SME 2713
Manufacturing Process

Sheet Metal Forming

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Outline

1. Introduction
2. Important characteristics
3. Cutting Operations
4. Bending Operations
5. Drawing Operations
6. Other Operations

1. Introduction

- The development is much at a later date as compared with forging, rolling or extrusion processes, a round 1850s.
- Sheets are widely used due to a few reasons – productivity, good surface finish, close tolerance, high strength and various shapes can be produced. For large quantities, economical mass production operations are available,
- Sheet metal working defined
  - Cutting and forming operations performed on relatively thin sheets of metal.
  - Thickness of sheet metal ranging from 0.4 mm to 6 mm.
  - Thickness of plate stock > 6mm.
  - Operations usually performed as cold working

1. Introduction

- Sheet and plate metal parts for consumer and industrial products are numerous, such as
  - Automobiles and trucks
  - Airplanes
  - Farm and construction equipment
  - Small and large appliances
  - Office furniture
  - Computers and office equipment

1. Introduction

Historical note

- Sheet metal stamping was developed as a mass production technology for production of bicycles around 1890's. This technology played an important role in making the system of interchangeable parts economical

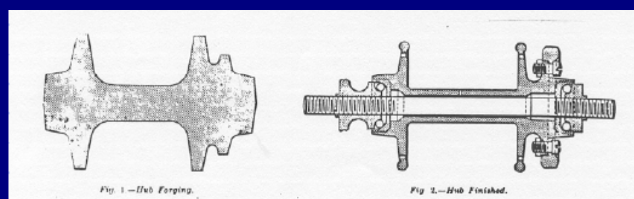
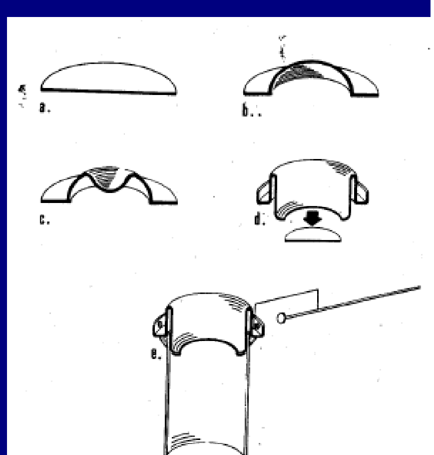
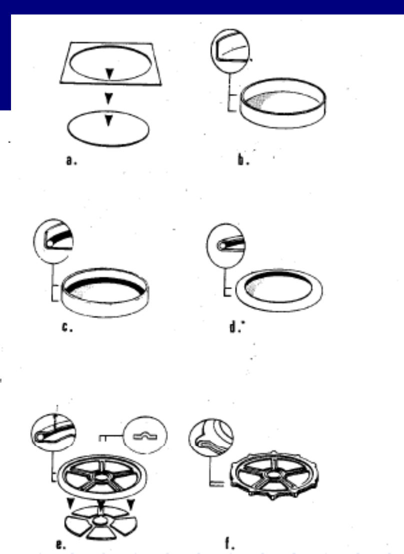


FIGURE 5.13. Sections of Hub Forging and Finished Hub for Columbia Bicycle, 1892. (*Iron Age*, June 1, 1892.)

1. Introduction





Steps in making Hub Steps in making Sprocket

Introduction

Three major categories of sheet metal processes

1. Cutting
   – Shearing to separate large sheets, or cut part perimeters or make holes in sheets
2. Bending
   – Straining sheet around a straight axis
3. Drawing
   – Forming of sheet into convex or concave shapes

SHEET METAL FORMING

FORMING 2

PROCESS

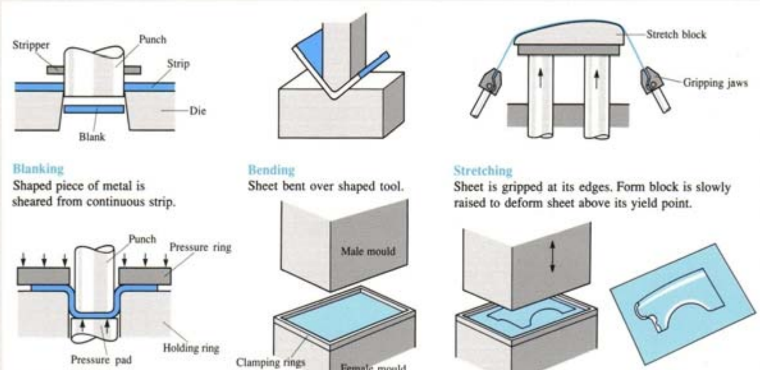
Sheet
Variety of sheet forming methods in which deformation is combination of blanking, bending, stretching and drawing.

SHAPE

3D
Shapes with essentially constant section thickness and no re-entrant angles. If depth:diameter ⩾ 1:1 the process is known as 'deep drawing'.

MATERIALS

Metals
Any ductile metal obtainable in sheet form.



Blanking
Shaped piece of metal is sheared from continuous strip.

Bending
Sheet bent over shaped tool.

Stretching
Sheet is gripped at its edges. Form block is slowly raised to deform sheet above its yield point.

Drawing
Sheet formed between tool and die

Pressing
Contains elements of bending, stretching and drawing

CYCLE TIME	QUALITY	FLEXIBILITY	MATERIALS UTILIZATION	OPERATING COST
Dictated normally by the rate of operation of the equipment, i.e. loading and unloading.	Surface texture usually good but depends on die design, lubrication and material. Problems include 'springback', wrinkling and Luders' band formation.	Tooling is dedicated. Setting up time depends on tooling complexity.	Scrap material is always produced by blanking and cannot be directly recycled.	Machines and dies are costly.

Introduction

- ***Sheet metal forming*** is a process that materials undergo ***permanent deformation*** by cold forming to produce a variety of complex three dimensional shapes
- The process is carried out in a plane of sheet by tensile forces with high ratio of surface area to thickness.
- ***Friction conditions*** at the tool-metal interface are very important and controlled by press conditions, lubrication, tool material and surface condition, and strip surface condition
- High rate of production and formability is determined by its mechanical properties

1. Introduction

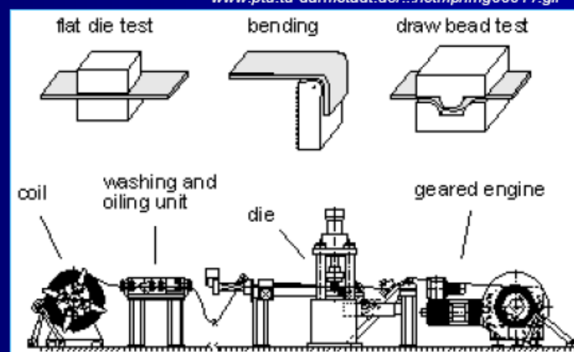
- Forming equipment include

1) Forming presses

2) Dies

3) Tools

www.ptu.tu-darmstadt.de/.../ictmp/img00011.gif



Equipments in sheet metal forming process

Sheet metal working in a factory

Sheet metal working in a factory

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Blanks are produced from rolled coils

Hot-rolled coils Cold-rolled coils

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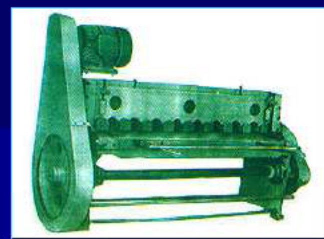
Forming machines

- Using mechanical or hydraulic presses.

1) ***Mechanical presses***
   - energy stored in a flywheel is transferred to the movable slide on the down stroke of the press.

   - quick - acting , short stroke.

2) ***Hydraulic presses***
   - slower - acting, longer stroke.



Shearing machine (mechanical)

Hydraulic deep drawing press

The machine (Mechanical press)

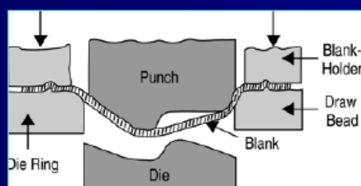
The tool (stamping dies)

Tools

Basic tools used with a metalworking press are the ***punch*** and the ***die***.

- ***Punch*** → A ***convex tool*** for making holes by shearing , or making surface or displacing metal with a hammer.
- ***Die*** → A ***concave die***, which is the female part as opposed to punch which is the male part.

Punches and dies



Punch and die in stamping

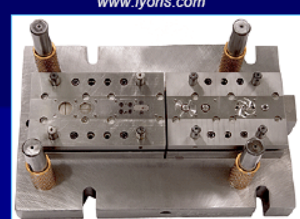
Die materials:

- High alloy steels heat treated for the punches and dies.

