Chapter 17: Sheet-Forming Processes

Introduction

- Sheet metal processes involve plane stress loadings and lower forces than bulk forming
- The main categories of sheet metal forming are:
  - Shearing (剪斷)
  - Bending (彎曲)
  - Drawing (引伸)

Metalforming

TABLE 17-1 Classification of the Nonsqueezing Metalforming Operations

Shearing	Bending	Drawing and Stretching
1. Simple shearing	1. Angle bending	1. Spinning
2. Slitting	2. Roll bending	2. Shear forming or flow turning
3. Piercing	3. Draw bending	3. Stretch forming
4. Blanking	4. Compression bending	4. Deep drawing and shallow drawing
5. Fineblanking	5. Press bending	5. Rubber-tool forming
6. Lancing	6. Tube bending	6. Sheet hydroforming
7. Notching	7. Roll forming	7. Tube hydroforming
8. Nibbling	8. Seaming	8. Hot drawing
9. Shaving	9. Flanging	9. High-energy-rate forming
10. Trimming	10. Straightening	10. Ironing
11. Cutoff		11. Embossing
12. Dinking		12. Superplastic sheet forming

Sheet Metalworking Defined

- Thin sheets of metal
  - Thickness of sheet metal = 0.4 mm (1/64 in) to 6 mm (1/4 in)
  - Thickness of plate stock > 6 mm
- Usually cold working

Sheet and Plate Metal Products

- Sheet and plate metal parts for consumer and industrial products such as
  - Automobiles and trucks
  - Airplanes
  - Railway cars and locomotives
  - Farm and construction equipment
  - Small and large appliances
  - Office furniture
  - Computers and office equipment
- You don't have to make these products from blocks.

Shearing Operations

- Shearing (剪斷) - mechanical cutting of material without the formation of chips or the use of burning or melting
  - Both cutting blades are straight
- Curved blades may be used to produce different shapes
  - Blanking (打胚、下料、沖胚料)
  - Piercing (沖孔)
  - Notching (沖凹口)
  - Trimming (修整)

Shearing Operations

- Fracture and tearing begin at the weakest point and proceed progressively or intermittently to the next-weakest location
  - Results in a rough and ragged edge
- Punch and die must have proper alignment and clearance
- Sheared edges can be produced that require no further finishing
  - Punch-die alignment and clearance

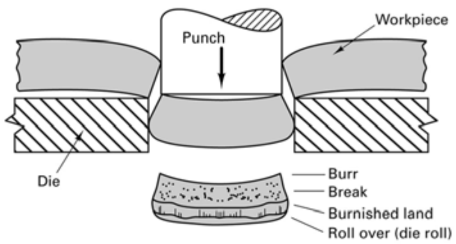


Figure 17-1 (Left) Simple blanking with a punch and die.

Figure 17-2 (Right) (Top) Conventionally sheared surface showing the distinct regions of deformation and fracture and (bottom) magnified view of the sheared edge. (*Courtesy of Feintool Equipment Corp., Cincinnati, OH.)*

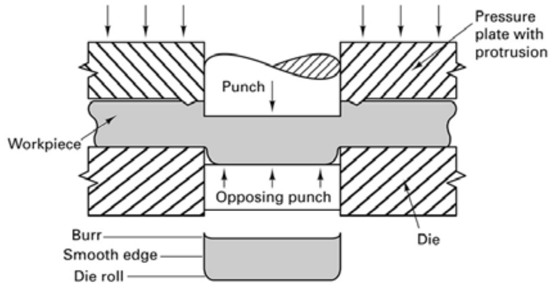


Figure 17-3 (Right) Method of obtaining a smooth edge in shearing by using a shaped pressure plate to put the metal into localized compression and a punch and opposing punch descending in unison.

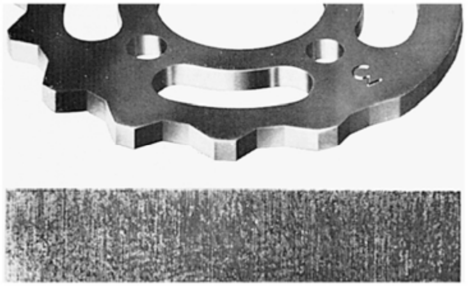


Figure 17-4 Fineblanked surface of the same component as shown in Figure 17-2. (*Courtesy of Feintool Equipment Corp., Cincinnati, OH.*)

Types of Shearing

- Simple shearing- sheets of metal are sheared along a straight line
- Slitting (分割)- lengthwise shearing process that is used to cut coils of sheet metal into several rolls of narrower width

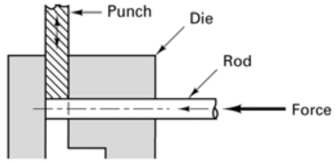


Figure 17-5 Method of smooth shearing a rod by putting it into compression during shearing.

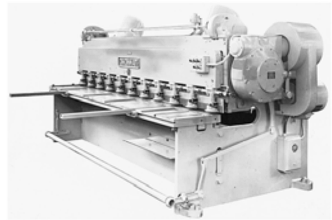


Figure 17-6 A 3-m (10ft) power shear for 6.5 mm (1/4-in.) steel. (*Courtesy of Cincinnati Incorporated, Cincinnati, OH.*)

Piercing and Blanking

- Blanking (打胚, 下料) - the piece being punched out becomes the workpiece
- Piercing (沖孔) - the remaining strip is the workpiece

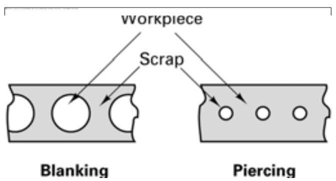


Figure 17-7 Schematic showing the difference between piercing and blanking.

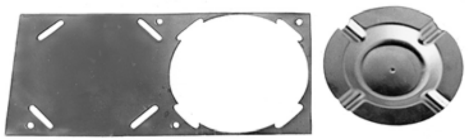
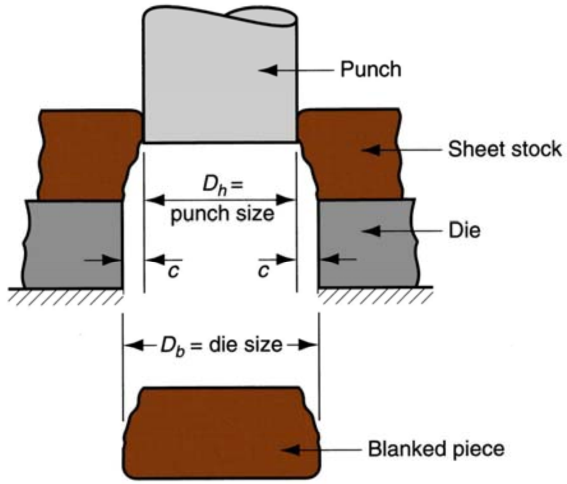


Figure 17-8 (Above) (Left to Right) Piercing, lancing, and blanking precede the forming of the final ashtray. The small round holes assist positioning and alignment.

