Before you begin: Turn on the sound on your computer. There is audio to accompany this presentation.

Chapter 17
Sheet Forming Processes

Types of Deformation

- The deformation that is done can be classified in several different ways:
  - Bulk deformation – flow in three dimensions.
  - Sheet forming deformation:
    - Shearing – compressive cutting type of operation.
    - Bending – deformation about an axis.
    - Drawing and Stretching – plastic flow over a curved axis.
  - Combinations of the above.
Sheet-Forming Processes

- Sheet-forming generally is a secondary process.
- Sheet-forming involves plane stress loading and lower forces compared to bulk deformation.

Shearing Operations

- Shearing is the mechanical cutting of material without the formation of chips.
- When blades are straight – process is called shearing.
- When blades are curved – processes called blanking, piercing, notching or trimming.
Simple Shearing Operations

- Metal flows plastically into the die as a punch pushes into the workpiece.
- Shear occurs in two distinct stages which is visible by examining the cut section:
  - Deformation – due to highly localized shear.
  - Fracture and tearing – begins at weakest point and continues progressively to the next weakest point.

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

Figure 17-2. (top) Conventionally sheared surface showing the distinct regions of deformation and fracture, and (bottom) magnified view of the sheared edge.
Fineblanking

- To eliminate the rough surface in simple shearing – modifications can be made.
- In this process, a V-shaped notch is used in the hold down plates external to the cut.
- As pressure is applied, the notch is driven into the workpiece compressing the region to be cut.
- Matching upper and lower punches move in unison and remove the desired material.
- Fineblanking usually limited to material $\frac{1}{4}''$ thick.

Figure 17-3. 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.
Simple Shearing

- Sheets are sheared along a straight line.
- Upper ram descends clamping sheet to table.
- Shearing blade moves across fixed blade to shear material.

Figure 17-6. A 10 ft power shear for ¼ in thick steel.

Slitting

- Is lengthwise shearing process used to cut rolls of sheet metal into several rolls of narrower width.
Piercing and Blanking

- Shear blades are closed, curved lines along the edges of a punch and die.
- Both involve same basic cutting action – difference is in the definition.
- Piercing – the punch-out is the scrap and remaining strip is workpiece.
- Blanking – the punch-out is the new workpiece and the remaining strip is scrap.

Variations

- Lancing – piercing operation that forms either a line cut (slit) or hole in the metal.
- Perforating – consists of piercing a large number of closely spaced holes.
- Notching – used to remove segments from along the edge of an existing product.
- Nibbling – contour is cut by making series of overlapping slits or notches.
Variations

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

Figure 17-9. Shearing operation being performed on a nibbling machine.

Variations

- **Shaving** – finishing operation to remove small amount of material around edges of already blanked part.
- **Cutoff** – used to separate a stamping from a strip.
- **Dinking** – modified shearing used to blank shapes from low strength materials (rubber, fiber, cloth).

Figure 17-10. The dinking process.

Piercing and Blanking Tools

- Basic components include:
  - Punch
  - Die
  - Stripper plate
- Punches and dies made from low-distortion tool steels hardened after machining.
- Clearance between punch and die should approach zero.
- Reduction of cutting forces can be achieved by tilting the angle of the punch face (known as shear or rake angle).
Piercing and Blanking Tools

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

Figure 17-12. Blanking with a square-faced punch (left) and on containing angular shear (right).

Piercing and Blanking Tools

A piercing and blanking setup using self-contained sub-press tool units.

Figure 17-13. Typical die set having two alignment posts.

Chapter 17 - 23

Piercing and Blanking Tools

Die configurations:

- Single die – one punch and die mounted together
- Progressive die – two or more sets of punches and dies mounted together. Typically involves strip feedstock.
- Transfer dies – separate workpieces moved mechanically between die sets.
- Compound die – combination of operations occur sequentially during one stroke of the ram with one die set.
Piercing and Blanking Tools

A progressive piercing, forming, and cutoff die set built up mostly from standard components.

Figure 17-14. Progressive piercing and blanking die for making a square washer. Note that the punches are of different length.

Chapter 17 - 25

Illustration: Transfer die set using table to move work between die sets.

Chapter 17 - 26

Piercing and Blanking Tools

Illustration: Transfer die set using robots for material transfer.

Chapter 17 - 26

Figure 17-16. 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.