Compound dies

- ***Several operations*** can be performed on the same piece in ***one stroke*** of the press.
- ***Combined processes*** and create a complex product in one shot.
- Used in metal stamping processes of thin sheets.

www.lyons.com



Compound die

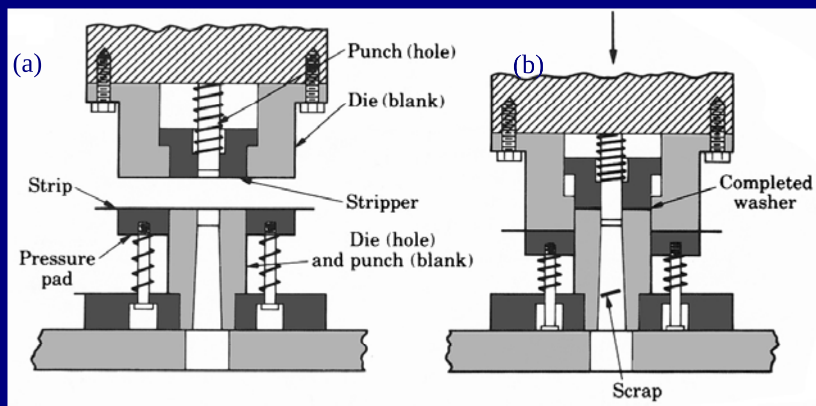
Transfer dies

- Transfer dies are also called ***compounding type dies***.
- The part is ***moved from station to station*** within the press for each operation.

www.deltatooling.co.jp/

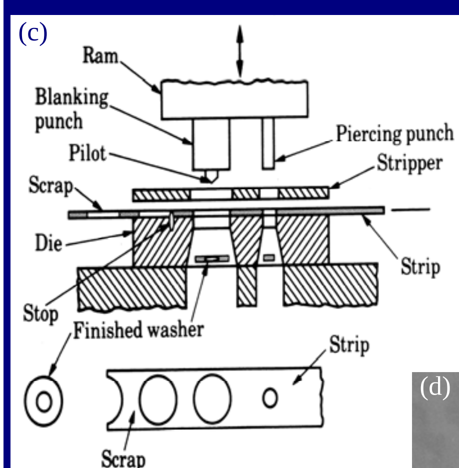
Transfer die

Compound Die

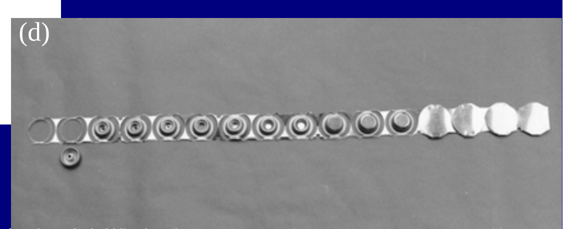


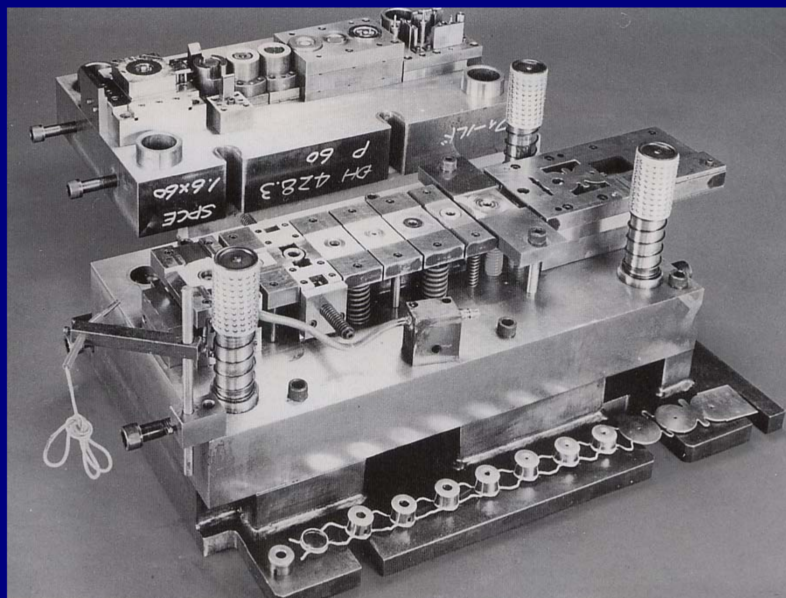
(a) before and (b) after blanking a common washer in a compound die. Note the separate movements of the die (for blanking) and the punch (for punching the hole in the washer).

Progressive Die



(c) Schematic illustration of making a washer in a progressive die. (d) Forming of the top piece of an aerosol spray can in a progressive die. Note that the part is attached to the strip until the last operation is completed.





2. Important Characteristics in Sheet Forming

1. **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*)desirable.

2. **Anisotropy (planar):** Exhibits different behavior in different planar directions; present in cold-rolled sheets because of preferred orientation or mechanical fibering; causes earing in drawing; can be reduced or eliminated by annealing but at lowered strength.

3. **Anisotropy (normal):** Determines thinning behavior of sheet metals during stretching; important in deep-drawing operations.

Important Characteristics……

4. **Grain size:** Determines surface roughness on stretched sheet metal; the coarser the grain, the rougher the appearance (orange peel); also affects material strength.

5. **Residual stresses:** Caused by nonuniform deformation during forming; causes part distortion when sectioned and can lead to stress-corrosion cracking; reduced or eliminated by stress relieving.

6. **Springback:** Caused by elastic recovery of the plastically deformed sheet after unloading; causes distortion of part and loss of dimensional accuracy; can be controlled by techniques such as overbending and bottoming of the punch.

Important Characteristics…….

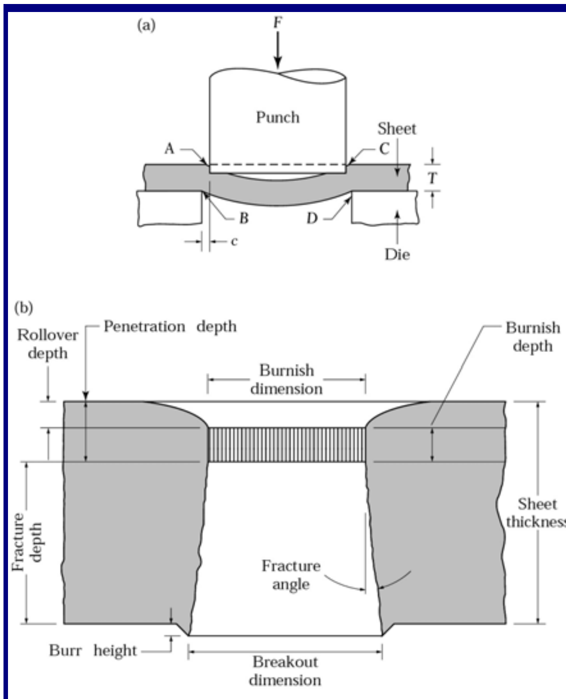
7. **Quality of sheared edges:** Depends on process used; edges can be rough, not square, and contain cracks, residual stresses, and a work-hardened layer, which are all detrimental to the formability of the sheet; quality can be improved by control of clearance, tool and die design, fine blanking, shaving,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

8. **Wrinkling:** Caused by compressive stresses in the plane of the sheet; can be objectionable or can be useful in imparting stiffness to parts; can be controlled by proper tool and die design.

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

3. Cutting Operations

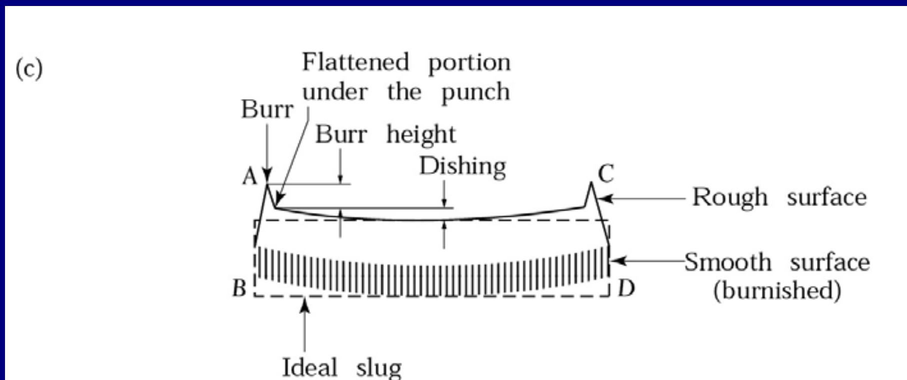
- Using the stamping press and die sets. For high quantity production
- Process parameters
  - Punch force
  - Punch speed
  - Lubrication
  - Workpiece surface condition
  - Material type and its thickness
  - Material for the punch and die
  - Edge radius of the punch and die
  - Clearance between die and punch



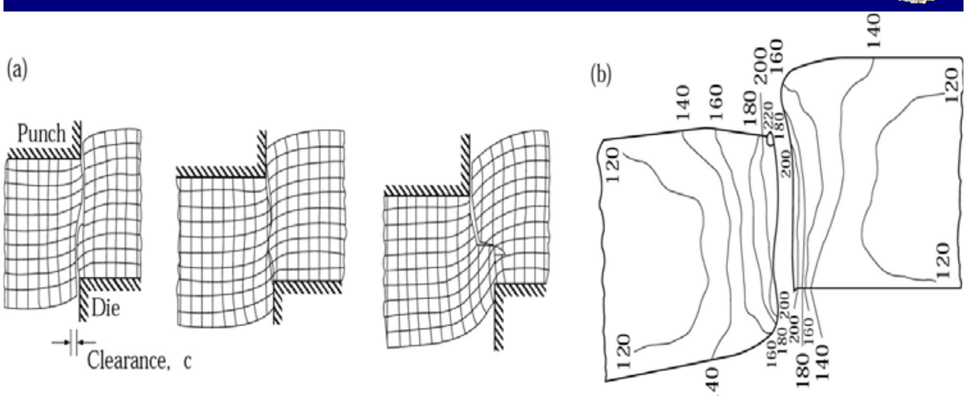
Shearing

(a) Schematic illustration of shearing with a punch and die, indicating some of the process variables. Characteristic features of (b) a punched hole and (c) the slug. Note that the scales of the two figures are different.