Punch and Die Sizes

Die size determines blank size D_b; punch size determines hole size D_h.; c = clearance



(Source:Groover, 2005)

Types of Piercing and Blanking

- Lancing- piercing operation that forms either a line cut or hole
- Perforating- piercing a large number of closely spaced holes
- Notching- removes segments from along the edge of an existing product
- Cutoff- to separate a stamping or other product from a strip of stock

Tools and Dies for Piercing and Blanking

- Basic components: punch, die, and stripper plate
- Punches and dies should be properly aligned
  - uniform clearance
- Punches are normally made from low-distortion or air-hardenable tool steel

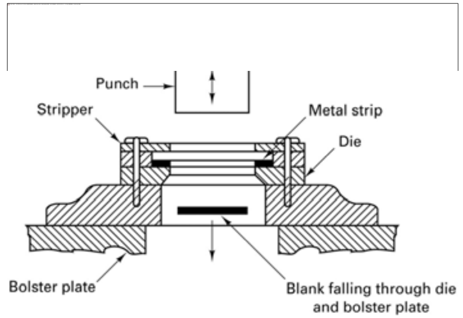


Figure 17-11 The basic components of piercing and blanking dies.

Blanking Operations

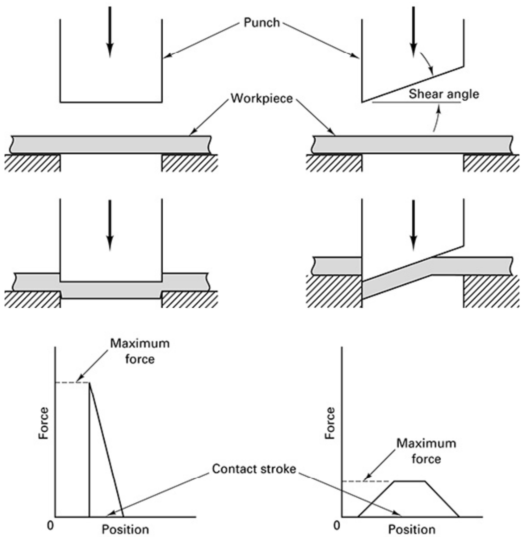
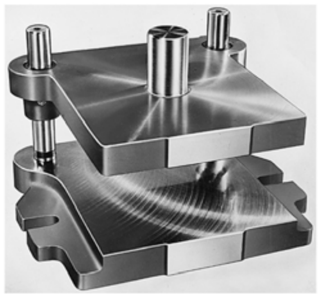


Figure 17-12 Blanking with a square-faced punch (left) and one containing angular shear (right). Note the difference in maximum force and contact stroke. The total work (the are under the curve) is the same for both processes.

Blanking Operations

Figure 17-13 (Below) Typical die set having two alignment guideposts. (*Courtesy of Danly IEM, Cleveland, OH.*)



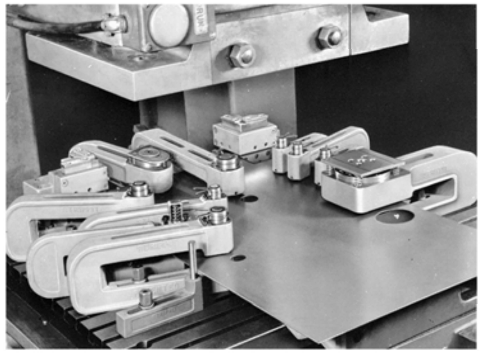


Figure 17-14 (Above) A piercing and blanking setup using self-contained subpress tool units. (*Courtesy of Strippit Division, Houdaille Industries, Inc., Akron, NY.*)

Progressive Die Sets

- Progressive die sets- two or more sets of punches and dies mounted in tandem
- Transfer dies move individual parts from operation to operation within a single press
- Compound dies combine processes sequentially during a single stroke of the ram

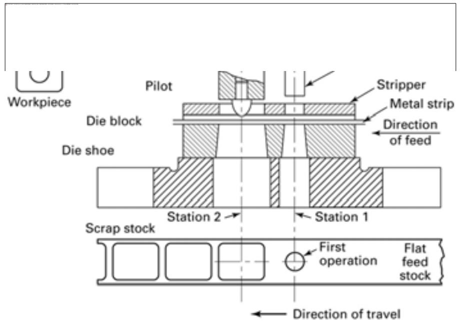


Figure 17-16 Progressive piercing and blanking die for making a square washer. Note that the punches are of different length.

Design Example

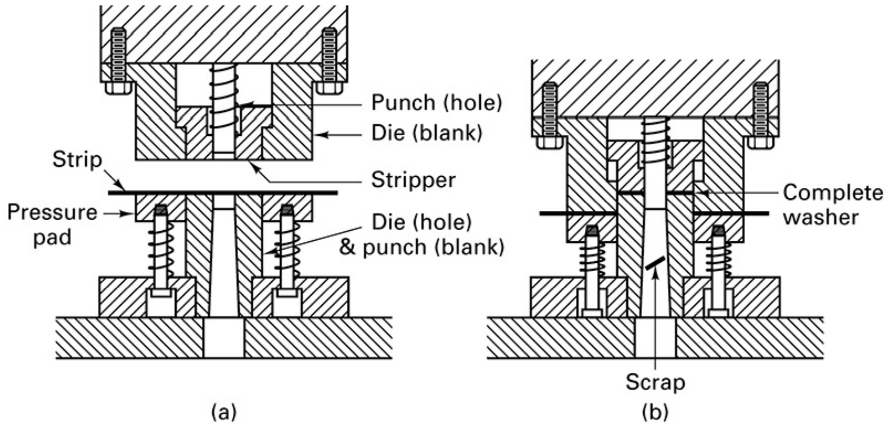


Figure 17-18 Method for making a simple washer in a compound piercing and blanking die. Part is blanked (a) and subsequently pierced (b) in the same stroke. The blanking punch contains the die for piercing.

Design for Piercing and Blanking

- Design rules
  - Diameters of pierced holes should not be less than the thickness of the metal (D > t)
  - Minimum distance between holes or the edge of the stock should be at least equal to the metal thickness (d > t)
  - The width of any projection or slot should be at least 1 times the metal thickness (w > t)
  - Keep tolerances as large as possible
  - Arrange the pattern of parts on the strip to minimize scrap

Bending

- Bending is the plastic deformation of metals about a linear axis with little or no change in the surface area
- Forming- multiple bends are made with a single die
- Drawing and stretching- axes of deformation are not linear or are not independent
- Springback is the “unbending” that occurs after a metal has been deformed

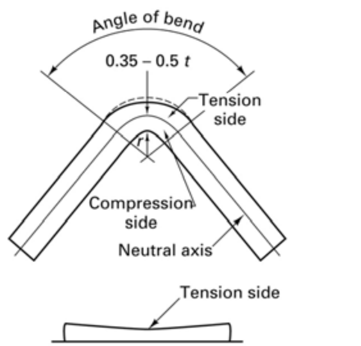


Figure 17-19 (Top) Nature of a bend in sheet metal showing tension on the outside and compression on the inside. (Bottom) The upper portion of the bend region, viewed from the side, shows how the center portion will thin more than the edges.

