Chapter 16
Sheet-Metal Forming Processes

Alexandra Schönning, Ph.D.
Mechanical Engineering
University of North Florida

Figures by
Manufacturing Engineering and Technology
Kalpakjian and Schmid

Introduction
- What is Sheet-Metal Forming Processes
  - Forming products from sheet metal
  - Sheet metal forming products include
    - File cabinets, car bodies, metal desks
- Advantages
  - Low weight
  - Versatile shape
- Materials
  - Most common is low carbon steel
    - Good strength and formability

Shearing
- Cut the sheet by subjecting it to shear stresses
  - Scissors
- A blank is created by shearing it from a larger sheet (coil)
- Shearing geometry
  - Sheared edges are not smooth, nor perpendicular to the plane of the sheet
  - Shearing starts by formation of cracks at A, B, C, and D
  - The cracks meet each other, resulting in separation
    - Results in a rough fracture surface
  - Burnish depth has a smooth surface resulting from rubbing against the walls of the punch and die

Shearing (cont.)
- Parameters
  - Shape and material of the punch and die
  - Speed of punching
  - Lubrication
  - Clearance
    - Increased clearance results in rough edges, and increased zone of deformation
    - Secondary operations may be necessary
  - (Burnished area) / (rough area)
    - Increases with ductility of sheet metal
    - Decreases with thickness of sheet metal
  - Edge quality increases with punch speed
    - up to 12 m/s
- Burr
  - A thin edge or ridge
    - Increases with clearance, ductility and dull tools

Punch Force
- Force required
  - Product of the shear strength and the area sheared
  \[ F = 0.7T\cdot L\cdot S_{ut} \]
  - \( T \) = thickness
  - \( L \) = length sheared (perimeter of a hole)
  - \( S_{ut} \) = ultimate shearing strength

Shearing Operations
- Punching
  - You discard the punched area
    - Similar to using a hole punch on paper
- Blanking
  - You keep the punched area and discard the area surrounding the hole
- Perforating
  - Punching a number of holes in a sheet
- Parting
  - Sheering the sheet into two or more pieces
- Notching
  - Removing pieces from the edges
- Lancing
  - Leaving a tab without removing any material
Shearing Operations (Cont.)

- Fine blanking
  - A stringer (impingement ring) holds the sheet in place during the shearing operation.
  - Clearance is finer: 1% of thickness.

- Slitting
  - A pair of circular blades are used.
  - Similar to a can opener.

- Nibbling
  - Many overlapping holes are made by moving the punch up and down (using a nibbler) while leaving the sheet.
  - Scrap
    - Try to minimize by optimizing how you place the shapes: called nesting.

- Tailor-welded blanks
  - Two or more flat sheet metal pieces are butt welded together.
  - Reduces the amount of scrap.

Shearing Dies

- Clearance
  - Dependent on material type and temper, thickness, size of blank, distance from the edge.
  - Soft materials have lower clearance than hard materials.
  - The thicker the sheets, the more clearance.
  - Small holes need more clearance than large holes.
  - Rough sheared edges are removed by shaving (figure).

- Punch and die shapes
  - Punch is often beveled.
    - To reduce the force needed at the beginning of each stroke.
    - Reduces noise levels.

- Compound dies
  - Several operations on the same strip are performed in one stroke at one station.
  - Slow process.
  - Expensive dies.
  - Simple shapes.

- Progressive dies
  - The sheet metal is fed through as a coil strip.
  - A different operation is performed at the same station with each stroke of a series of punches.

- Transfer dies
  - Different operations at different stations.
  - Sheet metal moves forward.

- Tool and die material
  - Tool steels.
  - Carbides.

- Bending Sheet and Plate

  - Bending: one of the most common forming operations.
  - Where do you see it?
    - File cabinets, paper clips.
  - Why do you bend?
    - Form flanges, seams and corrugations.
    - Increase stiffness by modifying the moment of inertia.