The Slug

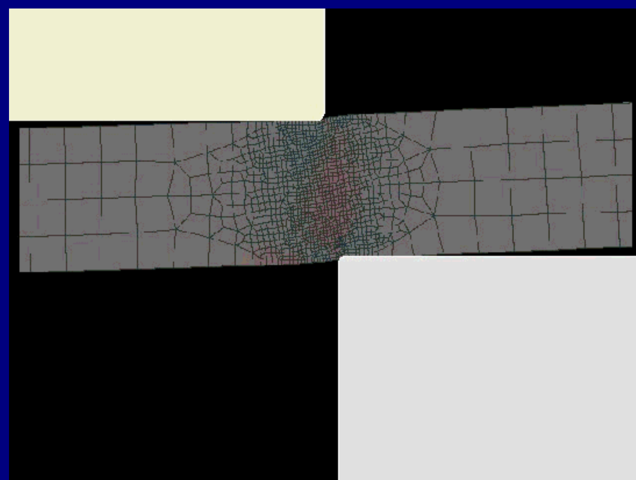


Clearance



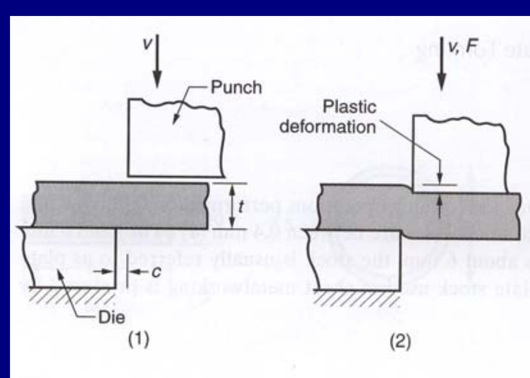
(a) Effect of the clearance, *c*, between punch and die on the deformation zone in shearing. As the clearance increases, the material tends to be pulled into the die rather than be sheared.

Shearing stages

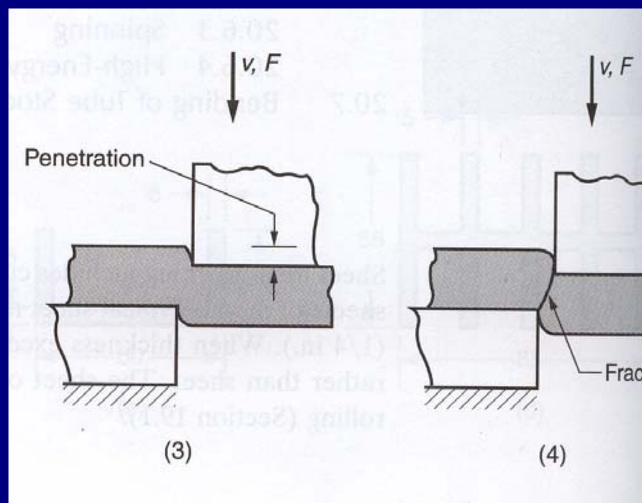


Shearing Stages

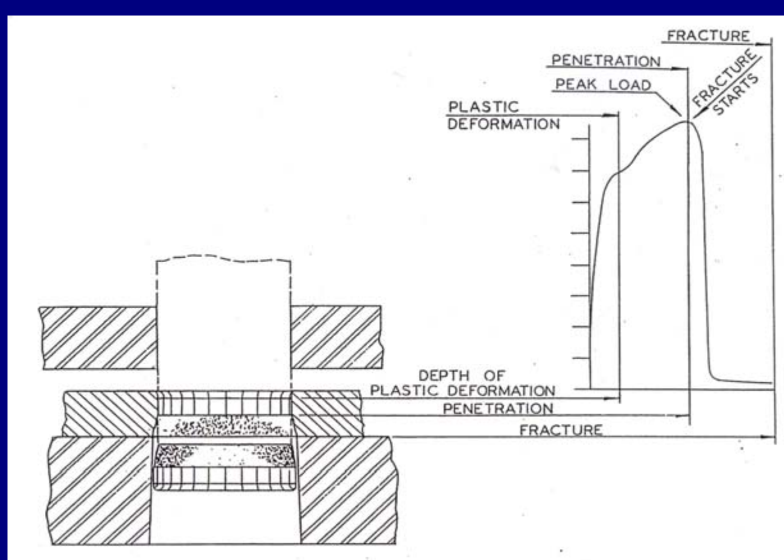
- Can be simplified into three main stages
  - plastic deformation
  - penetration
  - fracture



Shearing Stages



Cutting force related to stages of shearing action

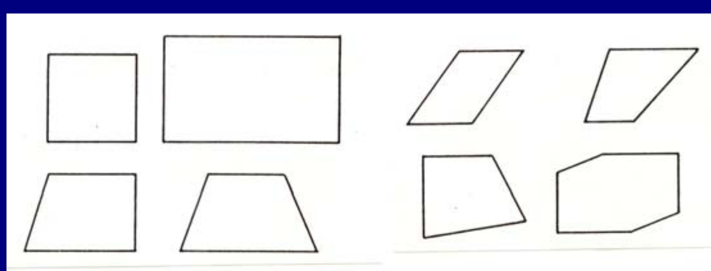


Cutting Operations

Various types of cutting operations – each operation requires a different type of die set.

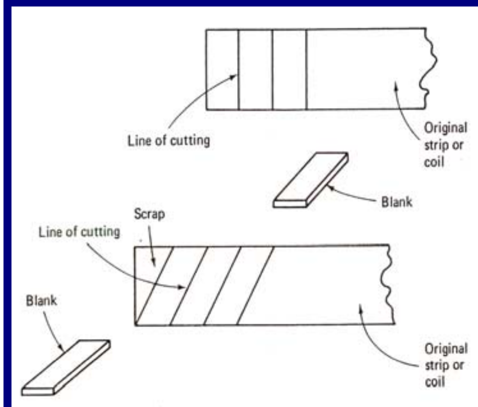
- Shearing,
- Cut-off,
- Parting,
- Blanking,
- Punching/piercing,
- Perforating
- Lanching
- Trimming
- Slitting
- Shaving

Shearing

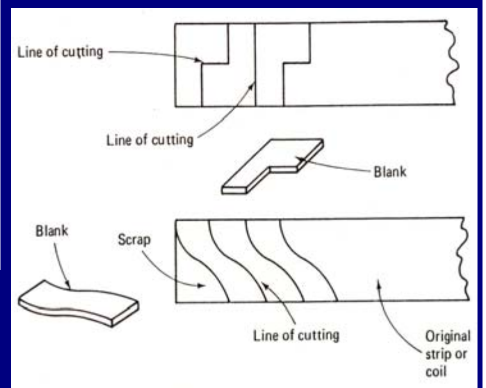


Shearing – the cutting action is along a straight line, using squaring shear machine – foot, hand or power operated. Cutting blades can be up to 20 feet long

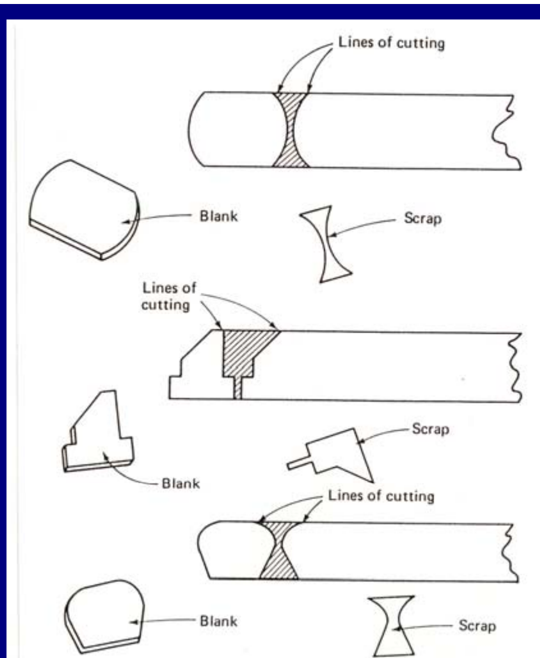
Cut-off



Part must fit or nest perfectly before cut-off operation. Performed in a die operated by a press



