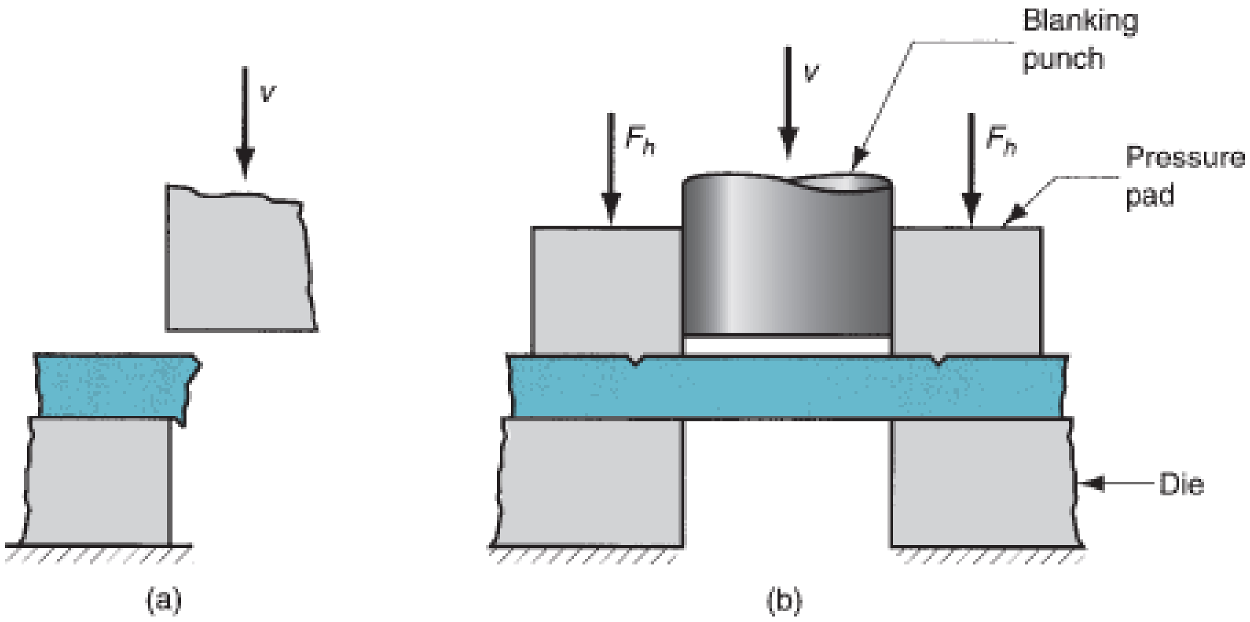
Trimming, Shaving and Fine Blanking

- ***Trimming*** is a cutting operation performed on a formed part to remove excess metal and establish size. A typical example in sheet metalwork is trimming the upper portion of a deep drawn cup to leave the desired dimensions on the cup.
- ***Shaving*** is a shearing operation performed with very small clearance to obtain accurate dimensions and cut edges that are smooth and straight. Shaving is typically performed as a secondary or finishing operation on parts that have been previously cut.
- ***Fine blanking*** is a shearing operation used to blank sheet-metal parts with close tolerances and smooth, straight edges in one step. At the start of the cycle, a pressure pad with a V-shaped projection applies a holding force F_h against the work adjacent to the punch in order to compress the metal and prevent distortion. The punch then descends with a slower-than-normal velocity and smaller clearances to provide the desired dimensions and cut edges.

SHEET METALWORKING

OTHER SHEET METAL CUTTING OPERATIONS

Trimming, Shaving and Fine Blanking

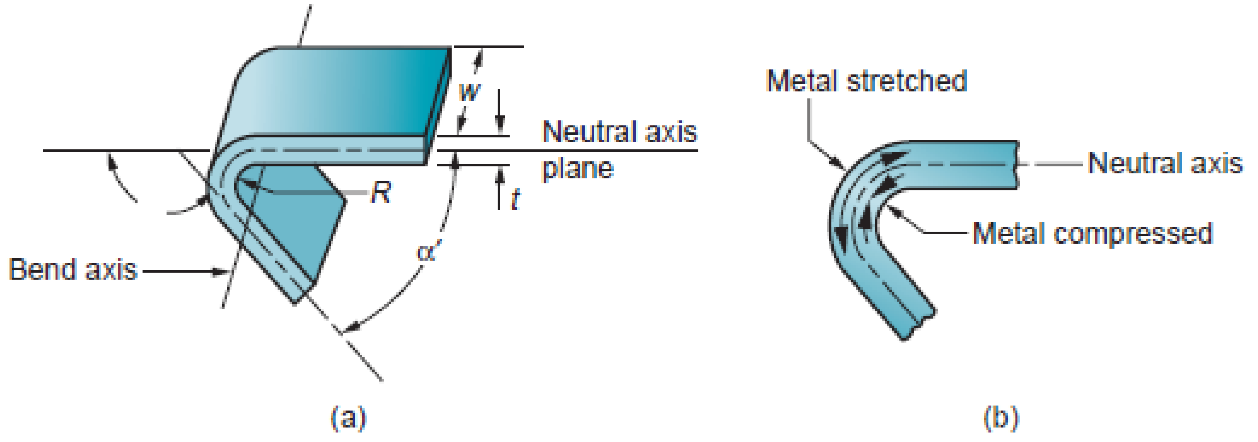


(a) Shaving and (b) fine blanking. Symbols: v = motion of punch, Fh = blank holding force

SHEET METALWORKING

BENDING OPERATIONS

- Bending in sheet-metalwork is defined as the straining of the metal around a straight axis.
- During the bending operation, the metal on the inside of the neutral plane is compressed, while the metal on the outside of the neutral plane is stretched.



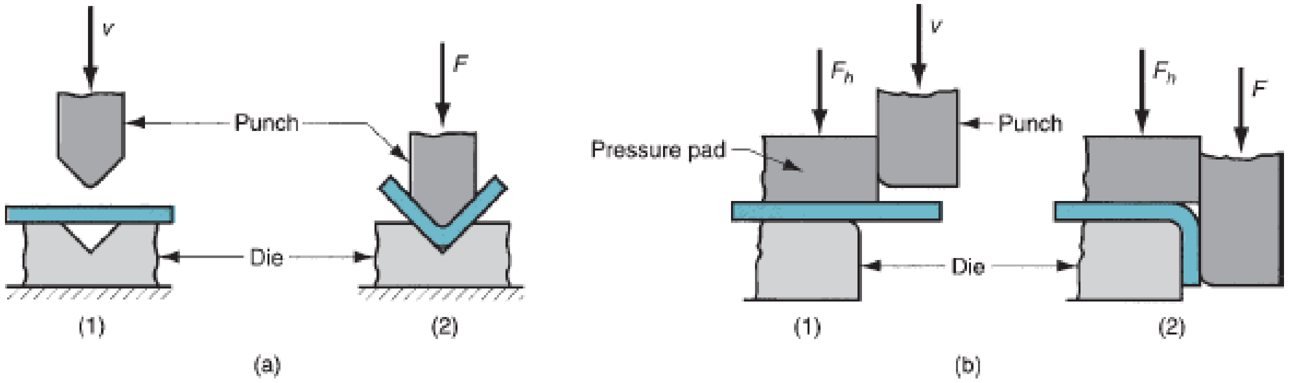
(a) Bending of sheet metal; (b) both compression and tensile elongation of the metal occur in bending

SHEET METALWORKING

BENDING OPERATIONS

V-BENDING AND EDGE BENDING

- The two common bending methods and associated tooling are V-bending, performed with a V-die; and edge bending, performed with a wiping die.
- In V-bending, the sheet metal is bent between a V-shaped punch and die.
- Edge bending involves cantilever loading of the sheet metal. A pressure pad is used to apply a force F_h to hold the base of the part against the die, while the punch forces the part to yield and bend over the edge of the die.