Chapter 17 - 27
Sheet-Forming Processes

<table>
<thead>
<tr>
<th>TABLE 17.1: Classification of Sheet-Forming Operations</th>
<th>Bending</th>
<th>Drawing and Stretching</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Simple bending</td>
<td>1. Angle bending</td>
<td>1. Spinning</td>
</tr>
<tr>
<td>2. Stamping</td>
<td>2. Roll bending</td>
<td>2. Sheet forming or blank turning</td>
</tr>
</tbody>
</table>

Bending Process

- Bending is plastic deformation about a linear axis with little or no change in the surface areas.
- If multiple bends are made with a single die – process is called forming.
- When axes of deformation are not linear – process is called drawing and/or stretching.

Simple bending causes metal on outside of bend to be stretched resulting in thinning.

Bending causes metal on inside to be compressed resulting in thickening.

Neutral axis – area that is neither stretched or compressed.

Figure 17-17. Nature of a bend in sheet metal.
Angle Bending

- Uses machines like bar folder or press brake.
- Press brakes are used for making complex bends and bends in heavier sheet metal.

Figure 17-18. Phantom section of a bar folder showing position and operation of internal components.

Press brakes use mechanical or hydraulic power.
- Metal is bent between interchangeable dies.

Figure 17-19. (left) Press brake with CNC gauging system. (right) Close-up view of press dies forming configurations.

Press brake dies can form a variety of angles and contours.

Figure 17-20. Press brake dies can form a variety of angles and contours.

Figure 17-21. Dies and operations used in the press brake forming a roll bead.
Design for Bending

Several factors must be considered when designing parts for bending including:

- Primary concern: minimum bend radius which depends on the ductility and the thickness of the material.
- Must consider springback (elastic deformation recovery) – less severe bends have large amounts of springback.
- Previous cold work imparts directional properties – best to make bend axis perpendicular to the direction of previous working.

Figure 17-22: 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).

Figure 17-23: 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.

Air-Bend, Bottoming, Coining Dies

Another design decision relates to the type of die to use:

- Bottoming dies contact and compress the full area within the tooling and the angle of the bend is set by the geometry of the tooling. (+ springback)

Figure 17-25: 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.
Air-Bend, Bottoming, Coining Dies

- **Air-bend dies** produce the bend geometry by 3-point bending:
  - A single set of tooling can produce a range of bend geometries – more flexibility than bottoming dies.
- **Coining dies** – if the bottoming dies continue to move beyond the bottoming position, plastic deformation occurs and this is called coining:
  - Springback is reduced, more consistent results are obtained, but loading is increased on the press and tools.

Roll Bending

- Continuous form of three-point bending.
- Used to form plates, sheets, beams, pipe, rolled shapes, and even extrusions.
- Orientation of the rolls can be adjusted to control curvature of product.
- Machines are available capable of bending plate up to 10 in. thick.

Figure 17-26. (left) Schematic of the roll-bending process. (right) The roll bending of an I-beam section. Note how the metal is continuously subjected to three-point bending.
Additional Bending Processes

- Bending machines can also utilize a clamp and pressure tool to bend material against a form block:
  - Draw bending – workpiece is clamped against a bending form and entire assembly is rotated to draw the workpiece under a stationary pressure tool.
  - Compression bending – bending form is stationary and pressure tool moves along surface of workpiece.
  - Press bending – has downward descending bend die that pushes into the center of the material which is supported on either side.

- Flexibility of these processes is limited because a certain length of the product must be used for clamping.

**Figure 17-27.** (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

- If material being bent is tube or pipe, geometry presents additional problems.
- Following situation can lead to flattening outer surface and wrinkling inner surface:
  - Increasing outer diameter of the stock.
  - Decreasing wall thickness.
  - Decreasing the radius of bend.
- Old process used sand to fill interior of tube/pipe, produce bend, and then remove sand.
- New methods use flexible mandrels.
Roll Forming

- Continuous process of flat strip into complex shapes.
- Replaces press brake forming, extrusion, and stamping for high volume products and longer length products.
- Uses progressive bending as strip passes through a series of forming rolls at speeds up to 270 ft/min.
- Only bending occurs and all bends are all parallel.
- Any material that can be bent can be roll formed.
- Changing rolls can produce different shapes, but this is an involved process that can take several hours – must justify with quantity.