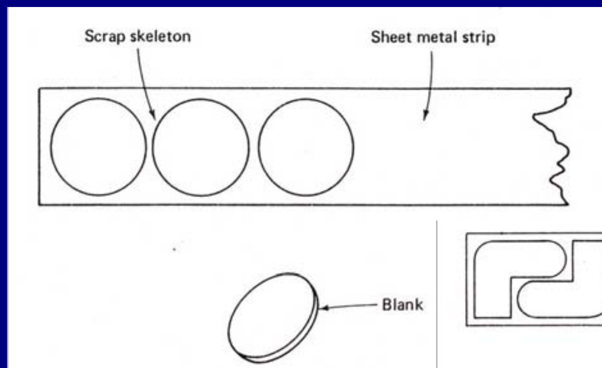
Cutting along a line – involve one or more cuts – straight, angular, jogged or curved design

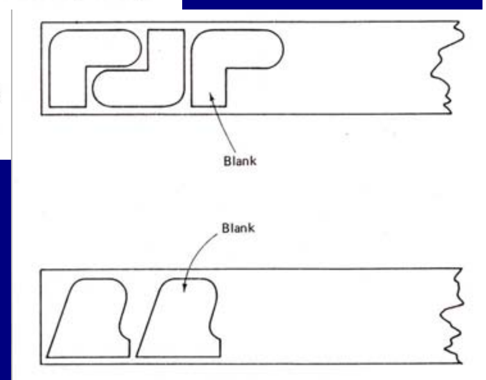


Parting

Two single-line cuts are made to cut blanks from strip, some scrap produced

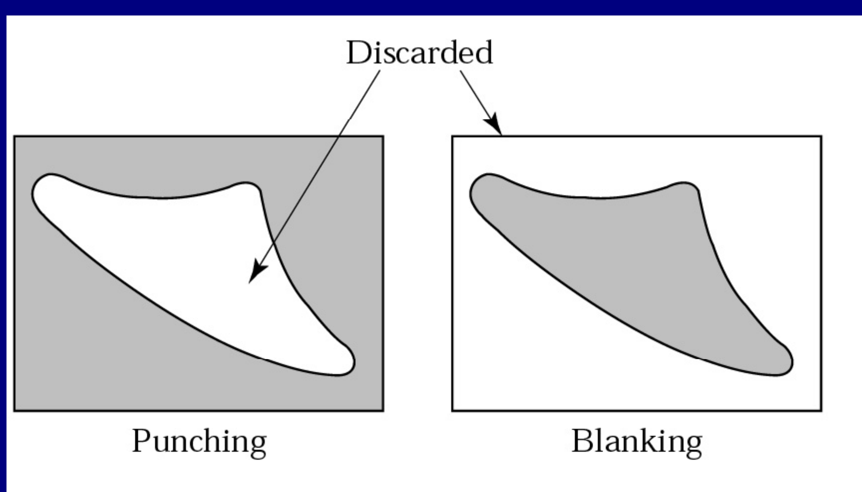
Blanking



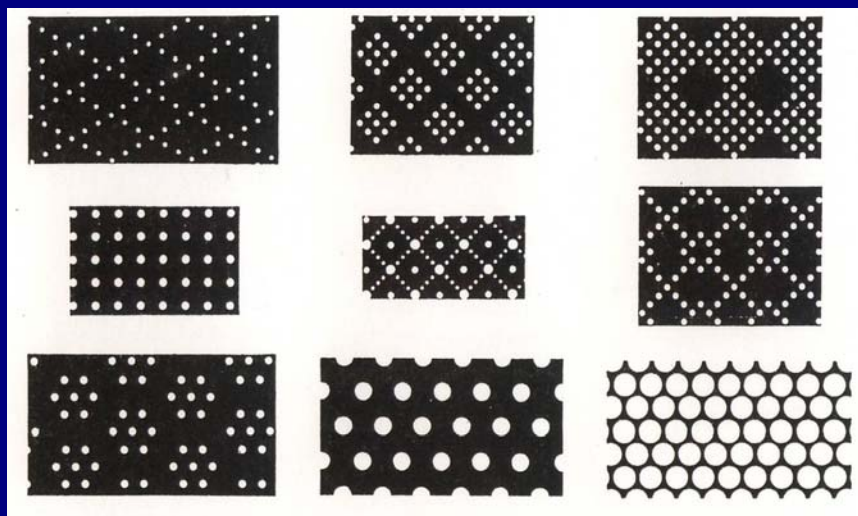


The cutting action make a complete or enclosed contour cut

Punching/Piercing



Perforating



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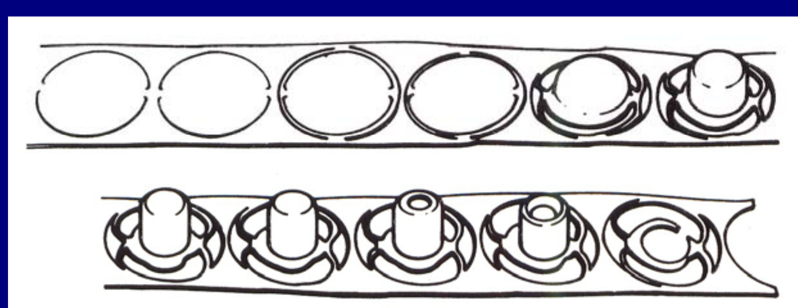
Lanching

Cut made partway through the metal, no scrap metal is freed from the strio. Lanching is frequently combined with bending to form tabs. Lanching cuts are necessary to create louvers for venting function, to release strip for forming operations



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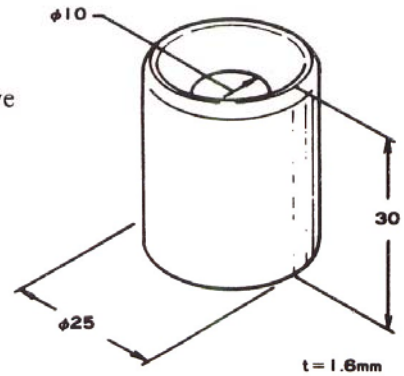
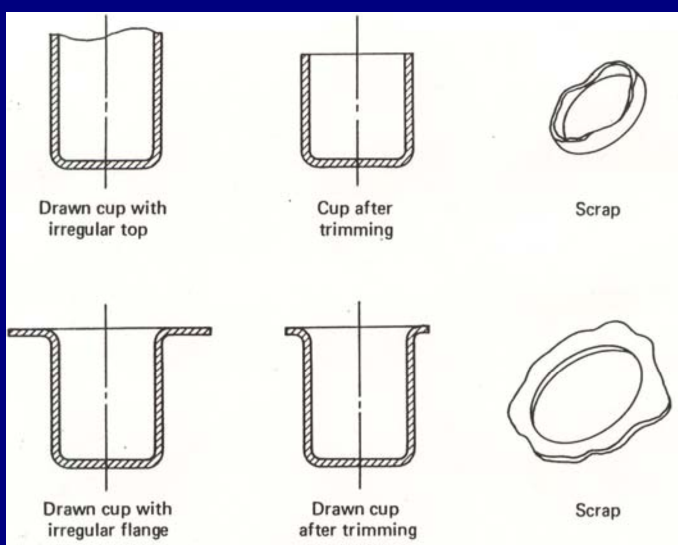
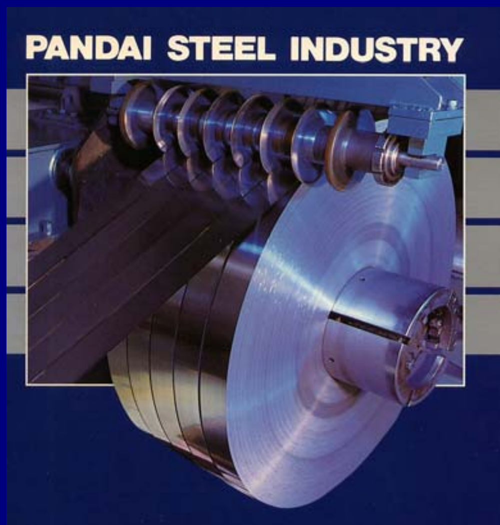
Part name: Case
Material: SPC
Press used: 150 tf progressive
Production rate: 40 per minute
Process:
1) Lancing
2) Idle
3) Lancing
4) Idle
5) Drawing
6) Redrawing
7) Redrawing
8) Restriking
9) Piercing
10) Forming
11) Blanking

