Introduction

- Products made of sheet metals are common
- Pressworking or press forming is used for general sheet-forming operations, as they are performed on presses using a set of dies
A sheet-metal part produced in presses is called a *stamping*.  
Low-carbon steel has low cost and good strength and formability characteristics.  
Manufacturing processes involving sheet metal are performed at room temperature.
# Introduction

## General Characteristics of Sheet-metal Forming Processes (in alphabetic order)

<table>
<thead>
<tr>
<th>Forming process</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing</td>
<td>Shallow or deep parts with relatively simple shapes, high production rates, high tooling and equipment costs</td>
</tr>
<tr>
<td>Explosive</td>
<td>Large sheets with relatively simple shapes, low tooling costs but high labor cost, low-quantity production, long cycle times</td>
</tr>
<tr>
<td>Incremental</td>
<td>Simple to moderately complex shapes with good surface finish; low production rates, but no dedicated tooling required; limited materials</td>
</tr>
<tr>
<td>Magnetic-pulse</td>
<td>Shallow forming, bulging, and embossing operations on relatively low strength sheets, requires special tooling</td>
</tr>
<tr>
<td>Peen</td>
<td>Shallow contours on large sheets, flexibility of operation, generally high equipment costs, process also used for straightening formed parts</td>
</tr>
<tr>
<td>Roll</td>
<td>Long parts with constant simple or complex cross sections, good surface finish, high production rates, high tooling costs</td>
</tr>
<tr>
<td>Rubber</td>
<td>Drawing and embossing of simple or relatively complex shapes, sheet surface protected by rubber membranes, flexibility of operation, low tooling costs</td>
</tr>
<tr>
<td>Spinning</td>
<td>Small or large axisymmetric parts; good surface finish; low tooling costs, but labor costs can be high unless operations are automated</td>
</tr>
<tr>
<td>Stamping</td>
<td>Includes a wide variety of operations, such as punching, blanking, embossing, bending, flanging, and coining; simple or complex shapes formed at high production rates; tooling and equipment costs can be high, but labor cost is low</td>
</tr>
<tr>
<td>Stretch</td>
<td>Large parts with shallow contours, low-quantity production, high labor costs, tooling and equipment costs increase with part size</td>
</tr>
<tr>
<td>Superplastic</td>
<td>Complex shapes, fine detail and close dimensional tolerances, long forming times (hence production rates are low), parts not suitable for high-temperature use</td>
</tr>
</tbody>
</table>
Shearing

- Before a sheet-metal part is made, a *blank* is removed from a large sheet by *shearing*.
- The edges are not smooth and perpendicular to the plane of the sheet.
Shearing

- Processing parameters in shearing are:
  1. The shape of the punch and die
  2. The speed of punching
  3. Lubrication
  4. The **clearance**, \( c \), between the punch and the die

- When clearance increases, the zone of deformation becomes larger and the sheared edge becomes rougher.

- Extent of the deformation zone depends on the punch speed.

- Height, shape, and size of the burr affect forming operations.
Shearing

**Punch Force**

- Maximum punch force, $F$, can be estimated from

\[ F = 0.7TL(UTS) \]

- $T = \text{sheet thickness}$
- $L = \text{total length sheared}$
- $UTS = \text{ultimate tensile strength of the material}$

- Friction between the punch and the workpiece can increase punch force
EXAMPLE 16.1

Calculation of Punch Force

Estimate the force required for punching a 25-mm diameter hole through a 3.2-mm thick annealed titanium-alloy Ti-6Al-4V sheet at room temperature.