Angle Bending (Bar Folder and Press Brake)

- Bar folders make angle bends up to 150 degrees in sheet metal
- Press brakes make bends in heavier sheets or more complex bends in thin material

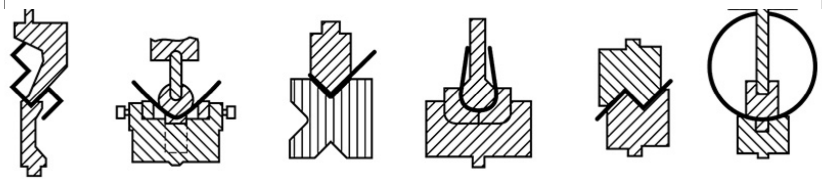


Figure 17-22 Press brake dies can form a variety of angles and contours. (*Courtesy of Cincinnati Incorporated, Cincinnati, OH.)*

Bar Folder

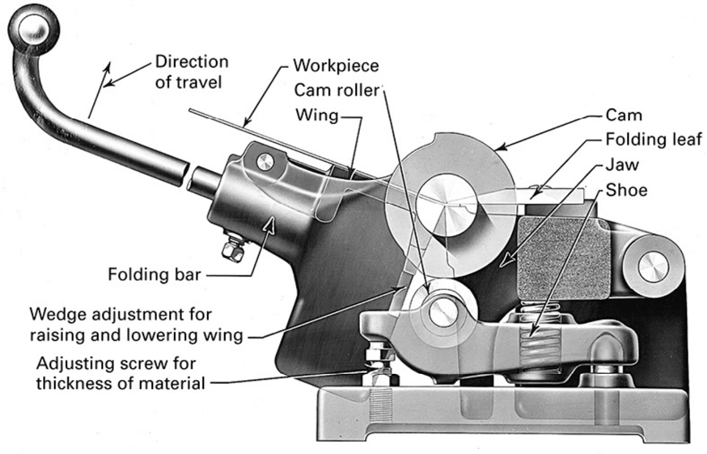


Figure 17-20 Phantom section of a bar folder, showing position and operation of internal components. (*Courtesy of Niagara Machine and Tool Works, Buffalo, N.Y.)*

Press Brake

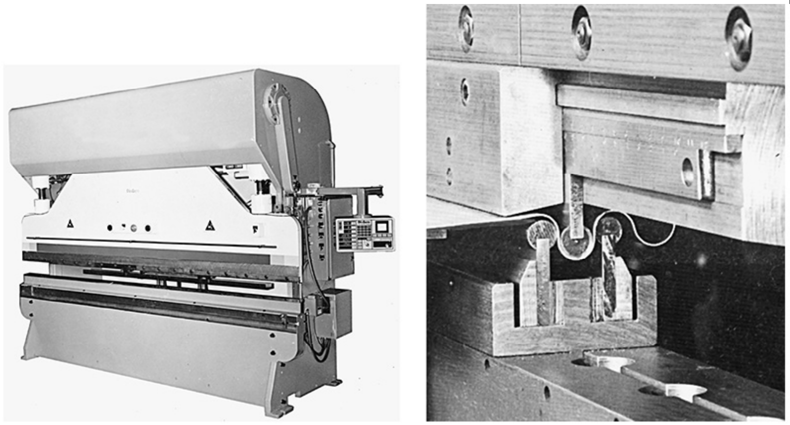


Figure 17-21 (Left) Press brake with CNC gauging system. (*Courtesy of DiAcro Division, Acrotech Inc., Lake City, MN.)* (Right) Close-up view of press brake dies forming corrugations. (*Courtesy of Cincinnati Incorporated, Cincinnati, OH.)*

Design for Bending

- Several factors are important in specifying a bending operation
  - Determine the smallest bend radius that can be formed without cracking the metal
    - Metal ductility
    - Thickness of material

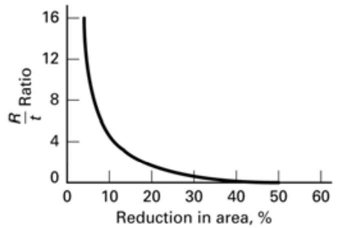


Figure 17-24 Relationship between the minimum bend radius (relative to thickness) and the ductility of the metal being bent (as measured by the reduction in area in a uniaxial tensile test).

Considerations for Bending

- If the punch radius is large and the bend angle is shallow, large amounts of springback are often encountered
- The sharper the bend, the more likely the surfaces will be stressed beyond the yield point
- Springback compensation
  - When bend radius > 4t

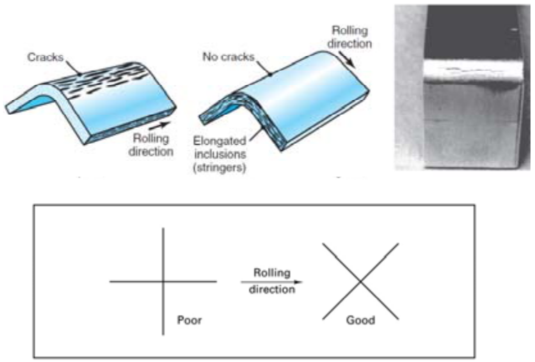


Figure 17-25 Bends should be made with the bend axis perpendicular to the rolling direction. When intersecting bends are made, both should be at an angle to the rolling direction, as shown.

Design Considerations

- Determine the dimensions of a flat blank that will produce a bent part of the desired precision
- Metal tends to thin when it is bent

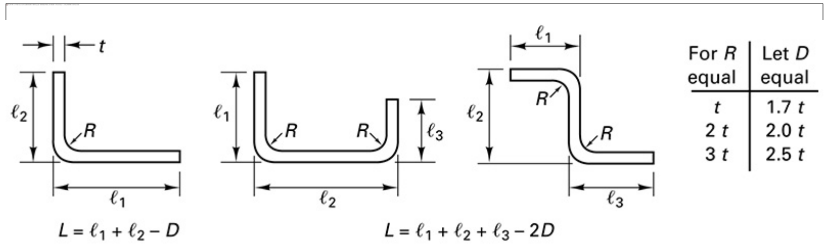


Figure 17-26 One method of determining the starting blank size (*L*) for several bending operations. Due to thinning, the product will lengthen during forming. l_1, l_2, and l_3 are the desired product dimensions. See table to determine *D* based on size of radius *R* where t is the stock thickness.