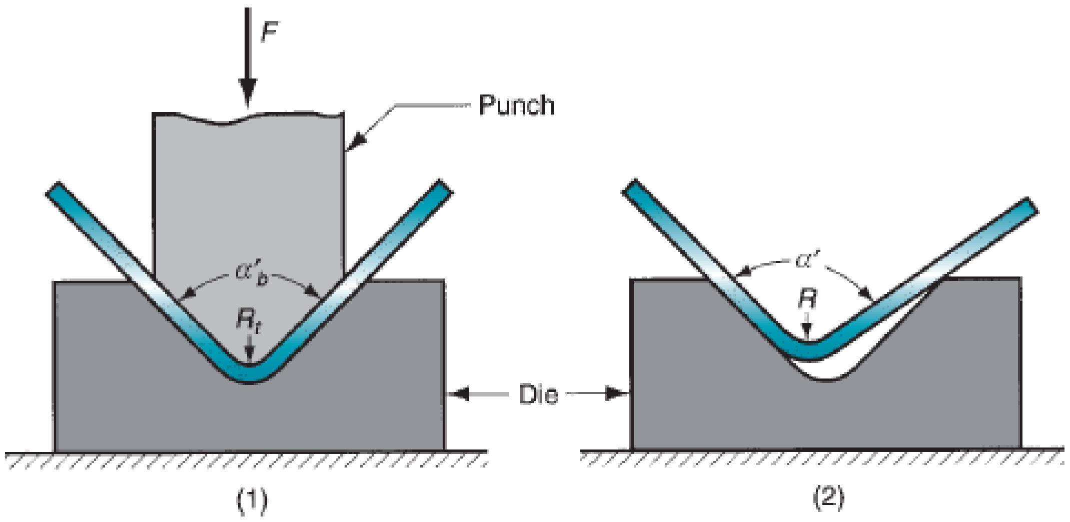
(a) V-bending and (b) edge bending; (1) before and (2) after bending.
Symbols: v = motion, F = applied bending force, F_h = blank

SHEET METALWORKING

BENDING OPERATIONS

Springback

When the bending pressure is removed at the end of the deformation operation, elastic energy remains in the bent part, causing it to recover partially toward its original shape. This elastic recovery is called ***springback***, defined as the increase in included angle of the bent part relative to the included angle of the forming tool after the tool is removed.



Springback in bending shows itself as a decrease in bend angle and an increase in bend radius: (1) during the operation, the work is forced to take the radius R_t and included angle α'_t = determined by the bending tool (punch in V-bending); (2) after the punch is removed, the work springs back to radius R and included angle α'. Symbol : F = applied bending force.

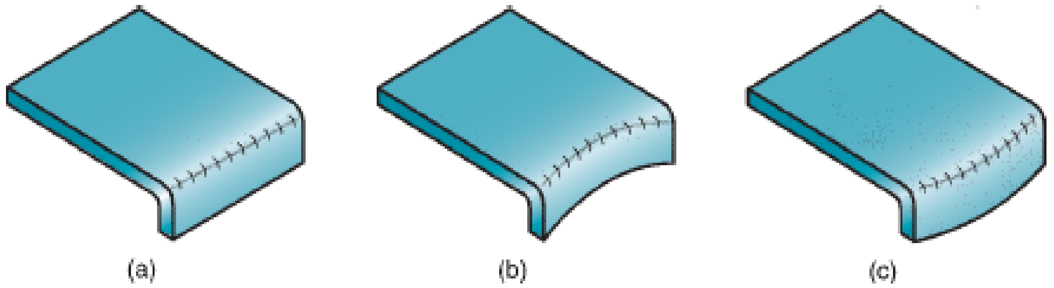
SHEET METALWORKING

BENDING OPERATIONS

OTHER BENDING and FORMING OPERATIONS

Flanging, Hemming, Seaming, and Curling

- ***Flanging*** is a bending operation in which the edge of a sheet-metal part is bent at a 90° angle (usually) to form a rim or flange. It is often used to strengthen or stiffen sheet metal. The flange can be formed over a straight bend axis. It can involve some stretching or shrinking of the metal.



Flanging: (a) straight flanging, (b) stretch flanging, and(c) shrink flanging

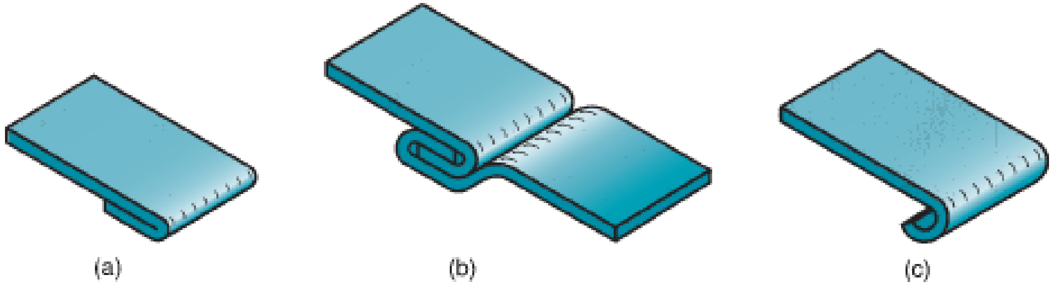
SHEET METALWORKING

BENDING OPERATIONS

OTHER BENDING and FORMING OPERATIONS

Flanging, Hemming, Seaming, and Curling

- ***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 on the piece, to increase stiffness, and to improve appearance. Seaming is a related operation in which two sheet-metal edges are assembled.
- ***Curling***, also called beading, forms the edges of the part into a roll or curl. As in hemming, it is done for purposes of safety, strength, and aesthetics. Examples of products in which curling is used include hinges, pots and pans, and pocket-watch cases.