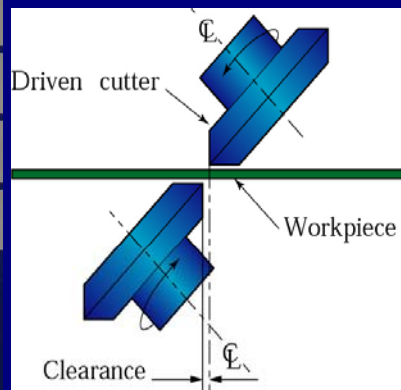


Trimming



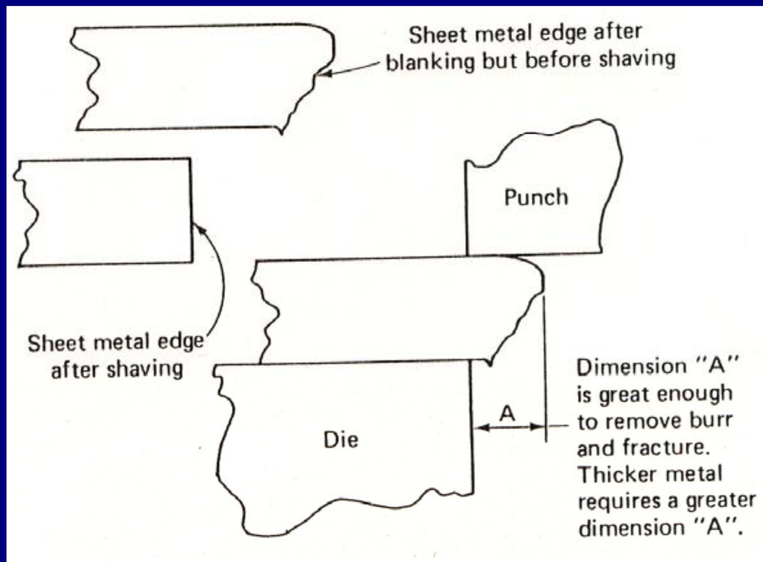
Slitting





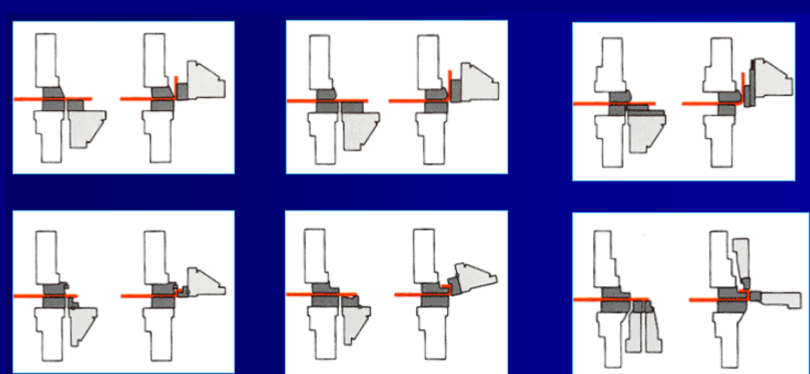
Slitting

Shaving



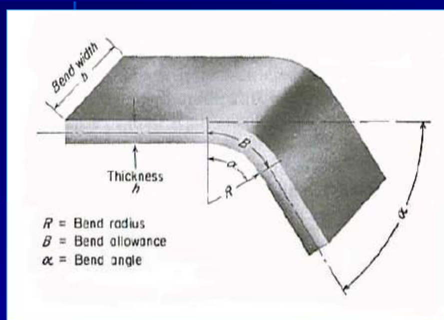
4. BENDING OPERATIONS

- A process by which a straight length is transformed into a curved length
- Produce channels, drums, tanks



4. BENDING OPERATIONS

The *bend radius R* = the radius of curvature on the concave, or inside surface of the bend



Fibres on the outer surface are ***strained*** more than fibres on the inner surface are ***contracted***. Fibres at the mid thickness is ***stretched***.

↓

Decrease in thickness (radius direction) at the bend to preserve the constancy of volume.

1 September 2008 Prof Madya Zainal Abidin Ahmad 47

The minimum bend radius

- For a given bending operation, the ***smallest bend radius*** can be made without ***cracking*** on the outer tensile surface.
- Normally expressed in multiples of sheet thickness.

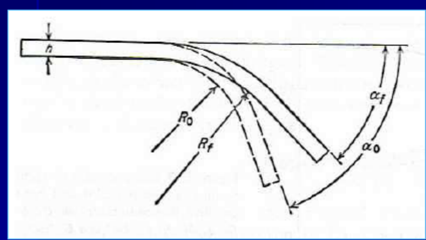
Example: a ***3T bend radius*** means the metal can be bend without cracking though a radius equal to three times the sheet thickness ***T***.

Minimum bend radii for various materials at room temperature.

MATERIAL	MATERIAL CONDITION	
	SOFT	HARD
Aluminum alloys	0	6T
Beryllium copper	0	4T
Brass, low-leaded	0	2T
Magnesium	5T	13T
Steels		
austenitic stainless	0.5T	6T
low-carbon, low-alloy, and HSLA	0.5T	4T
Titanium	0.7T	3T
Titanium alloys	2.6T	4T

Springback in Bending

- Dimensional change of the formed part after releasing the pressure of the forming tool due to the changes in strain produced by elastic recovery.
- Springback is encountered in all forming operations, but most easily occurs in bending

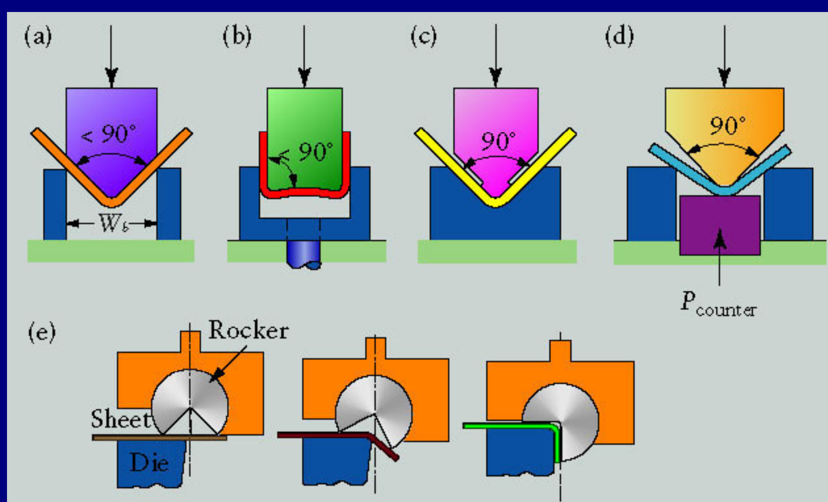


Yield stress	↑
Elastic modulus	↓

↓

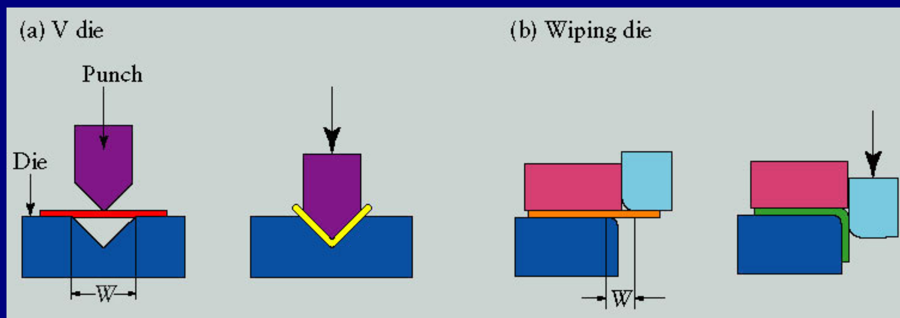
Plastic strain	↑
Spring back	↑

Methods of Reducing or Eliminating Springback



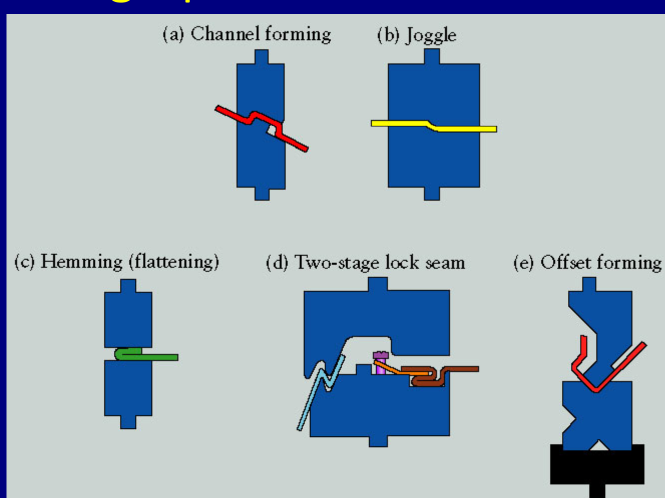
Methods of reducing or eliminating springback in bending operations. *Source*: V. Cupka, T. Nakagawa, and H. Tyamoto.