Air-Bend, Bottoming, and Coining Dies

- Bottoming dies contact and compress the full area within the tooling
- Air bend dies produce the desired geometry by simple three-point bending
- If bottoming dies go beyond the full-contact position, the operation is similar to coining
  - Reduced material thickness
  - Extensive plastic deformation

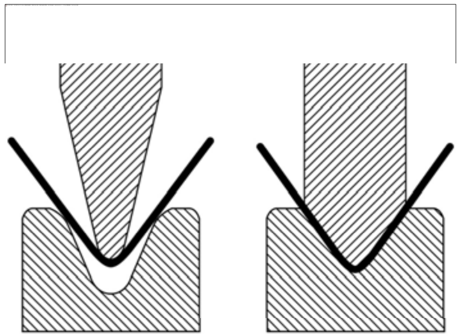


Figure 17-27 Comparison of air-bend (left) and bottoming (right) press brake dies. With the air-bend die, the amount of bend is controlled by the bottoming position of the upper die.

Roll Bending

- Roll bending is a continuous form of three-point bending
  - Plates, sheets, beams, pipes

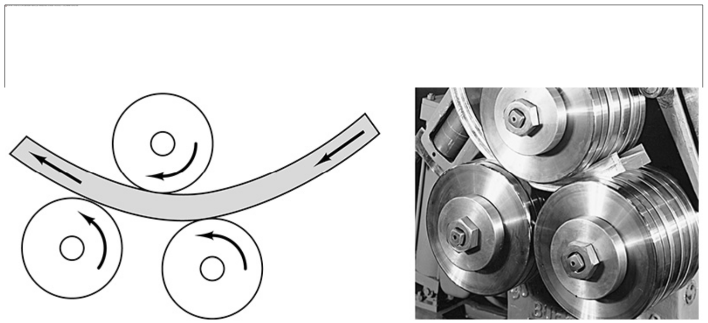


Figure 17-28 (Left) Schematic of the roll-bending process; (right) the roll bending of an I-beam section. Note how the material is continuously subjected to three-point bending. (*Courtesy of Buffalo Forge Company, Buffalo, NY.)*

Draw Bending, Compression Bending, and Press Bending

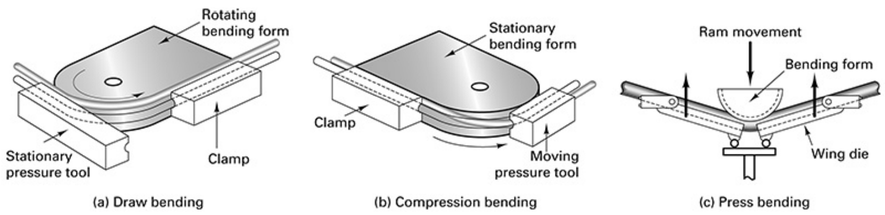
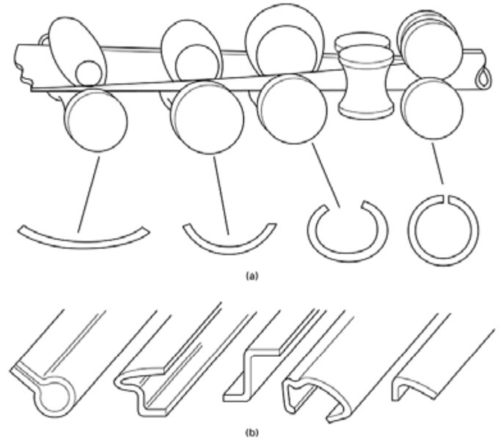


Figure 17-29 (a) Draw bending, in which the form block rotates; (b) compression bending, in which a moving tool compresses the workpiece against a stationary form; (c) press bending, where the press ram moves the bending form.

Tube Bending

- Key parameters: outer diameter of the tube, wall thickness, and radius of the bend

Figure 17-30 (a) Schematic representation of the cold roll-forming process being used to convert sheet or plate into tube. (b) Some typical shapes produced by roll forming.



Roll Forming

- A metal strip is progressively bent as it passes through a series of forming rolls
- Only bending takes place during this process
  - All bends are parallel to one another
- A wide variety of shapes can be produced
  - But changeover, setup, and adjustment may take several hours

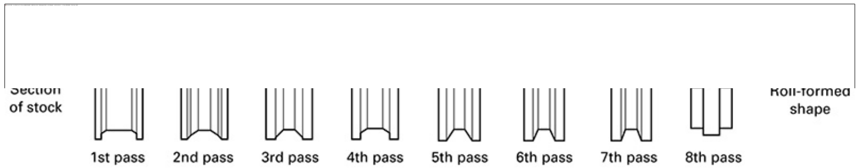


Figure 17-31 Eight-roll sequence for the roll forming of a box channel. (*Courtesy of the Aluminum Association, Washington, DC.)*

Seaming

- To join the ends of sheet metal in some form of mechanical interlock
- Common products include cans, pails, drums, and containers

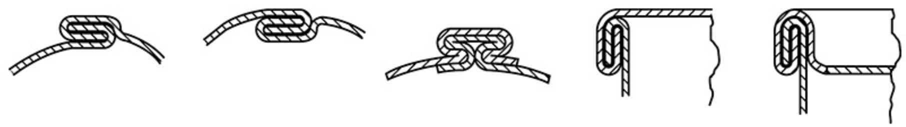


Figure 17-31 Various types of seams used on sheet metal.

Straightening

- Straightening or flattening is the opposite of bending
  - Done before subsequent forming to ensure the use of flat or straight material
- Various methods to straighten material
  - Roll straightening (Roller levering)
  - Stretcher leveling- material is mechanically gripped and stretch until it reaches the desired flatness

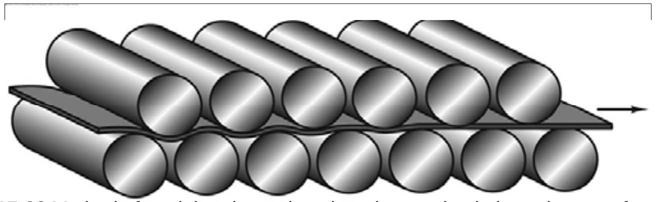


Figure 17-33 Method of straightening rod or sheet by passing it through a set of straightening rolls. For rods, another set of rolls is used to provide straightening in the transverse direction.