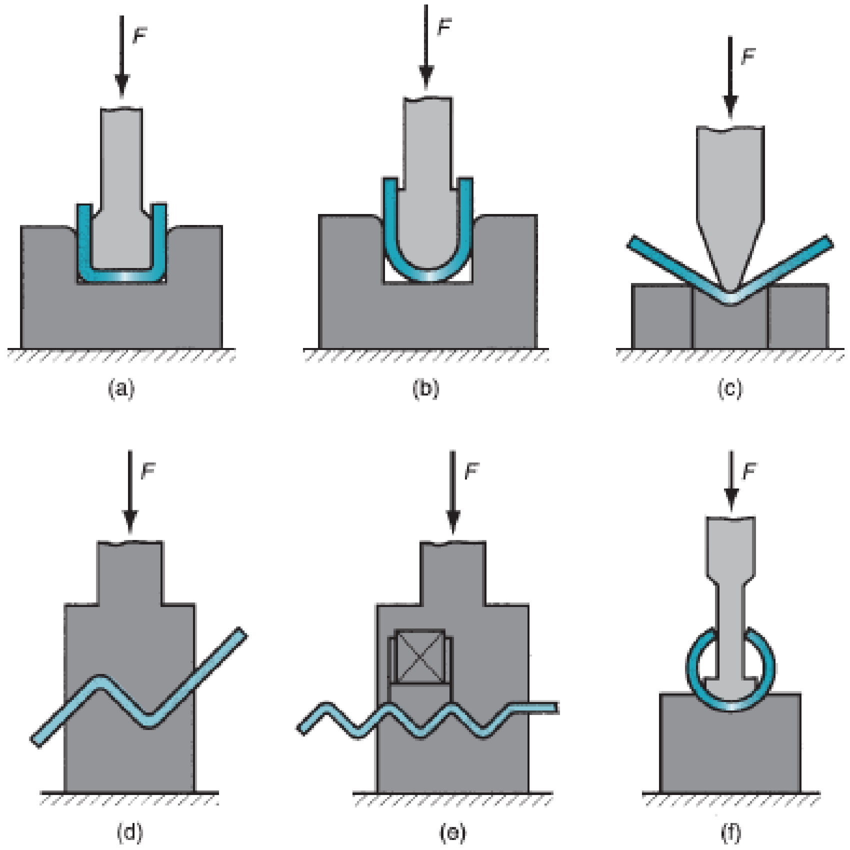


(a) Hemming, (b) seaming, and (c) curling

SHEET METALWORKING

BENDING OPERATIONS

OTHER BENDING and FORMING OPERATIONS



Miscellaneous bending operations: (a) channel bending, (b) U-bending, (c) air bending, (d) offset bending, (e) corrugating, and (f) tube forming. Symbol: F= applied force

SHEET METALWORKING

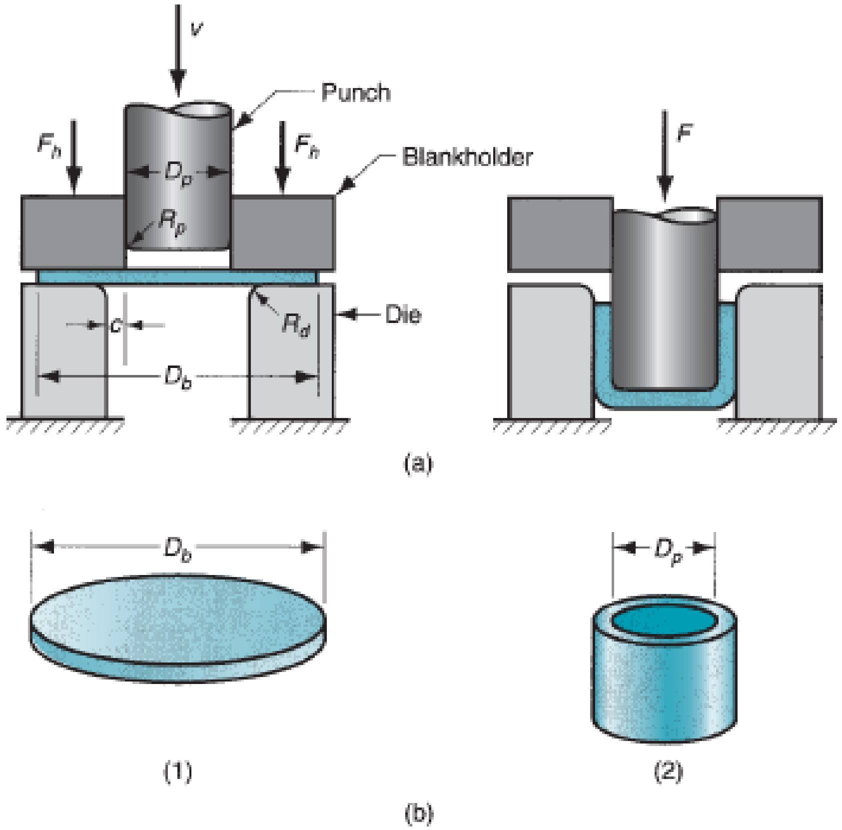
DRAWING

- *Drawing* is a sheet-metal-forming operation used to make cup-shaped, box-shaped, or other complex-curved and concave parts. It is performed by placing a piece of sheet metal over a die cavity and then pushing the metal into the opening with a punch.
- The blank must usually be held down flat against the die by a blankholder.
- Common parts made by drawing include beverage cans, ammunition shells, sinks, cooking pots, and automobile body panels.

SHEET METALWORKING

DRAWING

A blank of diameter Db is drawn into a die cavity by means of a punch with diameter Dp. The punch and die must have corner radii, given by Rp and Rd. If the punch and die were to have sharp corners (Rp and Rd = 0), a hole-punching operation (and not a very good one) would be accomplished rather than a drawing operation. The sides of the punch and die are separated by a clearance c. This clearance in drawing is about 10% greater than the stock thickness. The punch applies a downward force F to accomplish the deformation of the metal, and a downward holding force F_h is applied by the blankholder.



(a) Drawing of a cup-shaped part: (1) start of operation before punch contacts work, and (2) near end of stroke; and (b) corresponding workpart: (1) starting blank, and (2) drawn part. Symbols: c = clearance, Db = blank diameter, Dp = punch diameter, Rd = die corner radius, Rp = punch corner radius, F = drawing force, Fh = holding force.