Common Die-Bending Operations



Common die-bending operations

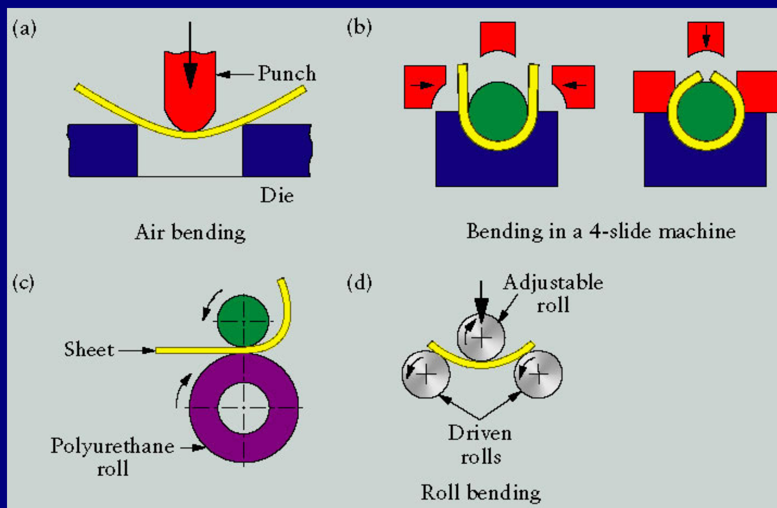
Bending Operations In a Press Brake



Schematic illustration of various bending operations

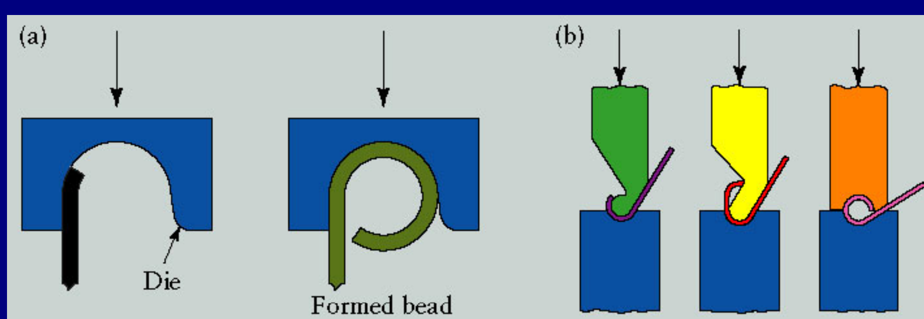
in a press brake.

Various Bending Operations



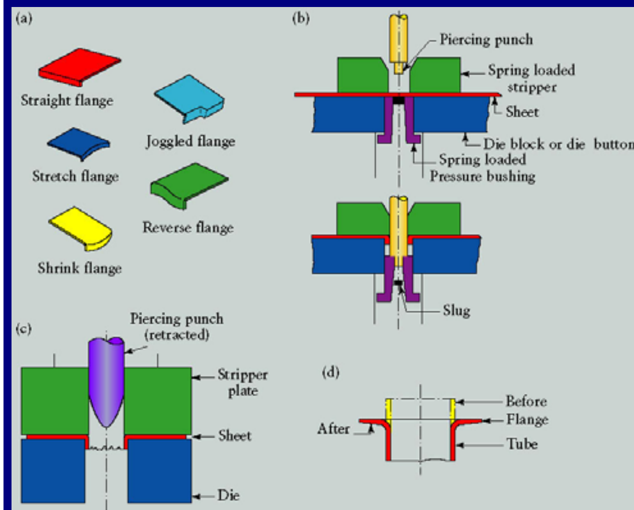
Examples of various bending operations.

Bead Forming



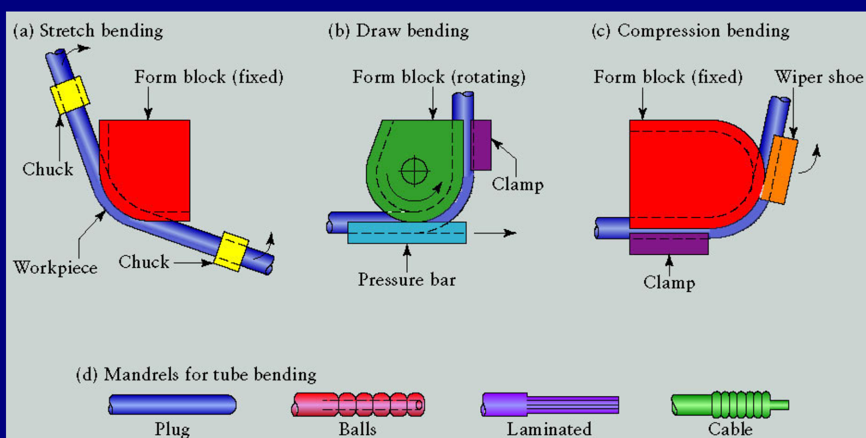
(a) Bead forming with a single die. (b) Bead forming with two dies in a press brake.

Flanging Operations



Various flanging operations. (a) Flanges on flat sheet. (b) Dimpling. (c) Piercing sheet metal to form a flange. in this operation, a hole does not have to be prepunched before the punch descends. Note, however, the rough edges along the circumference of the flange. (d) Flanging of a tube. Note the thinning of the edges of the flange.

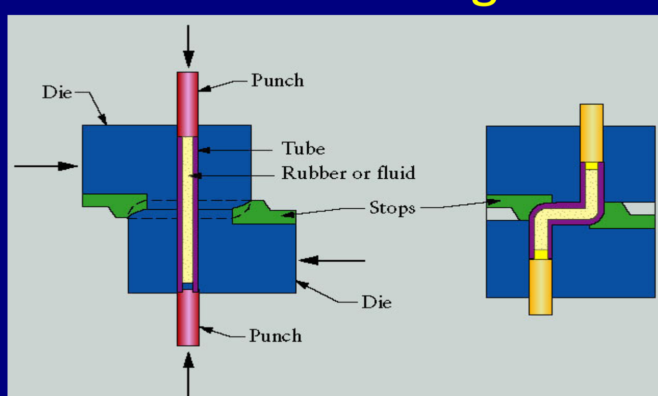
Bending of Tubes



Methods of bending tubes. Using internal mandrels, or filling tubes with particulate materials such as sand, is often necessary to prevent collapsing of the tubes during bending. Solid rods and structural shapes are also bent by these techniques.

Tube Bending

Tube Forming

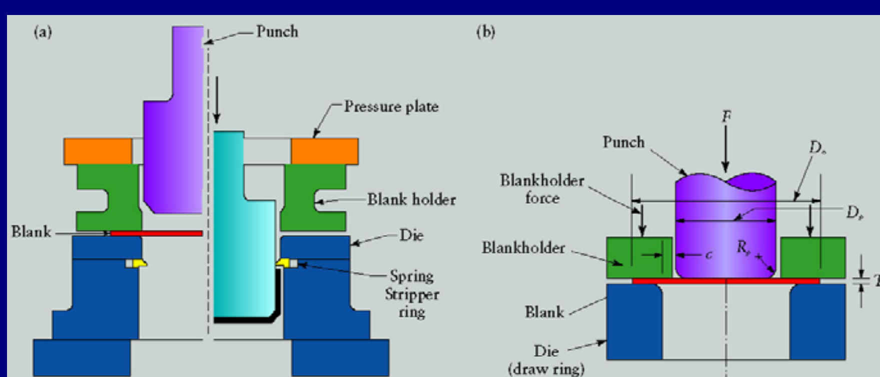


A method of forming a tube with sharp angles, using axial compressive forces. Compressive stresses are beneficial in forming operations because they delay fracture. Note that the tube is supported internally with rubber or fluid to avoid collapsing during forming. *Source*: After J. L. Remmerswaal and A. Verkaik.

5. Deep Drawing Process

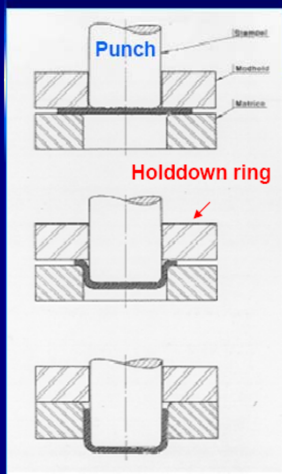
- The metalworking process used for shaping flat sheets into cup-shaped articles
- Examples – cooking pots, shell cases, automobile panels, bathtubs

5. Deep-drawing Process



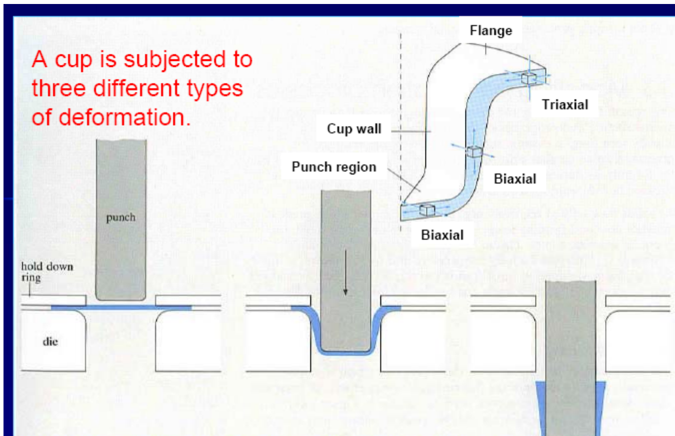
(a) Schematic illustration of the deep-drawing process. This procedure is the first step in the basic process by which aluminum beverage cans are produced today. The stripper ring facilitates the removal of the formed cup from the punch. (b) Variables in deep drawing of a cylindrical cup. Only the punch force in this illustration is a dependent variable; all others are independent variables, including the blankholder force.