Drawing and Stretching Processes

- Drawing - plastic flow occurs over a curved axis
  - the flat sheet is formed into a three-dimensional part
- Spinning (旋壓) is a cold forming operation
  - Sheet metal is rotated and shaped over a male form, or mandrel
  - Produces rotationally symmetrical shapes
    - Spheres, hemispheres, cylinders, bells, and parabolas

Spinning

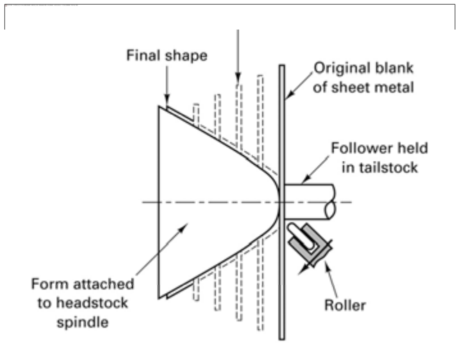
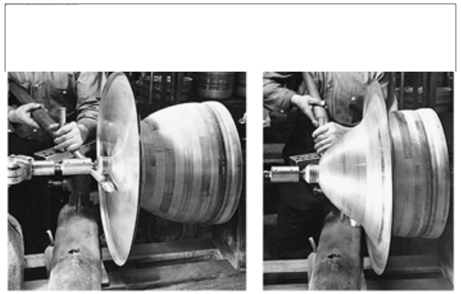


Figure 17-34 (Above) Progressive stages in the spinning of a sheet metal product.

Figure 17-35 (Below) Two stages in the spinning of a metal reflector. (*Courtesy of Spincraft, Inc. New Berlin, WI.)*



Shear Forming and Stretch Forming

- Shear forming is a version of spinning
- In stretch forming a sheet of is gripped and a form block shapes the parts

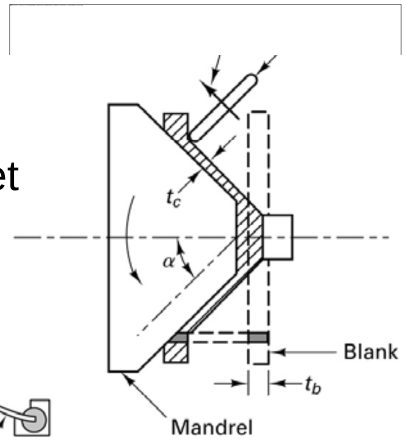


Figure 17-36 Schematic representation of the basic shear-forming process.

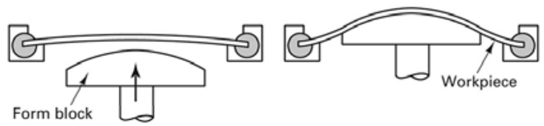


Figure 17-39 Schematic of a stretch-forming operation.

Deep Drawing and Shallow Drawing

- Deep drawing is typically used to form solid-bottom cylindrical or rectangular containers from sheet metal
- Key variables:
  - Blank and punch diameter
  - Punch and die radius
  - Clearance
  - Thickness of the blank
  - Lubrication
  - Hold-down pressure

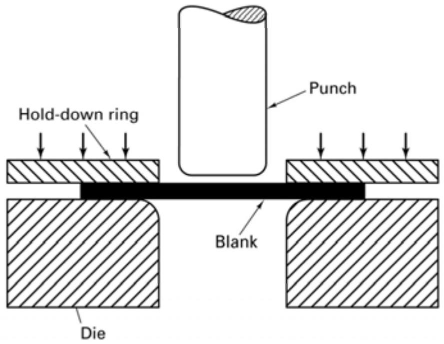


Figure 17-40 Schematic of the deep-drawing process.

Limitations of Deep Drawing

- Wrinkling (皺褶) and tearing are typical limits to drawing operations
- Different techniques can be used to overcome these limitations
  - Draw beads
    - Vertical projections and matching grooves in the die and blankholder
- Trimming may be used to reach final dimensions

Wrinkling and Tearing in Deep Darwing

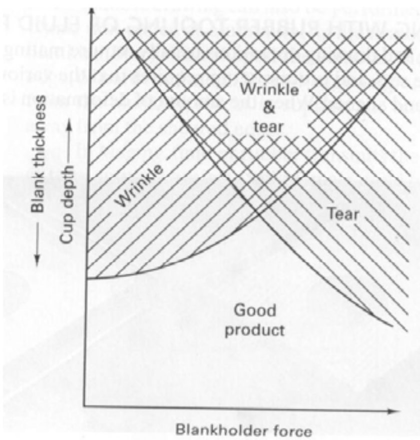
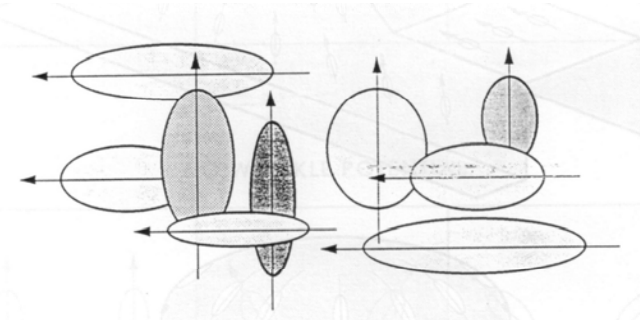


FIGURE 17-43 Defect formation in deep drawing as a function of blankholder force, blank thickness, and cup depth.

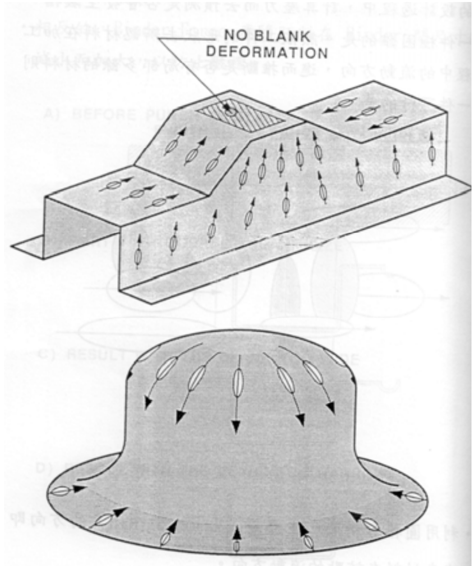
皺褶(Wrinkling)發生之預測方法

- 皺褶的發生係由過大的壓力(compressive force)造成之挫曲(buckle)現象或是多於的材料無法消化而起皺。
- 在實際的設計過程中，計算壓力而去預測是否會發生皺摺，是一件極困難的事。
- 依工件的形狀去辨認材料在加工過程中的流動方向，進而推斷是否有局部多餘的材料則是一件可行的事。

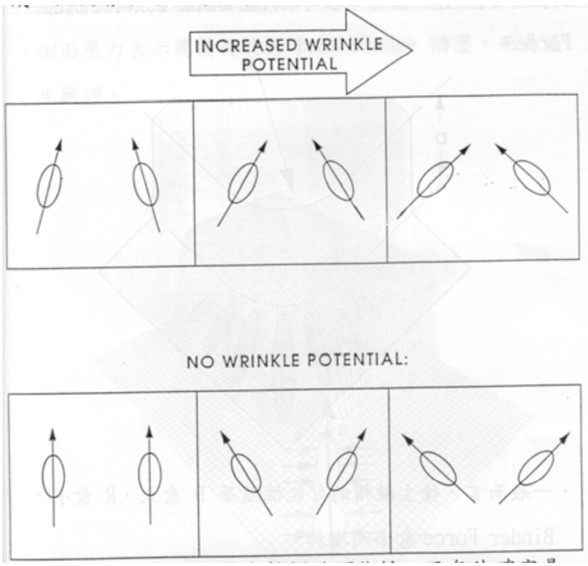
- 利用圓格分析法，主應變(major strain)的方向即代表材料在該點的流動方向。