- Terminology
  - Length width of the part
  - ε: smaller at the outer radius (then at the inner radius due to circularity).
  - Decrease by bending a rubber strip.
  - Bend radius.
  - Setback.
  - Bend radius.
  - Bend angle.
  - Bend angle.

- Sheet metal characteristics:

  - Elongation
    - Uniform region
    - Necking: after the ultimate tensile stress has been reached.

  - Yield Point Elongation
    - Common with low carbon steels.
    - Results in Lueder’s bands (stricture strain marks).

  - Anisotropy (different properties in different directions)
    - Two types:
      - Crystallographic anisotropy.
      - Mechanical anisotropy of the grain.
  - Grain Size
    - Grain size affects the mechanical properties and surface appearance.

  - Bend allowance (Lb): length of the neutral axis in the bend.

  - Bending: length of the neutral axis in the bend.

  - Setback:
    - Bend radius.
    - Bend radius.
    - Bend angle.

  - Lb = α (R + T)

- Shearing Dies (Cont.)

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Minimum Bend Radius

- Engineering Strain
  \[ \varepsilon = \frac{R}{T} + 1 \]
  - As R/T decreases, the tensile stress increases on the outer surface leading to cracks
- Minimum bend radius
  - The ratio at which cracks start to appear
  - 2T, 3T, 4T…

Bendability decreases with
- edge roughness
- cold working
- Annealing or machining can help
- inclusions
- Anisotropy affects bendability
  - Cut the sheet in an advantageous direction

Springback

- When the load is applied,
  - Elastic deformation begins
  - Plastic deformation follows
- As load is removed
  - Some elastic recovery occurs
  - Called “springback”

Springback
- Angle after springback is smaller
- Bend radius will be a little larger

\[ \theta = \frac{R}{T} \left( \frac{R}{T} + 1 \right) \]

- Ri, Rf as shown
- Y: yield stress
- E: elastic modulus

Springback increases with
- \( \frac{R}{T} \)
- Y

Decreases w/ E

Maximum bending force

\[ P = \frac{kYLT^2}{W} \]

- P: maximum bending force
- k: factor dependent on the type of die
  - Typical values from 0.3 – 1.3
- Y: yield strength
- T: thickness
- W: die opening dimension

Common bending operations

- Press brake forming
  - Long dies are used in a press (mechanical or hydraulic)

Common bending operations (cont.)

- Roll-bending
  - Plates are bent using a set of rolls
  - Various curvatures can be obtained by adjusting the position of the rolls
- Bending in a 4-slide machine
  - Bending of short pieces

- Beading
  - The periphery of the sheet is bent into the cavity of the die
Common bending operations (cont.)

- **Flanging**
  - Process of bending the edge of a sheet
  - Figure (a)

- **Dimpling**
  - A hole is punched and then expanded into the flange
  - Figure (b)

**Figure 16.25** Various flanging operations. (a) Flanges on a flat sheet. (b) Deep dimple. (c) A flange is formed by bending the sheet metal to form a flange. In this operation, holes do not have to be prepunched before the sheet descends. Note, however, the rough edges along the circumference of the flange. (d) The flanging of a tube; note the thinning of the edges of the flange.

- **Hemming**
  - Also called flattening
  - Edge of sheet is folded over itself
  - Increase stiffness, improve appearance

- **Seaming**
  - Joining two edges of sheet metal by hemming

**Common bending operations (cont.)**

- **Roll Forming**
  - Also called contour roll forming, cold roll forming
  - Metal is bent in stages by passing it through a series of rolls
  - Used to make
    - Gutters, door and picture frames, pipes and tubing with lock seams

**Tube bending and forming**

- How do you avoid the tube from buckling when you bend it?
  - Pack the inside with loose particles (sand) before bending.
  - Sand is shaken out after bend has been completed
  - Thick walls with a large bend radius can be bent without filling

**Bulging**

- Place a tubular, conical, curvilinear part (plug) into a split female die
- Expand the plug
  - Commonly polyurethane plug
- Retract the plug
- Open the die and remove the plug
- Used in making
  - Coffee / water pitchers
  - Barrels
- Internal fluid pressure
  - Replaces the plug
  - Ends are sealed mechanically
  - Exhaust pipes

**Segmented dies**

- Individual segments are placed inside the tube
- Expanded in the radial direction
- Retracted
### Stretch Forming
- Sheet metal is clamped along its edges then stretched over a die.
- Used in making wing-skin panels for aircrafts.
- Material will shrink in width as it is stretched.