Solution

UTS for this alloy is 1000 MPa, thus

\[ F = 0.7(32)(\pi)(25)(1000) = 0.18 \text{ MN} \]
Shearing: Shearing Operations

- **Punching** is where the sheared slug is scrap
- **Blanking** is where the slug is the part to be used and the rest is scrap

Die Cutting

- Shearing operation consists of:
  - **Perforating**: punching holes in a sheet
  - **Parting**: shearing sheet into pieces
  - **Notching**: removing pieces from the edges
  - **Lancing**: leaving a tab without removing any material
Fine Blanking

- Very smooth and square edges can be produced by *fine blanking*
- Fine-blanking process can control small range of clearances and dimensional tolerances
Shearing: Shearing Operations

Slitting

- Shearing operations are through a pair of circular blades, follow either a straight line, a circular path, or a curved path.
Shearing: Tailor-welded Blanks

- Laser-beam butt welding involves two or more pieces of sheet metal with different shapes and thicknesses.
- The strips are welded to obtain a locally thicker sheet and then coiled.
- Resulting in:
  1. Reduction in scrap
  2. Elimination of the need for subsequent spot welding
  3. Better control of dimensions
  4. Improved productivity

Copyright © 2010 Pearson Education South Asia Pte Ltd
EXAMPLE 16.2

Tailor-welded Sheet Metal for Automotive Applications

- Production of an outer side panel of a car body is by laser butt welding and stamping

Legend:
- g 60/60 (45/45) Hot-galvanized alloy steel sheet. Zinc amount: 60/60 (45/45) g/m².
- m 20/20 Double-layered iron–zinc alloy electroplated steel sheet. Zinc amount 20/20 g/m².
Shearing: Tailor-welded Blanks

EXAMPLE 16.2

Tailor-welded Sheet Metal for Automotive Applications

- Some of the examples of laser butt-welded and stamped automotive-body components.
Clearance

- Clearance control determine quality of its sheared edges which influence formability of the sheared part.
- Appropriate clearance depends on:
  1. Type of material and temper
  2. Thickness and size of the blank
  3. Proximity to the edges of other sheared edges
- When sheared edge is rough it can be subjected to a process called **shaving**
Shearing:
Characteristics and Type of Shearing Dies

Punch and Die Shape

- Punch force increases rapidly during shearing
- Location of sheared regions can be controlled by beveling the punch and die surfaces
Shearing: Characteristics and Type of Shearing Dies

**Compound Dies**

- Operations on the same sheet may be performed in one stroke with a *compound die*
- Limited to simple shapes due to:
  1. Process is slow
  2. Complex dies is more expensive
Shearing:
Characteristics and Type of Shearing Dies

Progressive Dies

- For high product production rates
- The part shown below is the small round piece that supports the plastic tip in spray cans
Shearing: Characteristics and Type of Shearing Dies

Transfer Dies

- Sheet metal undergoes different operations arranged along a straight line or a circular path

Tool and Die Materials

- Tool and die materials for shearing are tool steels and carbides
- Lubrication is needed for reducing tool and die wear, and improving edge quality
Shearing:

Miscellaneous Methods of Cutting Sheet Metal

- Other methods of cutting sheets
  1. Laser-beam cutting
  2. Water-jet cutting
  3. Cutting with a **band saw**
  4. Friction sawing
  5. Flame cutting
## Important Metal Characteristics for Sheet-forming Operations

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

- A specimen subjected to tension undergoes **uniform elongation**
- When the load exceeds the UTS, the specimen begins to neck

Yield-point Elongation

- **Yield-point elongation**: having both upper and lower yield points
- **Lüder’s bands** has elongated depressions on the surface of the sheet
Sheet-metal Characteristics and Formability

Yield-point Elongation

Anisotropy

- Obtained during the thermo-mechanical processing
- 2 types: crystallographic anisotropy and mechanical fibering
Sheet-metal Characteristics and Formability

Grain Size
- Affects mechanical properties and surface appearance
- Smaller the grain size, stronger is the metal

Dent Resistance of Sheet Metals
- Dents caused by dynamic forces from moving objects that hit the sheet metal
- *Dynamic yield stress*, instead of static yield stress, should be the significant strength parameter
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.
Forming-limit Diagrams