材料流動方向



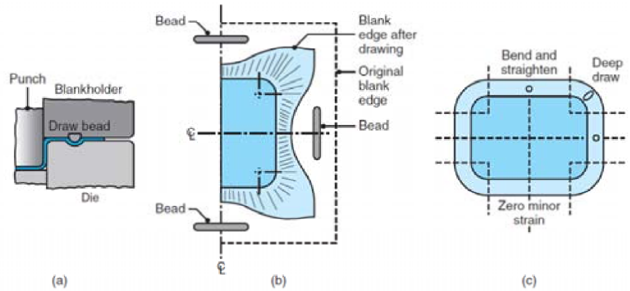
可能造成皺摺的材料流動模式



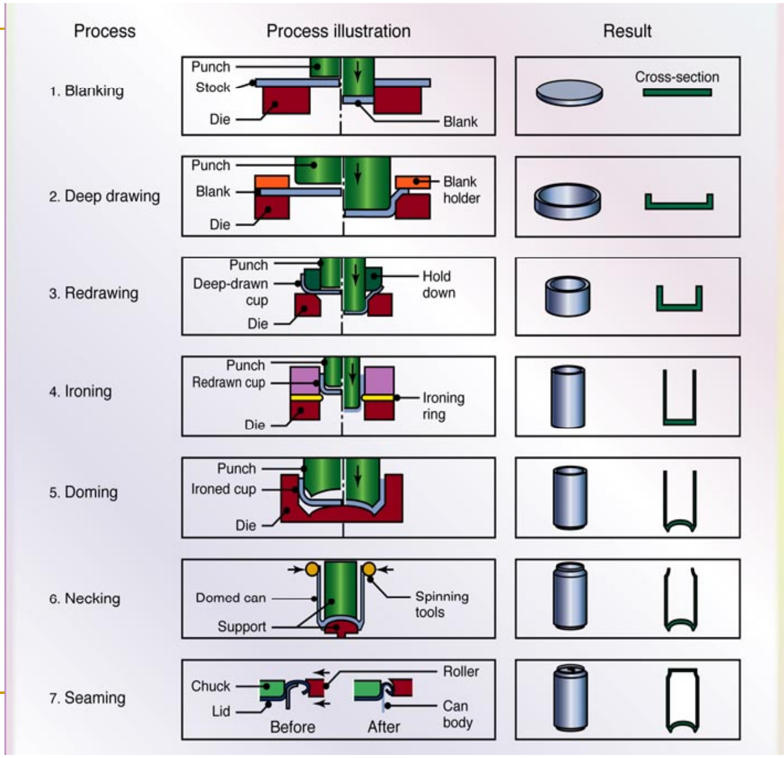
- 此種方法只能預知發生皺摺的可能性，無法確定是否一定會發生。

Draw Beads

- To control the flow of the blank into the die cavity and reduce the blankholder forces



(Source: Kalpakjian, 2010)



Forming with Rubber Tooling or Fluid Pressure

- Blanking and drawing operations usually require mating male and female die sets
- Processes have been developed that seek to
  - Reduce tooling cost
  - Decrease setup time and expense
  - Extend the amount of deformation for a single set of tools

Alternative Forming Operations

- Several forming operations replace one of the dies with rubber or fluid pressure
  - Guerin process
- Other forming operations use fluid or rubber to transmit the pressure required to expand a metal blank
  - Bulging (鼓脹)

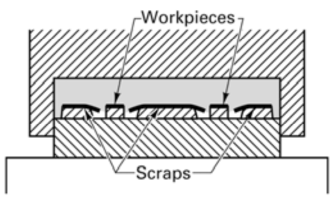


Figure 17-47 Method of blanking sheet metal using the Guerin process.

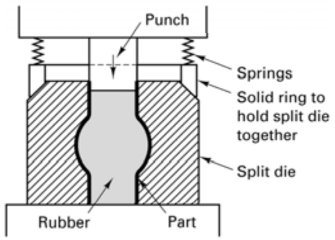


Figure 17-48 Method of bulging tubes with rubber tooling.

Sheet Hydroforming (液壓成形)

- Sheet hydroforming is a family of processes in which a rubber bladder backed by fluid pressure replaces either the solid punch or female die set
- Advantages
  - Reduced cost of tooling
  - Deeper parts can be formed without fracture
  - Excellent surface finish
  - Accurate part dimensions

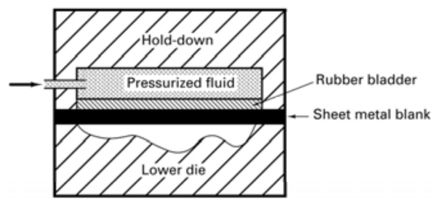


Figure 17-50 (Above) One form of sheet hydroforming.

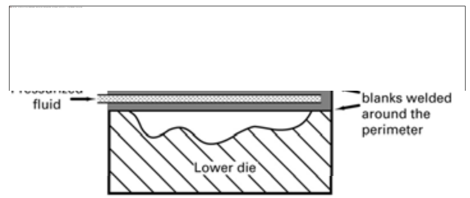


Figure 17-51 Two-sheet hydroforming, or pillow forming.

Tube Hydroforming (管件液壓成形)

- Process for manufacturing strong, lightweight, tubular components
- Frequently used process for automotive industry
- Advantages
  - Lightweight, high-strength materials
  - Designs with varying thickness or varying cross section can be made
  - Welded assemblies can be replaced by one-piece components
- Disadvantages
  - Long cycle time
  - Relatively high tooling cost and process setup

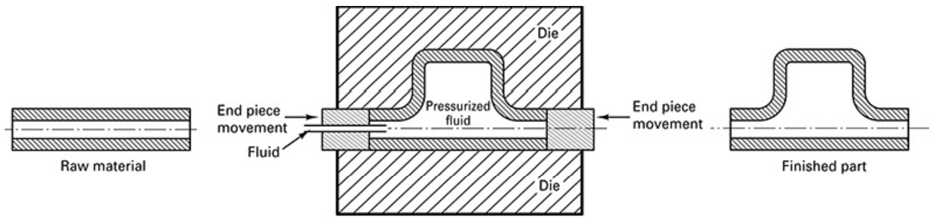


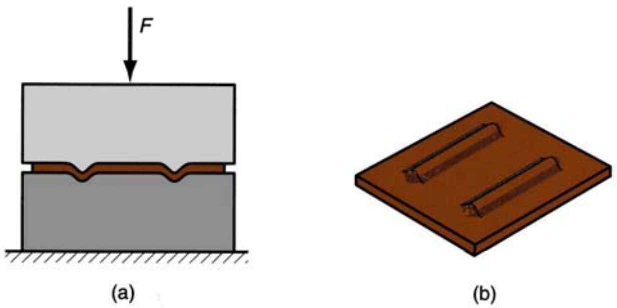
Figure 17-52 Tube hydroforming. (a) Process schematic.