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Seaming, Flanging & Straightening

- **Seaming** – a bending operation that can be used to join the ends of sheet metal in some interlock.
- **Flanges** – can be rolled on sheet metal in same manner as seams.
- **Straightening** – opposite of bending, used before cold forming to assure flatness, material is sent through a series of reverse bends.
- Forming both (seams and flanges) is a drawing operation since the bending occurs along a curved axis.
Seaming, Flanging & Straightening

Figure 17-30. Various types of seams used on sheet metal.

Figure 17-31. Method of straightening rod or sheet by passing it through a set of rolls. For rods, another set of rolls is used to provide straightening in the transverse direction.

Sheet-Forming Processes

<table>
<thead>
<tr>
<th>Table 17.1</th>
<th>Classification of the Nonspinning Metallicforming Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Meaning</td>
</tr>
<tr>
<td>1</td>
<td>Simple shearing</td>
</tr>
<tr>
<td>2</td>
<td>Rolling</td>
</tr>
<tr>
<td>3</td>
<td>Flanging</td>
</tr>
<tr>
<td>4</td>
<td>Planing</td>
</tr>
<tr>
<td>5</td>
<td>Earthing</td>
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<tr>
<td>6</td>
<td>Cutting</td>
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<tr>
<td>7</td>
<td>Notching</td>
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<tr>
<td>8</td>
<td>Stamping</td>
</tr>
<tr>
<td>9</td>
<td>Straightening</td>
</tr>
<tr>
<td>10</td>
<td>Channel</td>
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<tr>
<td>11</td>
<td>Draw</td>
</tr>
<tr>
<td>12</td>
<td>Straightening</td>
</tr>
</tbody>
</table>

Drawing and forming:
1. Spinning
2. Shirt forming or then forming
3. Sheet forming
4. Deep drawing and hollow drawing
5. Roll forming
6. Sheet ball forming
7. Tube forming
8. Cup and die forming
9. Tube forming into a tube
10. Rolling
11. Sympering
12. Squegpling and forming
Drawing and Stretching

- Cold drawing relates to very different operations.
  - If starting material is wire, rod, tubing: process reduces the cross section of the material by pulling it through a die (chapter 16).
  - If starting material is sheet: forming of parts where plastic flow occurs over a curved axis (chapter 17).

Spinning

- Cold forming operation where rotating disk of sheet metal is progressively shaped over a mandrel to produce rotationally symmetrical shapes.
- Shapes such as cones, hemispheres, cylinders, bells, and parabolas.
- Localized pressure is applied with simple wooden or metal tool.

Figure 17-32. Progressive stages in the spinning of a sheet metal product.
Shear Forming or Flow Turning
- Modification of the spinning process.
- Each element of the blank material maintains its distance from the axis of rotation – no change in circumference.
- Metal flow entirely by shear.

![Figure 17-34. Schematic representation of the basic shear-forming process.](image)

Stretch Forming
- Attractive means of producing large sheet metal parts in low quantities.
- Sheet metal gripped by two or more sets of jaws.
- Stretched and wrapped around single form block (acts as die).
- Popular in aircraft industry.

![Figure 17-37. Schematic of a stretch-forming operation.](image)

Deep and Shallow Drawing
- Forming process for solid-bottom cylindrical or rectangular containers from sheet metal.
- Deep Drawing – Depth > Diameter
- Shallow Drawing – Depth < Diameter

![Deep drawing](image)
Deep and Shallow Drawing

- One of the most important and widely used manufacturing processes.
- Concerns: thin metal will tear or wrinkle.

![Figure 17-40. Drawing on a double-action press, where the blankholder uses the second press action.]

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

Draw ratio – blank diameter and punch diameter. Determines height of side walls.

Trimming may be required for final dimensions.

![Figure 17-43. Pierced, blanked and drawn part before and after trimming.]

Hot-Drawing Operations

- Because sheet has a large surface area and is relatively thin, it cools very quickly so most sheet metal drawing is performed cold or warm.
- Hot drawing processes for sheet products are essentially identical to cold drawing processes and used for thicker workpieces.

![Figure 17-52. Methods of hot drawing a cup-shaped part. (upper left) First draw. (upper right) Second draw. (lower) Multiple die drawing.]
Other Forming Methods

- Blanking and drawing usually require mating male and female die sets.
- Several processes have been developed to replace one of the dies (male or female):
  - Guerin process — rubber die forming.
  - Sheet hydroforming — uses rubber bladder backed by oil pressure.
  - Tube hydroforming — uses a tube blank and then filled with fluid and sealed — pressure is used to expand tube to shape of die.