- *Forming-limit diagrams* is to determine the formability of 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*. 
Bending is a common industrial forming operation. Bending imparts stiffness to the part by increasing its moment of inertia. Outer fibers are in tension, while the inner is in compression. Poisson effect causes the width to be smaller in the outer region and larger in the inner region.
Approximate bend allowance is \( L_b = \alpha(R + kT) \)

For ideal case, \( k = 0.5 \), \( L_b = \alpha\left(R + \frac{T}{2}\right) \)

Minimum Bend Radius

Engineering strain during bending is \( e = \frac{1}{(2R/T) + 1} \)

Minimum bend radius, \( R \), is \( R = T\left(\frac{50}{r} - 1\right) \)
Minimum Bend Radius

- Increase the bendability by increasing their tensile reduction of area.
- Bendability also depends on the *edge condition* of the sheet.
- Improve resistance to edge cracking by removing the cold-worked regions.
- Cold rolling results in anisotropy by *preferred orientation* or *mechanical fibering*.
Springback

- Plastic deformation is followed by elastic recovery when the load is removed, called *springback*.
- Springback can be calculated by

\[
\frac{R_i}{R_f} = 4\left(\frac{R_i Y}{E T}\right)^3 - 3\left(\frac{R_i Y}{E T}\right) + 1
\]
Compensation for Springback

- Springback is compensated for by *overbending* the part.
- One method is *stretch bending* where the part is subjected to tension while being bent.

Bending Force

- Excluding friction, the *maximum bending force*, \( P \), is given by:
  \[
  P = \frac{kYLT^2}{W}
  \]
- For a V-die, it is modified to:
  \[
  P = \frac{(UTS)LT^2}{W}
  \]
Bending Sheets, Plates, and Tubes

Bending Force

- Examples of various bending operations

(a) Air bending
(b) Bending in a four-slide machine
(c) Roll bending
(d) Polyurethane roll
Sheet metal or plate can be bent easily with simple fixtures using a press.

The machine uses long dies in a mechanical / hydraulic press suitable for small production runs.

*Die materials* range from hardwood to carbides.
Bending in a Four-slide Machine

- Lateral movements are synchronized with vertical die movement to form the part into desired shapes.

Roll Bending

- Plates are bent using a set of rolls.
- Curvatures can be obtained by adjusting the distance between the three rolls.
Miscellaneous Bending and Related Operations

Beading

- Periphery of the sheet metal is bent into the cavity of a die
- The bead imparts stiffness to the part by increasing the moment of inertia of that section
Flanging

- **In shrink flanging**, the flange is subjected to compressive hoop stresses and cause the flange periphery to wrinkle.
Roll Forming

- Also called *contour-roll forming* or *cold-roll forming*
- Used for forming continuous lengths of sheet metal and for large production runs
- Dimensional tolerances, springback, tearing and buckling of the strip have to be considered
Oldest method of bending a tube is to first pack its inside with loose particles and then bend it into a suitable fixture.

Thick tube can be formed to a large bend radius without the use of fillers or plugs.
Miscellaneous Bending and Related Operations

Dimpling, Piercing, and Flaring

- In *dimpling*, a hole first is punched and then expanded into a flange.
- Flanges and tube ends may be produced by *piercing* with a shaped punch.
- When the bend angle is less than 90°, the process is called *flaring*.

Hemming and Seaming

- Hemming increases the stiffness and appearance of the part.
- *Seaming* is joining 2 edges of sheet metal by hemming.
Segmented Dies
- Dies consist of individual segments placed inside the part and expanded mechanically in a radial direction
- Inexpensive and used for large production runs

Stretch Forming
- Sheet metal is clamped along its edges and then stretched over a male die
- Die moves upward, downward, or sideways
- Used to make aircraft wing-skin panels, fuselages, and boat hulls
Miscellaneous Bending and Related Operations

Stretch Forming

(a) Diagram showing components of Stretch Forming:
- Workpiece
- Tool
- Stretch gripper
- Table-mounted gripper
- Hydraulic stretching unit
- Turntable
- Adjustable slide