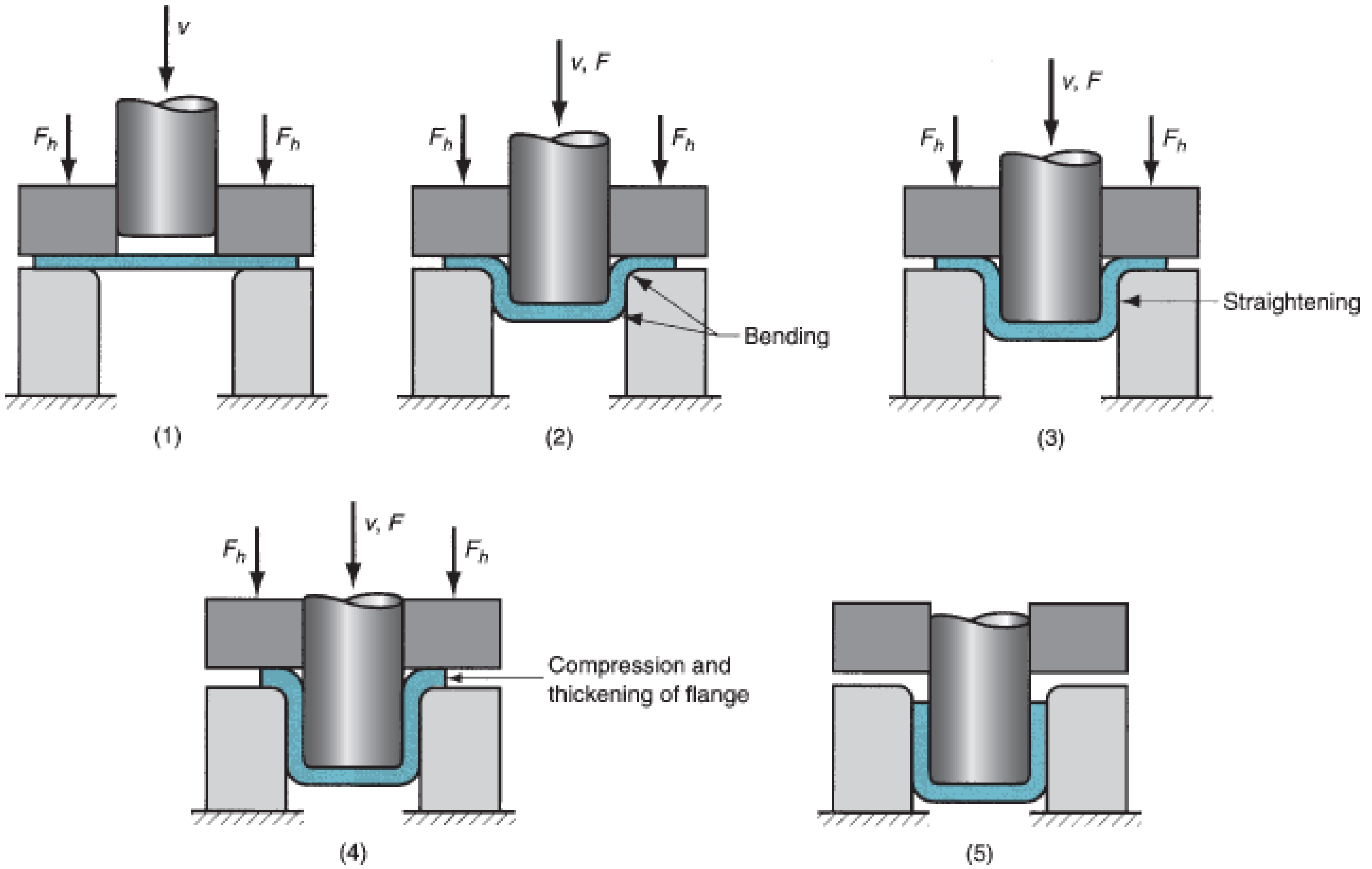
SHEET METALWORKING

DEEP DRAWING

- As the punch proceeds downward toward its final bottom position, the work experiences a complex sequence of stresses and strains as it is gradually formed into the shape defined by the punch and die cavity.
- As the punch first begins to push into the work, the metal is subjected to a *bending* operation. The sheet is simply bent over the corner of the punch and the corner of the die.
- As the punch moves further down, *straightening* action occurs in the metal that was previously bent over the die radius.

SHEET METALWORKING

DEEP DRAWING



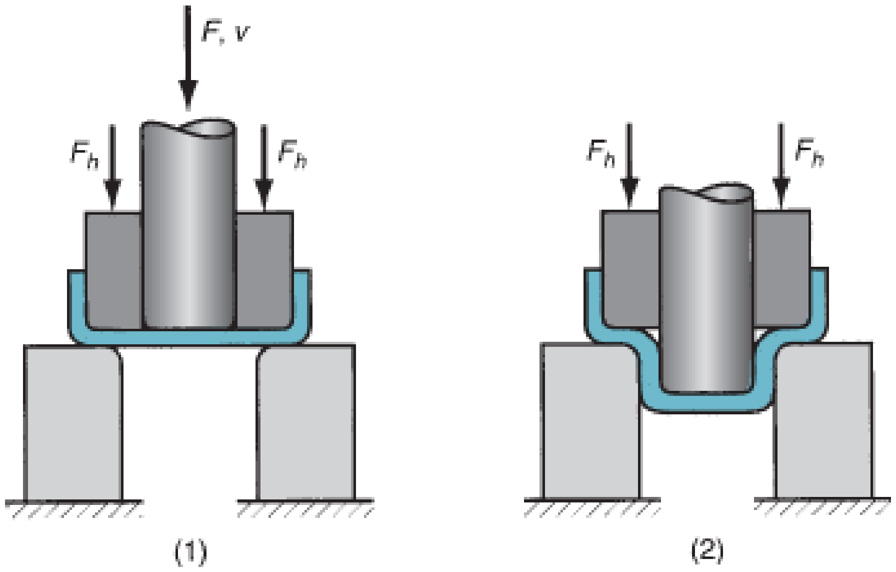
Stages in deformation of the work in deep drawing: (1) punch makes initial contact with work, (2) bending, (3) straightening, (4) friction and compression, and (5) final cup shape showing effects of thinning in the cup walls. Symbols: v = motion of punch, F = punch force, Fh = blankholder force

SHEET METALWORKING

OTHER DRAWING OPERATIONS

Redrawing

If the shape change required by the part design is too severe (drawing ratio is too high), complete forming of the part may require more than one drawing step. The second drawing step, and any further drawing steps if needed, are referred to as redrawing.



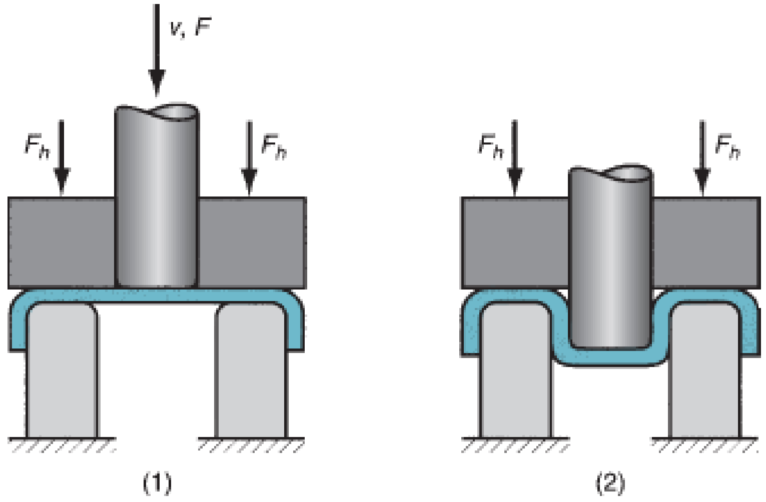
Redrawing of a cup: (1) start of redraw, and (2) end of stroke.
Symbols: v = punch velocity, F = applied punch force, Fh = blankholder force.