Additional Drawing Operations

- Hot-drawing
  - Sheet metal has a large surface area and small thickness, so it cools rapidly
  - Relatively thick-walled parts
- High-Energy Rate Forming
  - Large amounts of energy in a very short time
  - Large workpiece / difficult-to-form metals
  - Underwater explosions, underwater spark discharge, pneumatic-mechanical means, internal combustion of gaseous mixtures, rapidly formed magnetic fields
- Ironing
  - Process that thins the walls of a drawn cylinder by passing it between a punch and a die

Additional Drawing Operations

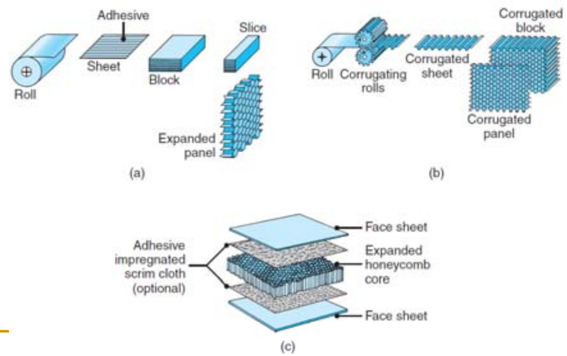
- Embossing
  - Pressworking process in which raised lettering or other designs are impressed in sheet material



(Source: Groover, 2005)

Manufacturing of Metal Honeycomb Structures

- A *honeycomb structure* consists of a core of honeycomb bonded to two thin outer skins
- Has a high stiffness-to-weight ratio and is used in packaging for shipping consumer and industrial goods



(Source: Kalpakjian, 2010)

Manufacturing of Metal Honeycomb Structures

- A *honeycomb structure* has light weight and high resistance to bending forces, used for aircraft and aerospace components

- 2 methods of manufacturing honeycomb materials:
  1. **Expansion process**
  2. **Corrugation process**

Properties of Sheet Material

- Tensile strength of the material is important in determining which forming operations are appropriate
- Sheet metal is often anisotropic- properties vary with direction or orientation
- Majority of failures during forming occur due to thinning or fracture
- Strain analysis can be used to determine the best orientation for forming

Sheet-metal Characteristics and Formability

Important Metal Characteristics for Sheet-forming Operations

Characteristic	Importance
Elongation	Determines the capability of the sheet metal to stretch without necking and failure; high strain-hardening exponent (n) and strain-rate sensitivity exponent (m) are desirable
Yield-point elongation	Typically observed with mild-steel sheets (also called Lüder's bands or stretcher strains); results in depressions on the sheet surface; can be eliminated by temper rolling, but sheet must be formed within a certain time after rolling
Anisotropy (planar)	Exhibits different behavior in different planar directions, present in cold-rolled sheets because of preferred orientation or mechanical fibering, causes earing in deep drawing, can be reduced or eliminated by annealing but at lowered strength
Anisotropy (normal)	Determines thinning behavior of sheet metals during stretching, important in deep drawing
Grain size	Determines surface roughness on stretched sheet metal; the coarser the grain, the rougher is the appearance (like an orange peel); also affects material strength and ductility
Residual stresses	Typically caused by nonuniform deformation during forming, results in part distortion when sectioned, can lead to stress-corrosion cracking, reduced or eliminated by stress relieving
Springback	Due to elastic recovery of the plastically deformed sheet after unloading, causes distortion of part and loss of dimensional accuracy, can be controlled by techniques such as overbending and bottoming of the punch
Wrinkling	Caused by compressive stresses in the plane of the sheet; can be objectionable; depending on its extent, can be useful in imparting stiffness to parts by increasing their section modulus; can be controlled by proper tool and die design
Quality of sheared edges	Depends on process used; edges can be rough, not square, and contain cracks, residual stresses, and a work-hardened layer, which are all detrimental to the formability of the sheet; edge quality can be improved by fine blanking, reducing the clearance, shaving, and improvements in tool and die design and lubrication
Surface condition of sheet	Depends on sheet-rolling practice; important in sheet forming, as it can cause tearing and poor surface quality

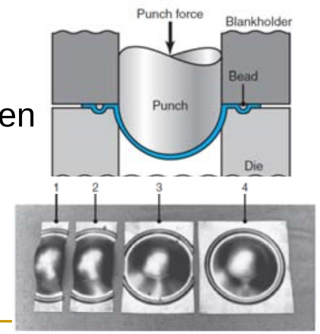
(Source: Kalpakjian, 2010)

Formability Tests for Sheet Metals

- **Sheet-metal formability** is the ability of the sheet metal to undergo the desired shape change without failure
- Sheet metals may undergo 2 basic modes of deformation: (1) *stretching* and (2) *drawing*

Cupping Tests

- In the *Erichsen test*, the sheet specimen is clamped and round punch is forced into the sheet until a crack appears

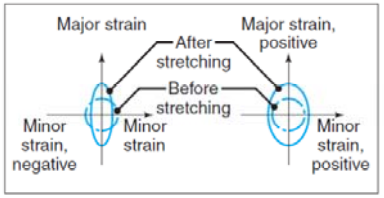


(Source: Kalpakjian, 2010)

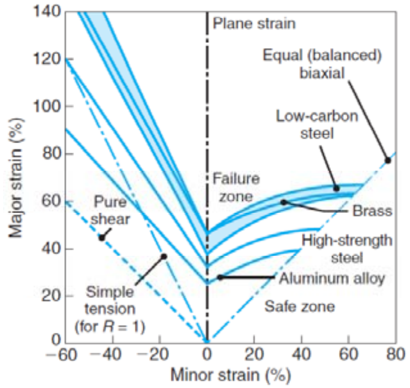
Formability Tests for Sheet Metals

Forming-limit Diagrams

- *Forming-limit diagrams* is to determine the formability of sheet metals



(Source: Kalpakjian, 2010)

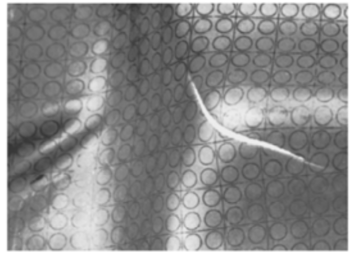


(Source: Kalpakjian, 2010)