5. Deep Drawing Process



- It is best done with ***double-action press.***
- Using a ***blank holder*** or a ***holddown ring***

- ***Complex interaction*** between metal and die depending on geometry.
- No precise ***mathematical description*** can be used to represent the processes in simple terms.



Stresses and deformation in a section from a drawn cup

As the metal being drawn,

- Change in radius
- Increase in cup wall

Thickness profile of drawn cup

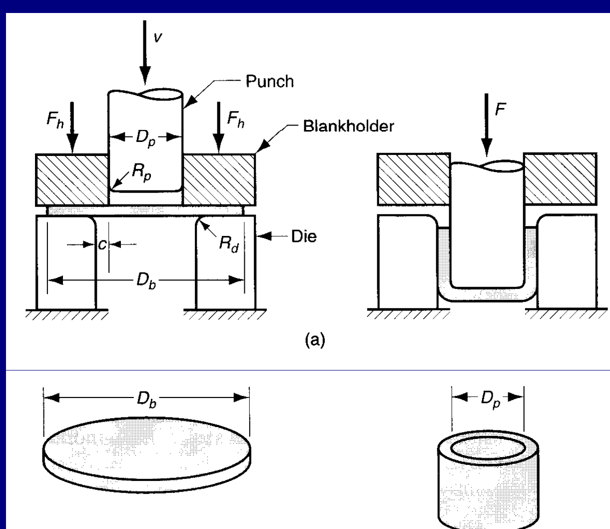
Clearance between the punch and the die > 10-20% thickness.

- Metal in the ***punch region*** is thinned down → ***biaxial tensile stress***.
- Metal in the ***cup wall*** is subjected to a ***circumference strain***, or hoop and a ***radial tensile strain.***
- Metal at the ***flange*** is ***bent*** and ***straightened*** as well as subjected to a ***tensile stress*** at the same time.

5. Deep Drawing

- Process parameters
  - Punch force and velocity
  - Edge radii of punch and die
  - *Drawing ratio*
  - Clearance
  - Lubrication
  - Blank holder & blank holding force
  - Type of material and thickness of the blank
- Drawing stages – as sown in the next figure. Normally carried out in a few stages before the final shape and size is achieved.

Drawing



c = Clearance

D_b = blank diameter

D_p = Punch diameter

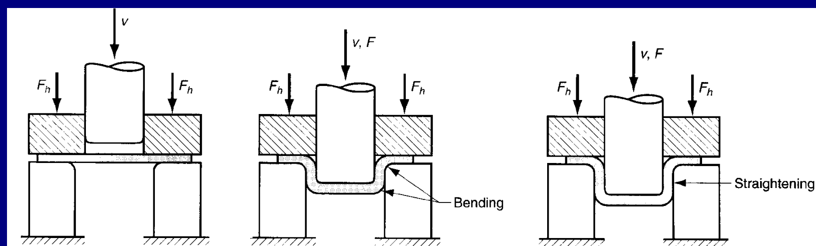
R_d = die corner radius

R_p = Punch corner radius

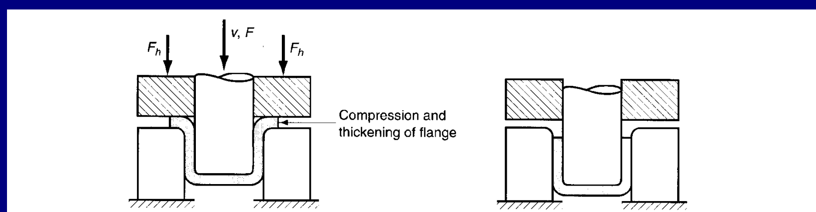
F = drawing force

F_h = holding force

Deep Drawing Stages



Initial step Bending of edge Straightening of side wall

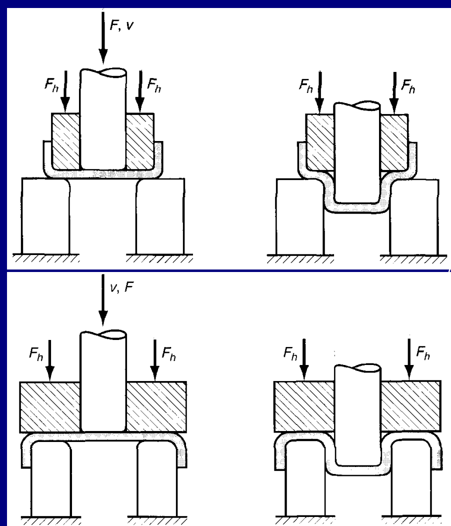


Thinning and drawing Final cup shape

Drawing Analysis

- Blank diameter can be calculated from the conservation of volume based on the final volume of the part.
- If the limits on the drawing ratio, reduction and thickness-to-diameter ratio are exceeded, the blank must be drawn in steps or having annealing between the steps.
- Process optimization:
  - Punch and die corner radii
  - friction
  - depth of draw (per step)
  - material characteristics

Other Drawing Operations

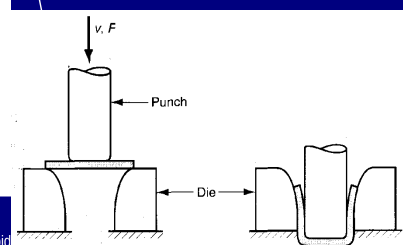


Redrawing

Reverse drawing

- r, 40%-45% first draw
- r, 30% second draw
- r, 16% third draw

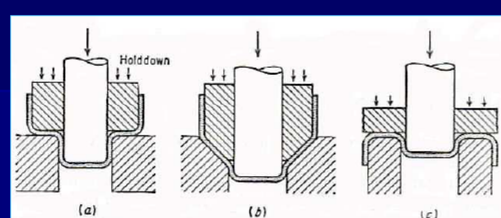
Drawing without blank holder, $D_b - D_p < 5t$



Redrawing

- Use successive drawing operations by reducing a cup or drawn part to a ***smaller diameter*** and ***increased height*** – known as ***redrawing***.

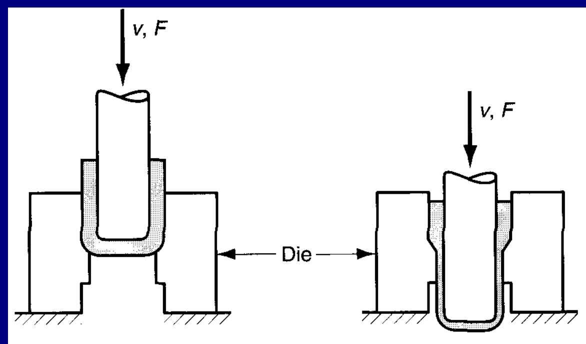
Examples: slender cups such as cartridge case and closed-end tubes.



1) Direct or regular redrawing : smaller diameter is produced by means of a ***hold-down ring***. The metal must be bent at the punch and unbent at the die radii see *Fig (a)*. ***Tapered die*** allows lower punch load, *Fig (b)*.

2) Reverse or indirect redrawing : the cup is turned inside out → the outside surface becomes the inside surface, *Fig (c)*. Better control of ***wrinkling*** and no ***geometrical limitations*** to the use of a hold-down ring.

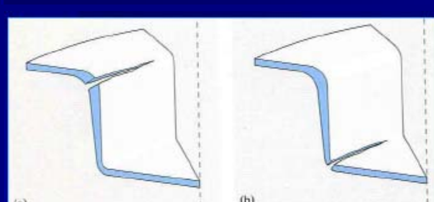
Ironing



Ironing - squeezing and drawing in conjunction

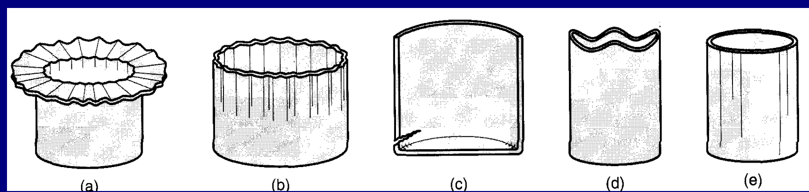
Practical considerations affecting drawability

- ***Die radius*** – should be about ***10 x sheet thickness.***
- ***Punch radius*** – a sharp radius leads to local thinning and tearing. Clearance between punch and die should be about 20-40% > sheet thickness.
- ***Hold-down pressure*** – about 2% of average σ_o and σ_u.
- ***Lubrication of die side*** - to reduce friction in drawing.
- ***Material properties*** - low yield stress, high work hardening rates, high values of strain ratio of width to thickness ***R***.