SHEET METALWORKING

OTHER DRAWING OPERATIONS

Reverse Drawing

A related operation is reverse drawing, in which a drawn part is positioned face down on the die so that the second drawing operation produces a reverse configuration.



Reverse drawing: (1) start and (2) completion.
Symbols: v = punch velocity, F = applied punch force, Fh = blankholder force.

SHEET METALWORKING

DEFECTS in DRAWING

A number of defects can occur in a drawn product:

(a) Wrinkling in the flange. Wrinkling in a drawn part consists of a series of ridges that form radially in the undrawn flange of the workpart due to compressive buckling.

(b) Wrinkling in the wall. If and when the wrinkled flange is drawn into the cup, these ridges appear in the vertical wall.

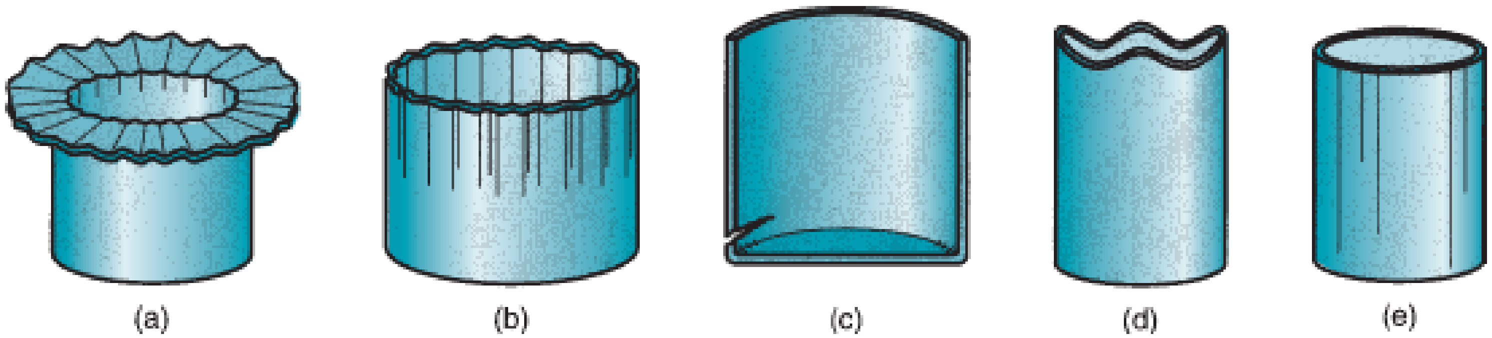
(c) Tearing. Tearing is an open crack in the vertical wall, usually near the base of the drawn cup, due to high tensile stresses that cause thinning and failure of the metal at this location. This type of failure can also occur as the metal is pulled over a sharp die corner.

(d) Earing. This is the formation of irregularities (called ears) in the upper edge of a deep drawn cup, caused by anisotropy in the sheet metal. If the material is perfectly isotropic, ears do not form.

(e) Surface scratches. Surface scratches can occur on the drawn part if the punch and die are not smooth or if lubrication is insufficient.

SHEET METALWORKING

DEFECTS in DRAWING



Common defects in drawn parts: (a) wrinkling can occur either in the flange or (b) in the wall, (c) tearing, (d) earing, and (e) surface scratches.

Some deep-drawn parts

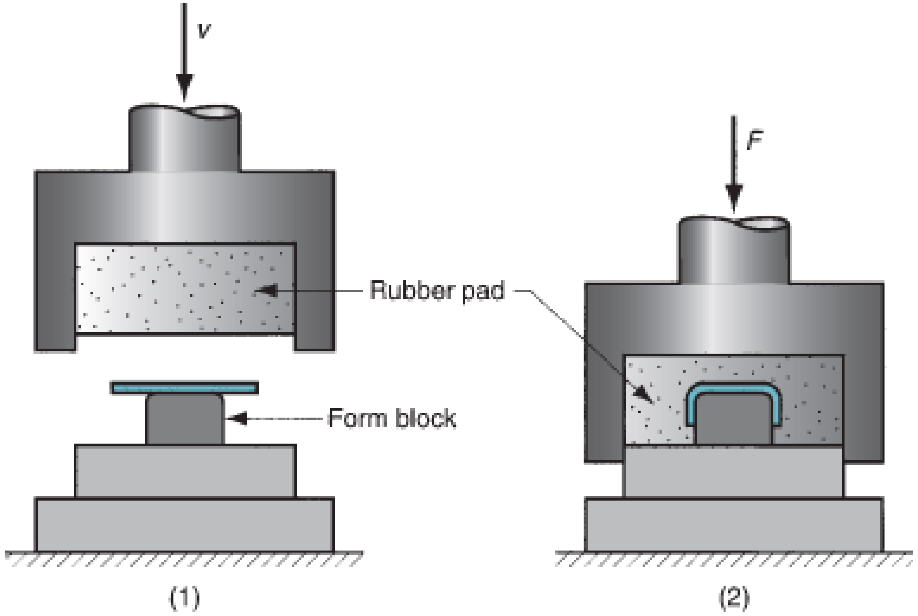
Deep-drawing step by step

SHEET METALWORKING

OTHER SHEET METAL FORMING OPERATIONS

Guerin Process

- The Guerin process uses a thick rubber pad (or other flexible material) to form sheet metal over a positive form block.
- As the ram descends, the rubber gradually surrounds the sheet, applying pressure to deform it to the shape of the form block.
- It is limited to relatively shallow forms, because the pressures developed by the rubber—up to about 10 MPa are not sufficient to prevent wrinkling in deeper formed parts