#### Disadvantages
- Can’t produce parts with:
  - Sharp corners
  - Re-entrant corners

#### Advantages
- Little (or no) lubrication is necessary.
- Versatile.
- Economical.
- Used for low production runs.

### Deep Drawing
- Deep drawing can be used to make cylindrical and box shaped parts using deep drawing.
- Kitchen sinks.

#### Process
- A sheet metal blank is placed over a die opening and is held in place with a blank holder (hold-down ring).
- A punch forces the blank into the cavity.
- Forming a cup.
- Cup wall may be subjected to a tensile stress in order to elongate the wall.

#### Important Variables
- Sheet metal properties.
- Blank diameter / punch diameter.
- Clearance.
- Punch radius.
- Die corner radius.
- Blank holder force.
- Friction.
- Lubrication.

#### Deep Drawability
- Failure typically occurs from thinning of the cup walls under high tensile stresses.
- Tensile tests are performed to determine the deep drawability of the material.

#### Earining
- Edges of the cups may be wavy called earing.

#### Draw Beads
- Controls the flow of the blank into the cavity.

#### Ironing
- Ensuring the wall thickness is constant.
- Cup is pushed through ironing rings.

### Deep Drawing (cont.)
- Draw beads
  - Controls the flow of the blank into the cavity

- Ironing
  - Ensuring the wall thickness is constant
  - Cup is pushed through ironing rings

### Deep Drawing (cont.)
- Redrawing
  - When the shells are too difficult to draw in one operation

- Embossing
  - Shallow or moderate draws.
  - Used for:
    - stiffening of flat panels
    - Decorations
    - Logo, text

### Steps in Manufacturing an Aluminum Can
Rubber Forming
➢ One of the dies in a set are made of a flexible material (polyurethane)
➢ Female die is replaced with a rubber pad
   • Protects the outer surface of the sheet from scratches

Figure 16.38 Examples of the bending and the embossing of sheet metal with a metal punch and with a flexible pad serving as the female die. Source: Polyurethane Products Corporation.

Hydroform Process
➢ Also called fluid-forming process
   • Pressure over the rubber membrane is controlled by a fluid
   • Close control of the part during forming
   • Deeper draws can be obtained with the hydroform process than with conventional deep drawing techniques
     • since the pressure around the rubber membrane aids in reducing the longitudinal tensile stresses in the sheet

Figure 16.39 The hydroform (or fluid forming) process. Note that, in contrast to the ordinary deep-drawing process, the pressure in the dome forces the cup walls against the punch. The cup travels with the punch in this case, deep drawability is improved.

Spinning
➢ Forming of axisymmetric parts over a mandrel
   • Conventional
     • Sheet metal is held against the mandrel and rotated
     • Conical and curvilinear shapes
   • Shear
     • Rollers are used during the forming process
     • Conical or curvilinear shapes
     • Max diameter is maintained
     • Thickness is reduced
   • Tube spinning
     • Thickness is reduced resulting in thinner tubes

Dent Resistance
➢ Dynamic forces causes localized dents
➢ Static forces spreads the dent
➢ Dent resistance
   • Increases with
     • Increased yield strength
     • Increased thickness
   • Decreases with
     • Increased elastic modulus

Economics of sheet metal forming
➢ A part can often be manufactured using numerous different techniques
   • Even different sheet metal forming techniques
➢ Need to do a cost analysis before deciding which technique to use
➢ Sheet metal processes can be considered economical