(b) Stages of Stretching:
1. Stretching
2. (b) Initial positioning
3. Final positioning

Copyright © 2010 Pearson Education South Asia Pte Ltd
Deep Drawing

- Parts are made by having punch forces on a flat sheet-metal blank into a die cavity, a process called *deep drawing*.
- Also used to make parts that are shallow or have moderate depth.
- A round sheet-metal blank is placed over a circular die opening and is held in place with a **blankholder**.
Deep Drawing

1. Blanking

   Process:
   - Punch
   - Stock
   - Die
   - Blank

   Result:
   - Cross section

2. Deep drawing

   Process:
   - Punch
   - Blank
   - Die
   - Blank-holder

   Result:
   -

3. Redrawing

   Process:
   - Punch
   - Deep-drawn cup
   - Die
   - Hold down

   Result:
   -

4. Ironing

   Process:
   - Punch
   - Redrawn cup
   - Die
   - Ironing ring

   Result:
   -

5. Doming

   Process:
   - Punch
   - Ironed cup
   - Die

   Result:
   -

6. Necking

   Process:
   - Domed can
   - Support
   - Spinning tools

   Result:
   -

7. Seaming

   Process:
   - Chuck
   - Lid
   - Before
   - After
   - Roller
   - Can body

   Result:
   -
Wrinkling can be reduced if a blankholder is loaded by \textit{maximum punch force}

\[ F_{max} = \pi D_p T(UTS) \left[ \left( \frac{D_0}{D_p} \right)^2 - 0.7 \right] \]

The force increases with increasing blank diameter, thickness, strength and the ratio.
Deep Drawing: Deep Drawability

- Failure results from the *thinning* of the cup wall under high longitudinal tensile stresses ratio

- *Deep drawability* generally is expressed by the **limiting drawing ratio** (LDR) as

\[
LDR = \frac{\text{Max blank diameter}}{\text{Punch diameter}} = \frac{D_0}{D_p}
\]

- Normal anisotropy is defined as

\[
R = \frac{\text{Width strain}}{\text{Thickness strain}} = \frac{\varepsilon_w}{\varepsilon_t}
\]
Deep Drawing: Deep Drawability

- $R$ value depend on its orientation with respect to the rolling direction of the sheet.
- Thus the average is

$$R_{\text{avg}} = \frac{R_0 + 2R_{45} + R_{90}}{4}$$

### Typical Ranges of Average Normal Anisotropy, $R_{\text{avg}}$, for Various Sheet Metals

<table>
<thead>
<tr>
<th>Material</th>
<th>$R_{\text{avg}}$ Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc alloys</td>
<td>0.4–0.6</td>
</tr>
<tr>
<td>Hot-rolled steel</td>
<td>0.8–1.0</td>
</tr>
<tr>
<td>Cold-rolled, rimmed steel</td>
<td>1.0–1.4</td>
</tr>
<tr>
<td>Cold-rolled, aluminum-killed steel</td>
<td>1.4–1.8</td>
</tr>
<tr>
<td>Aluminum alloys</td>
<td>0.6–0.8</td>
</tr>
<tr>
<td>Copper and brass</td>
<td>0.6–0.9</td>
</tr>
<tr>
<td>Titanium alloys ($\alpha$)</td>
<td>3.0–5.0</td>
</tr>
<tr>
<td>Stainless steels</td>
<td>0.9–1.2</td>
</tr>
<tr>
<td>High-strength, low-alloy steels</td>
<td>0.9–1.2</td>
</tr>
</tbody>
</table>
Earing

- In deep drawing, the edges of cups may become wavy and the phenomenon is called *earing*.
- Earing is caused by the **planar anisotropy**.
- Planar anisotropy of the sheet is indicated by

\[
\Delta R = \frac{R_0 - 2R_{45} + R_{90}}{2}
\]
Earing

- Too high a blankholder force increases the punch force and causes the cup wall to tear.
- **Draw beads** are needed to control the flow of the blank into the die cavity and reduce the blankholder forces.
Ironing

- If the clearance between the punch and the die is large, the drawn cup will have thicker walls.
- Thickness of the cup wall can be controlled by ironing, where drawn cup is pushed through one or more ironing rings.