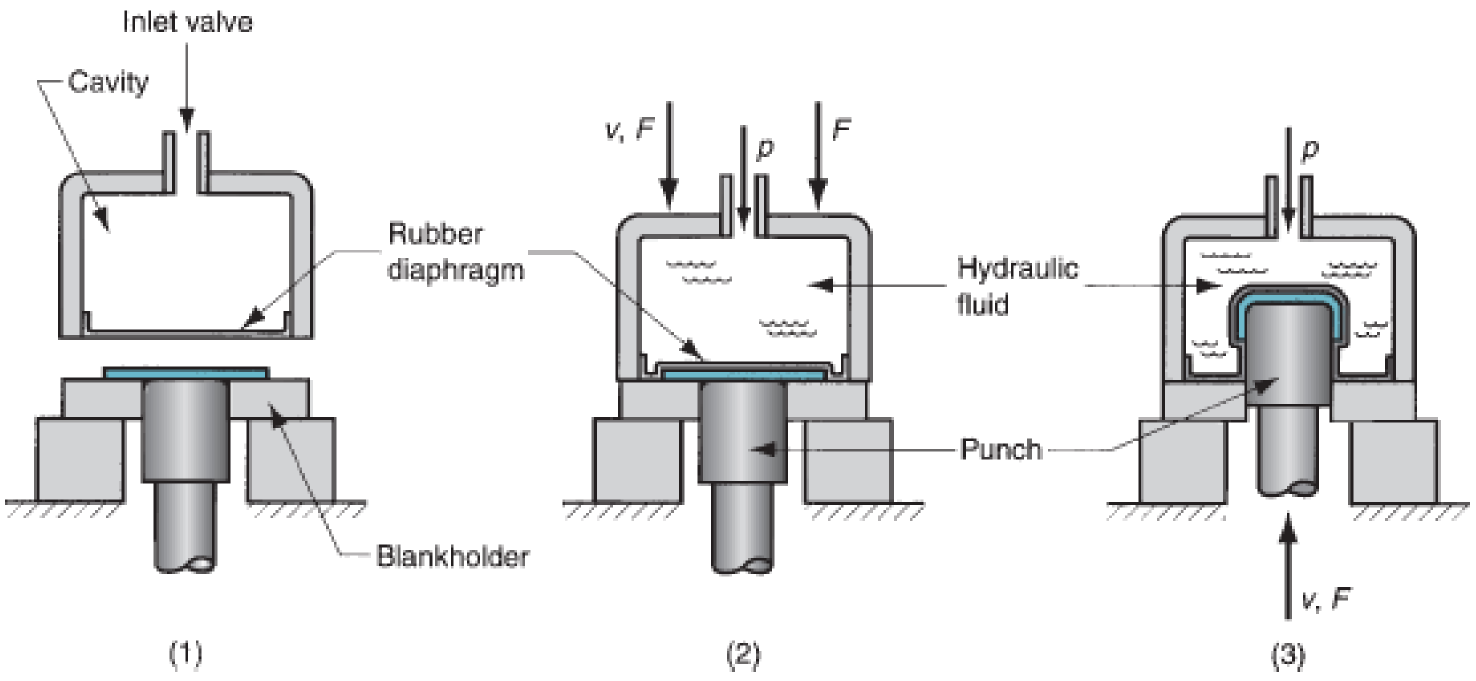
Guerin process: (1) before and (2) after. Symbols v and F indicate motion and applied force, respectively

SHEET METALWORKING

OTHER SHEET METAL FORMING OPERATIONS

Hydroforming

- Hydroforming is similar to the Guerin process; the difference is that it substitutes a rubber diaphragm filled with hydraulic fluid in place of the thick rubber pad.
- This allows the pressure that forms the workpart to be increased—to around 100 MPa—thus preventing wrinkling in deep formed parts.
- In fact, deeper draws can be achieved with the hydroform process than with conventional deep drawing. This is because the uniform pressure in hydroforming forces the work to contact the punch throughout its length, thus increasing friction and reducing the tensile stresses that cause tearing at the base of the drawn cup.

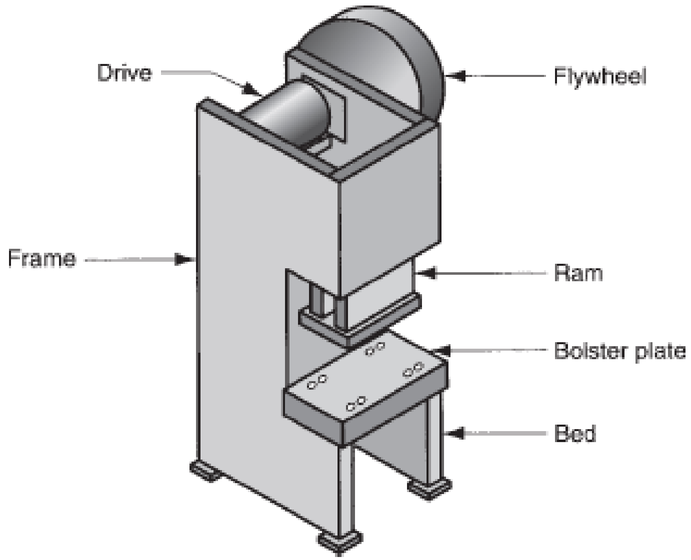


Hydroform process: (1) start-up, no fluid in cavity; (2) press closed, cavity pressurized with hydraulic fluid; (3) punch pressed into work to form part. Symbols: v = velocity, F = applied force, p = hydraulic pressure

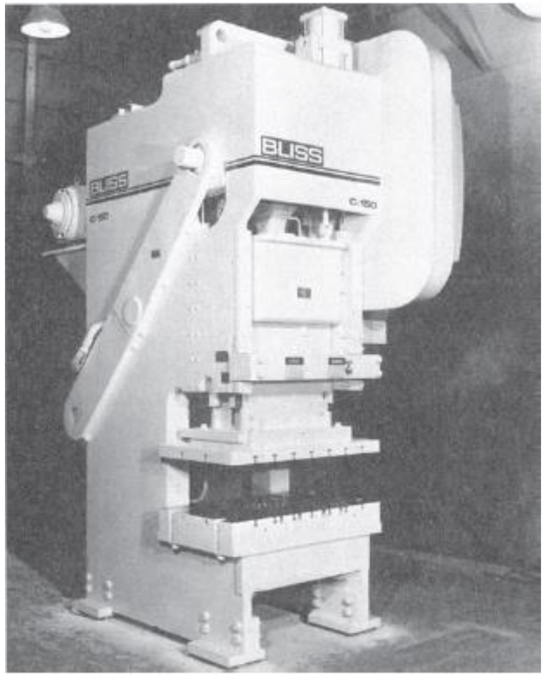
SHEET METALWORKING

PRESSES for SHEET METAL WORKING

A press used for sheet metalworking is a machine tool with a stationary bed and a powered ram (or slide) that can be driven toward and away from the bed to perform various cutting and forming operations. The relative positions of the bed and ram are established by the frame, and the ram is driven by mechanical or hydraulic power.



Components of a typical (mechanical drive) stamping press.