- Since the forming load is carried by the side wall of the cup, failure therefore occurs at the thinnest part.
- In practice the materials always fails either at *(a)* ***the shoulder of the die*** and *(b)* ***the shoulder of the punch.***

Drawing Defects



a) Wrinkling in flange - small holding force
b) Wrinkling in the wall - insufficient holding force, wrinkling initially occurring on the flange.
c) Tearing - high stress, sharp die radius
d) Earing - anisotropy of the material
e) Surface scratches - Die or punch not having a smooth surface, insufficient lubrication

6. Other processes – Stretch Forming

- Forming by using *tensile forces* to stretch the material over a tool or form block
- Used most extensively in the *aircraft industry* to produce parts of large radius of curvature (normally for uniform cross-section)
- Required materials with appreciable ductility
- *Springback* is largely eliminated because the stress gradient is relatively uniform

6. Other processes – Stretch Forming

Stretch forming feasible for aluminium, stainless steel, titanium.

6. Other processes – Stretch Forming

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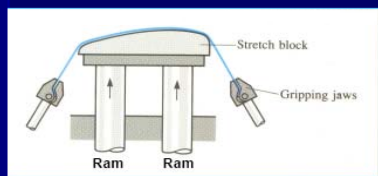
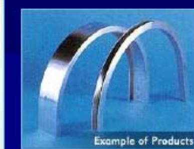
Stretch forming equipment

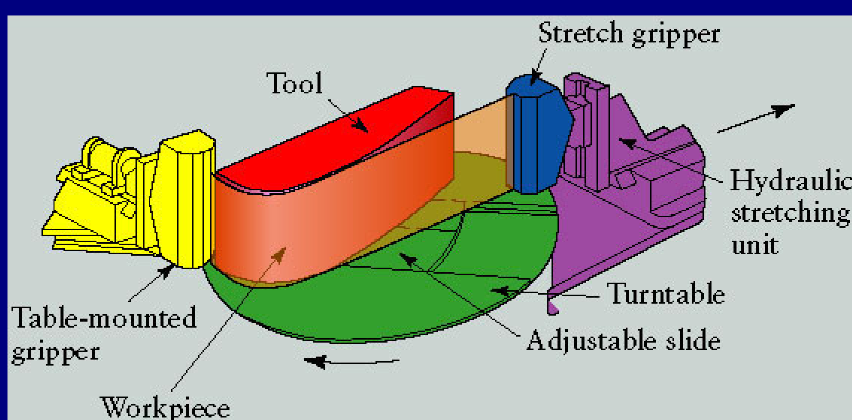




- Using a hydraulic driven ram (normally vertical).
- Sheet is gripped by two jaws at its edges.
- Form block is slowly raised by the ram to deform sheet above its ***yield point***.
- The sheet is strained plastically to the required final shape.

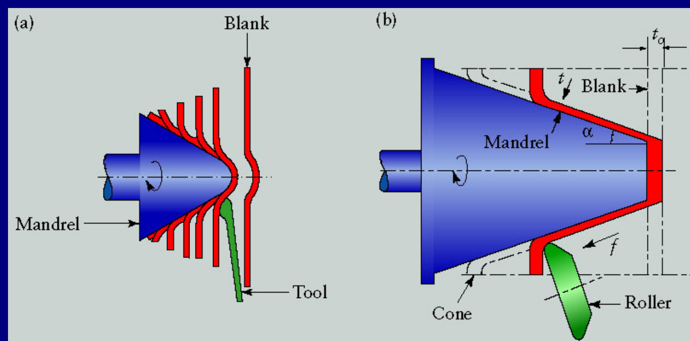
Examples: large thin panel, most complex automotive stamping involve a stretching component.

Stretch-Forming Process



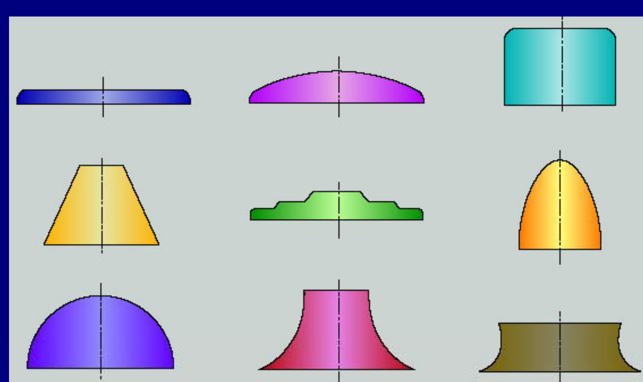
Schematic illustration of a stretch-forming process. Aluminum skins for aircraft can be made by this process. *Source*: Cyril Bath Co.

6. Spinning Processes



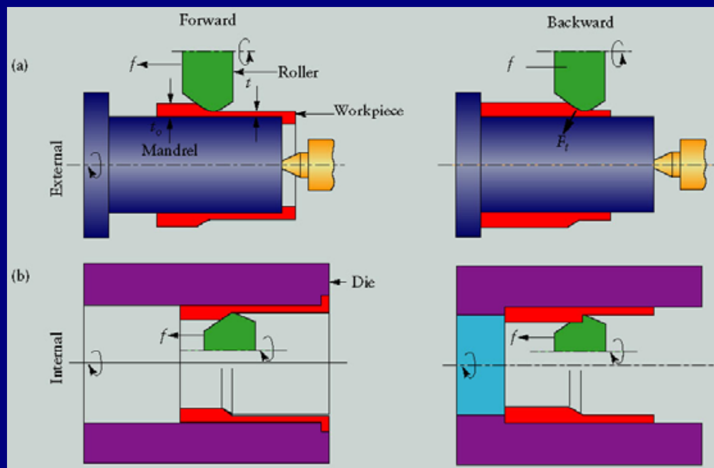
Schematic illustration of spinning processes: (a) conventional spinning and (b) shear spinning. Note that in shear spinning, the diameter of the spun part, unlike in conventional spinning, is the same as that of the blank. The quantity *f* is the feed (in mm/rev or in./rev).

Shapes in Spinning Processes



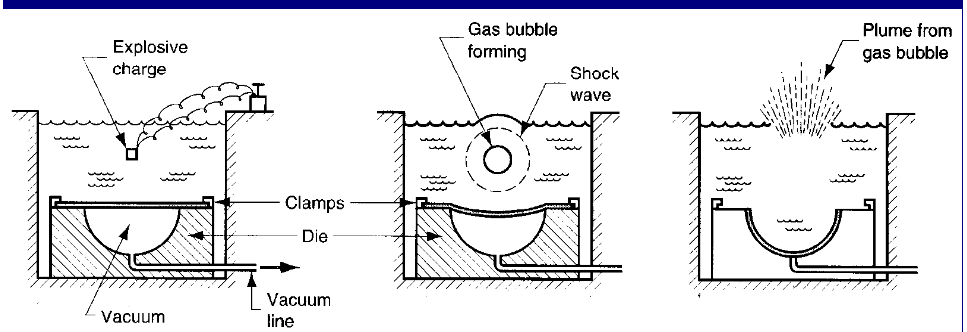
Typical shapes produced by the conventional-spinning process. Circular marks on the external surfaces of components usually indicate that the parts have been made by spinning. Examples include aluminum kitchen utensils and light reflectors.

Internal And External Tube Spinning



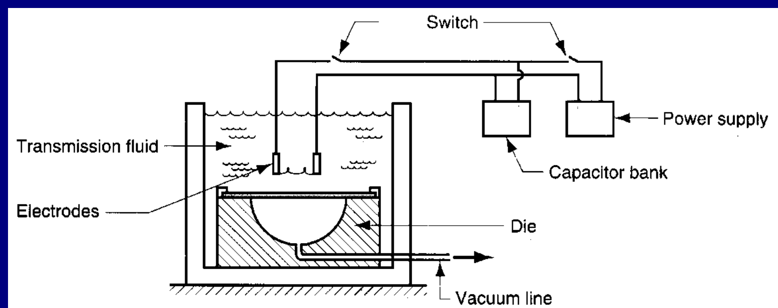
Examples of external and internal tube spinning and the variables involved.

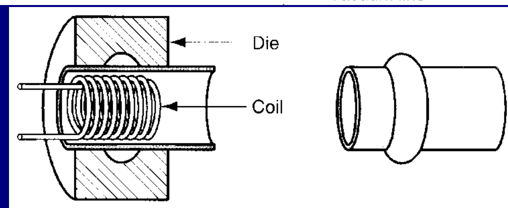
6. High Energy Forming



Explosive forming

High Energy Forming





Electrohydraulic forming, Electromagnetic forming

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