Redrawing

- Containers that are difficult to draw undergo redrawing.
- Cup becomes longer as it is redrawn to smaller diameters since volume of the metal is constant.
Deep Drawing: Deep-drawing Practice

Drawing without Blankholder

- Typical range of the diameter is \( D_0 - D_p < 5T \).

Embossing

- Embossing is used for the stiffening of flat sheet-metal panels.

Tooling and Equipment for Drawing

- Common materials: steels and cast irons.
CASE STUDY 16.1
Manufacturing of Food and Beverage Cans
- Aluminum beverage cans have excellent surface finish
- Detail of the can lid is shown
Dies are made of solid materials, such as steels and carbides.

The dies in *rubber forming* is made of a flexible material (polyurethane membrane).

In the bending and embossing of sheet metal, the female die is replaced with a rubber pad.
In the hydroform, or fluid-forming process, the pressure over the rubber membrane is controlled throughout the forming cycle.

Control of frictional conditions in rubber forming is a factor in making parts successfully.
Rubber Forming and Hydroforming

- In *tube hydroforming* metal tubing is formed in a die and pressurized internally by a fluid, usually water.
- Rubber-forming and hydroforming processes have the advantages of:
  1. Capability to form complex shapes
  2. Flexibility and ease of operation
  3. Low tooling cost
CASE STUDY 16.2

Tube Hydroforming of an Automotive Radiator Closure

- Figure shows a hydroformed automotive radiator closure
- Sequence of operations: (1) tube as cut to length; (2) afterbending; (3) after hydroforming
CASE STUDY 16.2
Tube Hydroforming of an Automotive Radiator Closure

- Conventional hydroforming involves the following:
Spinning

- *Spinning* is a process that involves the forming of axisymmetric parts over a mandrel

Conventional Spinning

- A circular blank of flat sheet metal is held against a mandrel and rotated while a rigid tool deforms and shapes the material over the mandrel
- Suitable for conical and curvilinear shapes
Shear Spinning

- Also known as *power spinning*, *flow turning*, *hydrospinning*, and *spin forging*
- Use to produce an axisymmetric conical or curvilinear shape while reducing the sheet’s thickness and maintaining its maximum (blank) diameter
Spinning

Tube Spinning

- The thickness of hollow, cylindrical blanks is reduced by spinning them on a solid, round mandrel using rollers
- Can be carried out externally or internally
- Various external and internal profiles can be produced from cylindrical blanks with constant wall thickness
Incremental Forming

- Simplest version is *incremental stretch expanding*
- A rotating blank is deformed by a steel rod with a smooth hemispherical tip to produce axisymmetric parts
- **CNC incremental forming** uses a CNC machine tool to follow contours at different depths across the sheet-metal surface
- Advantages are low tooling costs and high flexibility in the product shapes
Superplastic Forming

- The behavior of superplastic are where tensile elongations were obtained within certain temperature ranges
- Superplastic alloys can be formed into complex shapes by superplastic forming
- Have high ductility but low strength
- Advantages:
  1. Complex shapes can be formed
  2. Weight and material savings
  3. Little residual stresses
  4. Tooling costs are lower
Superplastic Forming

- Limitations of superplastic forming:
  1. Part will undergo shape changes
  2. Must be formed at sufficiently low strain rates

**Diffusion Bonding/Superplastic Forming**

- Fabricating of complex sheet-metal structures by combining *diffusion bonding* with *superplastic forming* (SPF/DB)
- Application for aerospace industry
- Improves productivity and produces parts with good dimensional accuracy and low residual stresses
Superplastic Forming