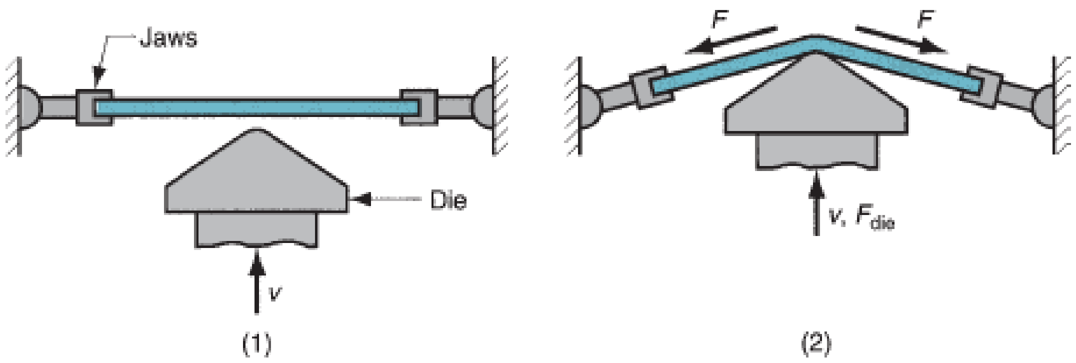


SHEET METALWORKING

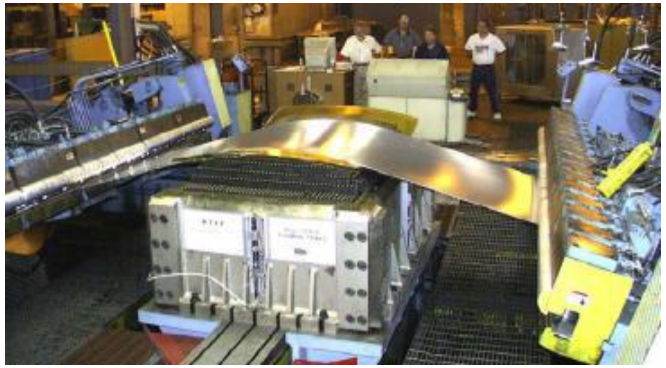
SHEET METAL OPERATIONS NOT PERFORMED on PRESSES

Stretch Forming

- Stretch forming is a sheet-metal deformation process in which the sheet metal is intentionally stretched and simultaneously bent in order to achieve shape change.
- The workpart is gripped by one or more jaws on each end and then stretched and bent over a positive die containing the desired form.
- The metal is stressed in tension to a level above its yield point.



Stretch forming: (1) start of process; (2) form die is pressed into theworkwith force Fdie, causing it to be stretched and bent over the form. F ¼ stretching force.



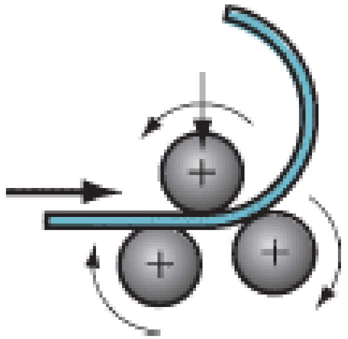
Stretch Forming Video

SHEET METALWORKING

SHEET METAL OPERATIONS NOT PERFORMED on PRESSES

Roll Bending and Roll Forming

- ***Roll bending*** is an operation in which (usually) large sheet-metal or plate-metal parts are formed into curved sections by means of rolls.
- As the sheet passes between the rolls, the rolls are brought toward each other to a configuration that achieves the desired radius of curvature on the work.
- Components for large storage tanks and pressure vessels are fabricated by roll bending.



Roll bending

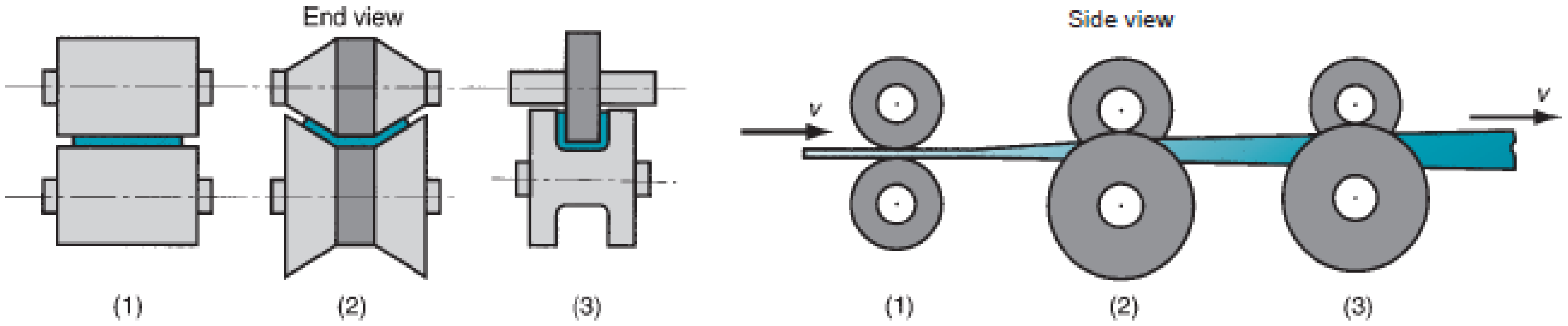
Roll Bending Video

SHEET METALWORKING

SHEET METAL OPERATIONS NOT PERFORMED on PRESSES

Roll Bending and Roll Forming

- ***Roll forming*** (also called contour roll forming) is a continuous bending process in which opposing rolls are used to produce long sections of formed shapes from coil or strip stock.
- Several pairs of rolls are usually required to progressively accomplish the bending of the stock into the desired shape.



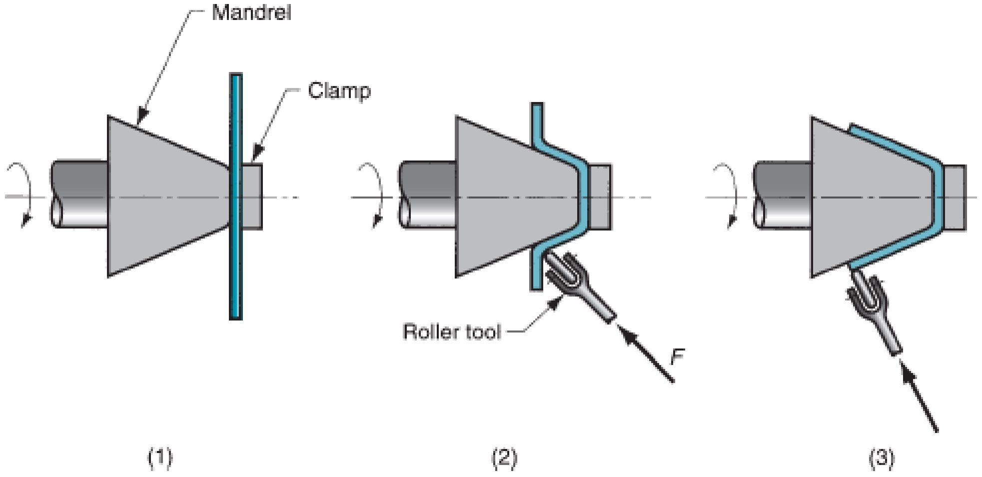
Roll forming of a continuous channel section: (1) straight rolls, (2) partial form, and (3) final form

SHEET METALWORKING

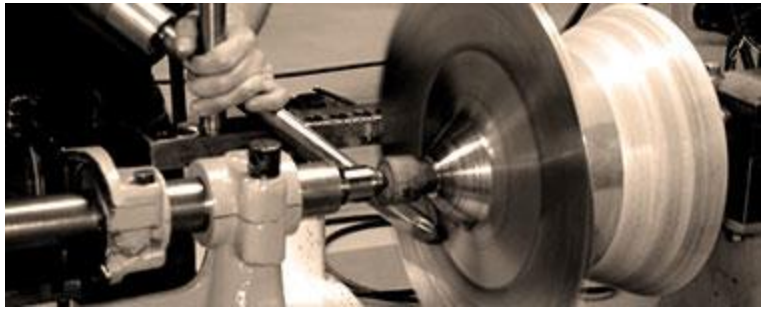
SHEET METAL OPERATIONS NOT PERFORMED on PRESSES

Spinning

- Spinning is a metal-forming process in which an axially symmetric part is gradually shaped over a mandrel or form by means of a rounded tool or roller.
- The tool or roller applies a very localized pressure (almost a point contact) to deform the work by axial and radial motions over the surface of the part.
- Basic geometric shapes typically produced by spinning include cups, cones, hemispheres, and tubes.