Guerin Process

- Uses principle that rubber will act as a fluid when totally confined.
- Forming blocks can be made of wood, plastics or low-melting temperature metals.
- Process used extensively by aerospace industry.
Sheet Hydroforming

- Replaces rubber used in Guerin process with rubber membrane backed by fluid pressure.
- Pressures vary between 20,000-30,000 psi.
- Slow process offset by low tooling cost for limited production.

Figure 17-47. High-pressure flexible-die forming.

Tube Hydroforming

- Tubular blank placed in encapsulating die and the ends are sealed.
- Fluid introduced under pressure forming the tube to the die shape.
- Low-pressure hydroforming – pressure up to 5,000 psi.
- High-pressure hydroforming – pressure 15,000 to 100,000 psi.

Figure 17-50. Tube hydroforming. (a) Process schematic; (b) actual copper product. Note the inward movement of the tube ends and the non-uniform wall thickness of the non-symmetric product.
Other Processes

- High energy rate forming (HERF) – uses application of large amounts of energy in very short time. Methods:
  - Underwater explosion
  - Underwater spark discharge
  - Pneumatic-mechanical
  - Internal combustions of gas mixtures
  - Use of rapidly formed magnetic fields

- Ironing – thins walls of drawn cylinder by passing it between a punch and die with smaller clearance than original wall thickness (similar to extrusion type process).

- Embossing – pressworking process in which raised letter is impressed in sheet metal – very shallow drawing operation.
Other Processes

- **Superplastic sheet forming** – by producing sheets with ultra-fine grain size and performing deformation at low strain rates and elevated temps – elongation can exceed 100%.
  - Sometimes as much as 2000-3000%.
  - Typical ductility is in the area of 10-30%.
  - Termed superplasticity.
  - Uses temperatures > 0.5 of melting temperature.

Alternate Sheet Producing Methods

- **Electroforming** – metal directly deposited onto forms and mandrels via plating process.
  - Thickness controlled by plating time.

- **Spray forming** – powdered material injected into a plasma torch (20,000 °F) and spray deposited onto shaped form or mandrel.
  - Thickness controlled number of layers.
Pipe Welding

- Used to make large quantities of steel pipe incorporating hot forming with deformation welding.
- Made by forming steel strip (skelp) coupled with deformation induced welding of free edges.
- Two processes:
  - Butt welding
  - Lap welding

Presses

- Most bulk and sheet forming processes make use of some type of press.
- Press selection criteria includes:
  - Required capacity
  - Type of power
  - Number of slides or drives
  - Type of drive
  - Stroke length
  - Type of frame or construction
  - Speed of operation

Presses

- Presses can be classified by drive mechanism.
  - Mechanical – provide faster motion, positive displacement control and higher forces to 9000 metric tons.
  - Hydraulic – allows variable stroke and accurate control of pressures. Forces to 50,000 metric tons available.
Presses

- Presses can be classified by drive mechanism.

![Figure 17-56. Schematic representation of various types of press drive mechanisms.](image)

Presses

- Presses can be classified by frame type.

<table>
<thead>
<tr>
<th>Type of Frame</th>
<th>Classification of Presses According to Type of Frame</th>
<th>Inclinable gap-frame press with sliding bolster to accommodate two die sets for rapid change of tooling.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclinable</td>
<td>Gap-frame press</td>
<td>Inclined gap-frame press with sliding bolster to accommodate two die sets for rapid change of tooling.</td>
</tr>
<tr>
<td>Straight</td>
<td>Straight-side press</td>
<td>Straight-side press</td>
</tr>
<tr>
<td>Tilt</td>
<td>Tilt-back press</td>
<td>Tilt-back press</td>
</tr>
<tr>
<td>Variable</td>
<td>Variable-stroke press</td>
<td>Variable-stroke press</td>
</tr>
</tbody>
</table>

Hydraulic C-frame press.
Mechanical OBI (open back inclinable) press.
200-ton straight-sided press.
Chapter 17 - 76

Presses


Chapter 17 - 77

Presses


Chapter 17 - 78

Turret-Type Punch Presses

Turret-type Punch Presses – as many as 60 separate punches and dies contained within a turret that can be selectively rotated to select desired tooling.

The End – See Oncourse for Videos