Diffusion Bonding/Superplastic Forming

Before

Stop-off  Clamp

After

Stop-off (no bonding)

Mold

Product

(a)

(b)

(c)
Specialized Forming Processes

Explosive Forming

- Used for demolition in construction, in road building and for many destructive purposes
- In *explosive forming*, the entire assembly is lowered into a tank filled with water
- The air in the die cavity is then evacuated, an explosive charge is placed at a certain height, and the charge is detonated
Explosive Forming

- The peak pressure, $p$, is given by
  \[ p = k \left( \frac{\sqrt[3]{W}}{R} \right)^a \]
  - $p =$ pressure, psi
  - $K =$ constant that depends on the type of explosive

- The mechanical properties of parts similar to those made by conventional forming methods
- The dies may be made of aluminum alloys, steel, ductile iron or zinc alloys
Electromagnetically Assisted Forming

- Also called *magnetic-pulse forming*
- Energy stored in a capacitor bank is discharged rapidly through a magnetic coil
- A magnetic field is produced when the coil crosses the metal tube and generates *eddy currents* in the tube
- Higher the electrical conductivity of the workpiece, the higher the magnetic forces
- Improved dimensional accuracy, springback and wrinkling are reduced
Peen Forming

- Used to produce curvatures on thin sheet metals by *shot peening* one surface of the sheet.
- Surface of the sheet is subjected to compressive stresses.
- The process also induces compressive surface residual stresses, which improve the fatigue strength of the sheet.
Laser Forming

- Involves the application of laser beams as a heat source in specific regions of the sheet metal.
- Process produce thermal stresses, which can cause localized plastic deformation of the sheet.
- In **laser-assisted forming**, the laser acts as a localized heat source, thus reducing the strength of the sheet metal at specific locations.
- Improve formability and increasing process flexibility.
Microforming

- Used to produce very small metallic parts and components
- Small shafts for micromotors, springs and screws

Electrohydraulic Forming

- Also called *underwater spark* or *electric-discharge forming*
- Source of energy is a spark between electrodes that are connected with a short thin wire
CASE STUDY 16.3

Cymbal Manufacture

1. As cast
2. After rolling; multiple rolling–annealing cycles necessary
3. Stretch formed and trimmed
4. Hang hole punched
5. Stretch formed
6. Hammered
7. Lathe turned and polished
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.
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
Blank Design

- Poorly designed parts will not *nest* properly
- Blanks should be designed to reduce scrap to a minimum
Bending

- A sheet-metal part with a flange when undergo compression can cause buckling.
- Can be controlled with a relief notch cut to limit the stresses from bending.
Bending

- Right-angle bends with relief notches can be used to avoid tearing.
- It is advantageous to move the hole away from the bend area and a crescent slot can be used.
Design Considerations in Sheet-metal Forming

Bending

- When tabs are necessary, large radii should be used to reduce stress concentration
- Bending sharp radii can be accomplished through scoring or embossing
Design Considerations in Sheet-metal Forming

Roll Forming

- Process should be designed to control springback
- Not difficult to include perforating rolls in the forming line

Stamping and Progressive-die Operations

- Tooling cost and the number of stations are determined by the number and spacing of features on a part
- Advantageous to hold the number of features to a minimum in order to minimize tooling cost
Proper equipment design, is needed to achieve a high production rate, good dimensional control and high product quality.

Traditional **C-frame** structure is used for ease of tool and workpiece accessibility.
Press selection for sheet-metal forming operations depends on:

1. Type of forming operation
2. Size and shape of workpieces
3. Number of slides
4. Maximum force required
5. Type of mechanical, hydraulic, and computer controls
6. Features for changing dies
7. Safety features
Sheet-forming operations are versatile and can produce the same part.

The costs involved depend on die and equipment costs and labor.

For small and simple sheet-metal parts, die costs and lead times to make the dies are low.

Deep drawing requires expensive dies and tooling.

Equipment costs depend on the complexity of the forming operation.