Conventional spinning:(1) setup at start of process; (2) during spinning; and (3) completion of process

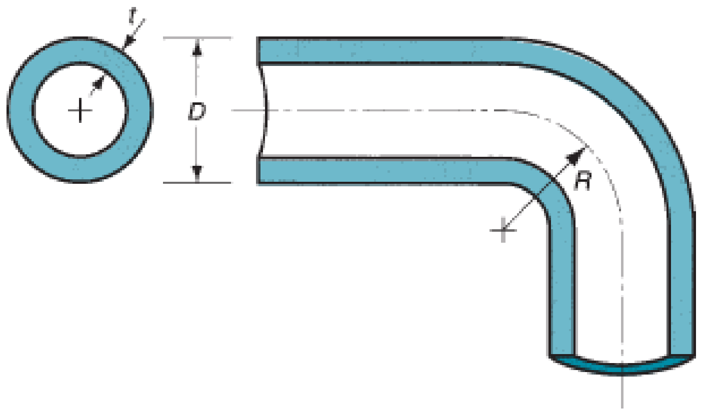


[Spinning Video]

SHEET METALWORKING

BENDING of TUBE STOCK

- When the tube is bent, the wall on the inside of the bend is in compression, and the wall at the outside is in tension.
- These stress conditions cause thinning and elongation of the outer wall and thickening and shortening of the inner wall.



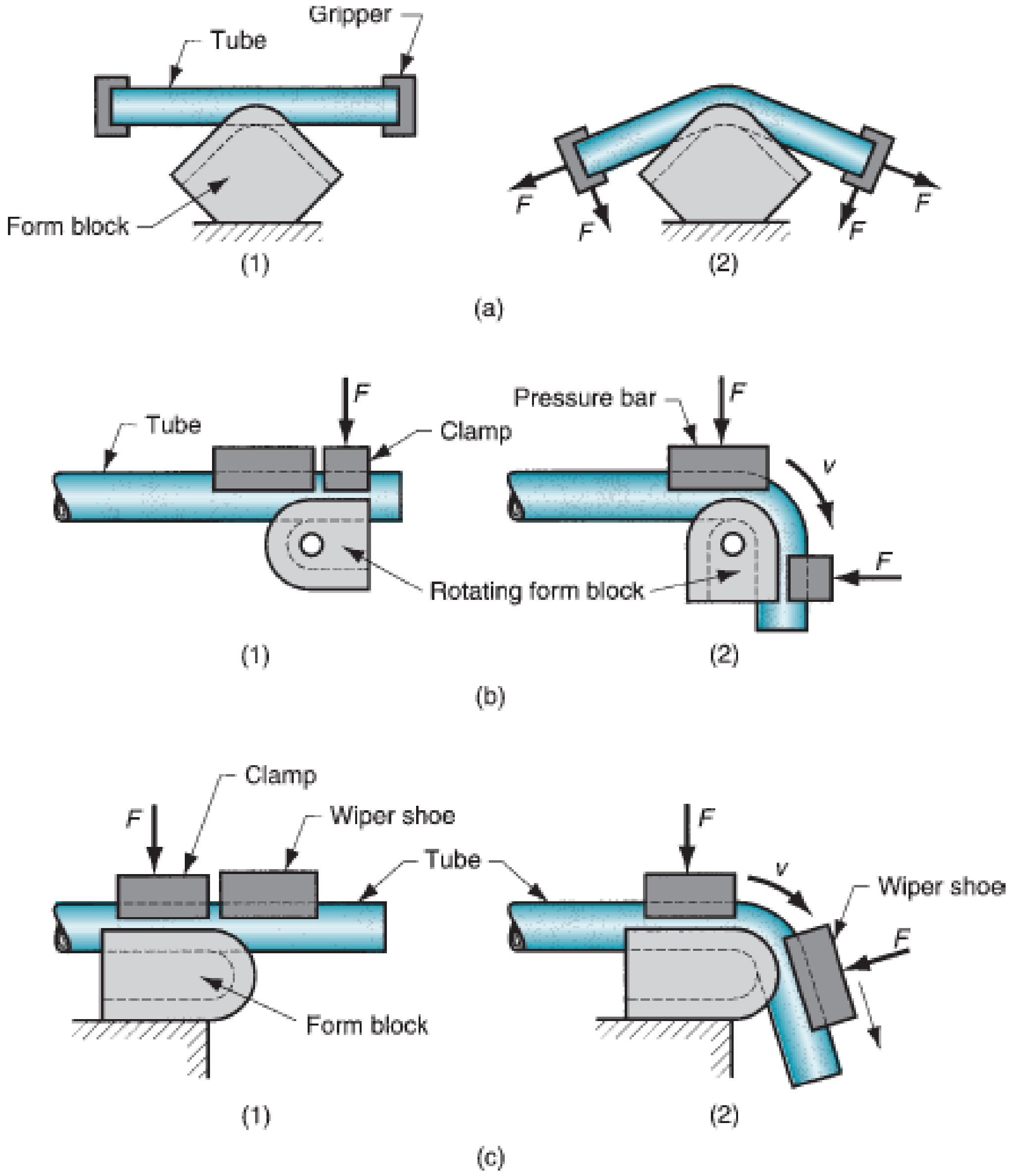
Dimensions and terms for a bent tube: D = outside diameter of tube, R = bend radius, t = wall thickness.

SHEET METALWORKING

BENDING of TUBE STOCK

Tube Bending Methods

- *Stretch bending* is accomplished by pulling and bending the tube around a fixed form block.
- *Draw bending* is performed by clamping the tube against a form block, and then pulling the tube through the bend by rotating the block. A pressure bar is used to support the work as it is being bent.
- In *compression bending*, a wiper shoe is used to wrap the tube around the contour of a fixed form block.



Tube bending methods: (a) stretch bending, (b) draw bending, and (c) compression bending. For each method: (1) start of process, and (2) during bending. Symbols v and F indicate motion and applied force, respectively