Formability Tests for Sheet Metals

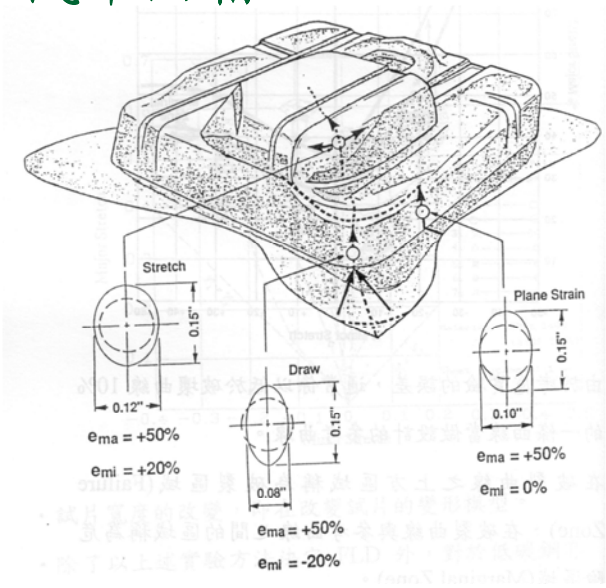
Forming-limit Diagrams

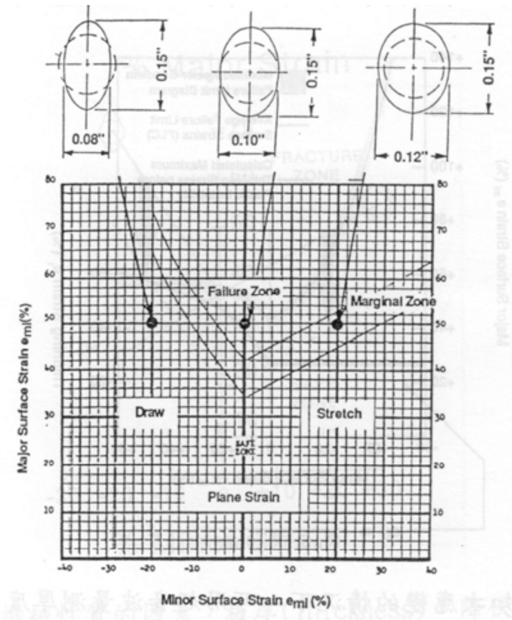
- To develop a forming-limit diagram, the major and minor engineering strains are obtained
- *Major axis* of the ellipse represents the major direction and magnitude of stretching
- Major strain is the *engineering strain* and is always *positive*
- Minor strain can be *positive* or *negative*
- Curves represent the boundaries between *failure* and *safe zones*



(Source: Kalpakjian, 2010)

Example: 汽車油箱





Presses

Manual	Mechanical	Hydraulic
Kick presses	Crank	Single slide
	Single	Multiple slide
	Double	
	Eccentric	
	Cam	
	Knuckle joint	
	Toggle	
	Screw	
	Rack and pinion	

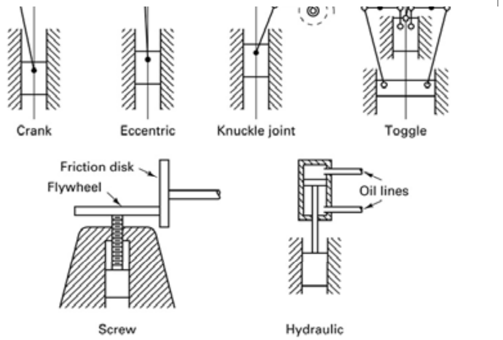


Figure 17-58 Schematic representation of the various types of press drive mechanisms.

Types of Press Frame

Arch	Gap	Straight Sided
Crank or eccentric	Foot	Many variations, but all with straight-sided frames
Percussion	Bench	
	Vertical	
	Inclinable	
	Inclinable	
	Open back	
	Horn	
	Turret	

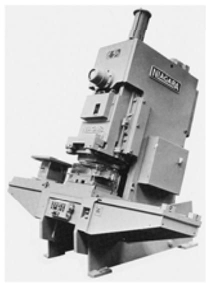


Figure 17-60 (Left) Inclinable gap-frame press with sliding bolster to accommodate two die sets for rapid change of tooling. (*Courtesy of Niagara Machine & Tool Works, Buffalo, NY.)*

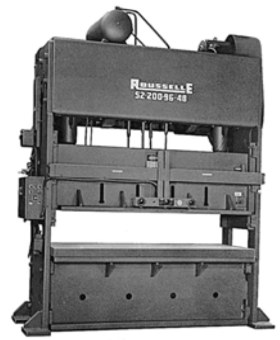


Figure 17-61 (Right) A 200-ton (1800-kN) straight-sided press. (*Courtesy of Rousselle Corporation, West Chicago, IL.)*

Special Types of Presses

- Presses have been designed to perform specific types of operations
- Transfer presses have a long moving slide that enables multiple operations to be performed simultaneously in a single machine

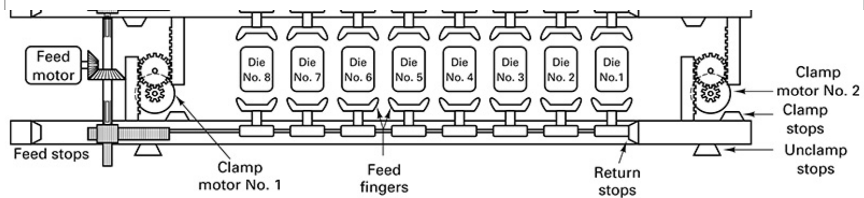


Figure 17-62 Schematic showing the arrangement of dies and the transfer mechanism used in transfer presses. (*Courtesy of Verson Allsteel Press Company, Chicago, IL.)*

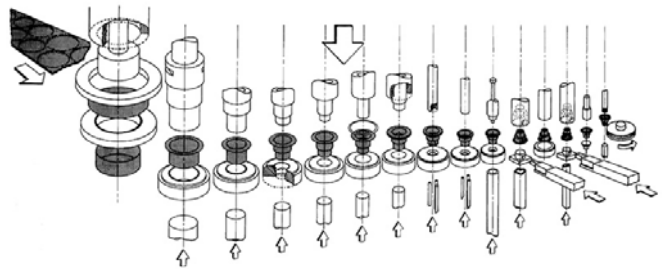


Figure 17-63 Various operations can be performed during the production of stamped and drawn parts on a transfer press. (Courtesy of U.S. Baird Corporation, Stratford, CT.)

Summary

- Sheet forming processes can be grouped in several broad categories
  - Shearing
  - Bending
  - Drawing
  - Forming
- Basic sheet forming operations involve a press, punch, or ram and a set of dies
- Material properties, geometry of the starting material, and the geometry of the desired final product play important roles in determining the best process