Introduction

Products made of sheet metals are common.

Press working 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.
## Sheet Forming Processes

### 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>
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

• The shape of the punch and die
• The speed of punching
• Lubrication
• 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.
Punch Force

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

$$F = 0.7TL \left( UTS \right)$$

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

Friction between the punch and the workpiece can increase punch force. Furthermore, in addition to the punch force, a force is required to strip the punch from the sheet during its return stroke.

Estimate the force required for punching a 1-in. (25-mm) diameter hole through a $\frac{1}{8}$-in. (3.2-mm) thick annealed titanium-alloy Ti-6Al-4V sheet at room temperature.

$$F = 0.7 \left( \frac{1}{8} \right) (\pi) (1) (140,000) = 38,500 \text{ lb} = 19.25 \text{ tons}$$

$$= 0.17 \text{ MN}.$$
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** is a shearing operation that consists of the following basic processes

- 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
Shearing Operations

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 Operations

Slitting

Shearing operations are through a pair of circular blades, follow either a straight line, a circular path, or a curved path.

If not performed properly, slitting operations can cause various distortions of the sheared edges.
Shearing Operations

Scrap in Shearing

The amount of scrap (trim loss) produced in shearing operations can be significant and can be as high as 30% on large stampings.

Scrap can be a significant factor in manufacturing cost.

Can be reduced substantially by efficient arrangement of the shapes on the sheet to be cut (nesting).
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:

- Reduction in scrap
- Elimination of the need for subsequent spot welding
- Better control of dimensions
- Improved productivity

Shearing: Tailor-welded Blanks
Shearing: Tailor-welded Blanks

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

Tailor-welded Sheet Metal for Automotive Applications

Some of the examples of laser butt-welded and stamped automotive-body components.
Shearing: Characteristics and Type of Shearing Dies

Clearance

Clearance control determines the quality of the sheared edges which influence the formability of the sheared part.

Appropriate clearance depends on:
- Type of material and temper
- Thickness and size of the blank
- Proximity to the edges of other sheared edges

When a sheared edge is rough, it can be subjected to a process called shaving.
Punch and Die Shape

Punch force increases rapidly during shearing.

Location of sheared regions can be controlled by beveling the punch and die surfaces.
Compound Dies

Operations on the same sheet may be performed in one stroke with a compound die

Limited to simple shapes due to:

Process is slow

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
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
• Laser-beam cutting:
• Water-jet cutting
• Cutting with a band saw
• Friction sawing
• Flame cutting
# Sheet-metal Characteristics and Formability

## 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 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); results in depressions on the sheet surface; can be eliminated by temper rolling, but sheet 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 because of preferred orientation or mechanical fibering, causes earing in deep drawing, can 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 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 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 of part and loss of dimensional accuracy, can be controlled by techniques such as overbending 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 its extent, can be useful in imparting stiffness to parts by increasing their section modulus; 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, and a work-hardened layer, which are all detrimental to the formability of the sheet; edge quality can be improved by fine blanking, reducing the clearance, shaving, and improvements in tool and die design and lubrication</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 poor surface quality</td>
</tr>
</tbody>
</table>
Elongation

A specimen subjected to tension undergoes uniform elongation.

Observations from tensile testing are useful and necessary for understanding the behavior of metals in these operations.

When the load exceeds the UTS, the specimen begins to neck and thus elongation is no longer uniform.

Elongation is not uniform after necking. Engineering "strain" at fracture:

$$\varepsilon_{eng} = \frac{\ell_{frac} - \ell_0}{\ell_0}$$
Sheet-metal Characteristics and Formability

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

To eliminate or reduce yieldpoint elongation by reducing the thickness of the sheet 0.5 to 1.5% by cold Rolling is a method of avoiding Lüder’s bands
Sheet-metal Characteristics and Formability

Anisotropy
Obtained during the thermo-mechanical processing
2 types: crystallographic anisotropy and mechanical fibering

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

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 in compression.

Poisson effect causes the width to be smaller in the outer region and larger in the inner region.
Approximate bend allowance is

\[ L_b = \alpha \left( R + kT \right) \]

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

\[ R = T \left( \frac{50}{r} - 1 \right) \]
Bending Sheets, Plates, and Tubes

**Minimum Bend Radius**

Increase the bendability by increase 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

Terminology for springback in bending. Note that the bend angle has become smaller. There are situations whereby the angle becomes larger, called negative springback.

Springback factor, $K_s$, for various materials: (a) 2024-0 and 7075-0 aluminum; (b) austenitic stainless steels; (c) 2024-T aluminum; (d) 1/4-hard austenitic stainless steels; and (e) 1/2-hard to full-hard austenitic stainless steels. A factor of $K_s = 1$ indicates that there is no springback.

Springback factor:

$$K_s = \frac{\alpha_f}{\alpha_i} = \frac{(2R_i/t) + 1}{(2R_f/t) + 1}$$

Springback estimation:

$$\frac{R_i}{R_f} = 4\left(\frac{R_i Y}{ET}\right)^3 - 3\left(\frac{R_i Y}{ET}\right) + 1$$
Negative Springback

Schematic illustration of the stages in bending round wire in a V-die. This type of bending can lead to negative springback, which does not occur in air bending.
Springback Compensation

Methods of reducing or eliminating springback in bending operations.

(a) (b) (c) (d)

Sheet

Die

Rocker

1. 2. 3. (e)
Common die-bending operations, showing the die-opening dimension $W$, used in calculating bending forces.

Bending force: 

$$P = \frac{(UTS)LT^2}{W}$$
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
Miscellaneous Bending and Related Operations

Tube Bending and Forming

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.

(a) Stretch bending
(b) Draw bending
(c) Compression bending
(d) Mandrels for tube bending
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) Workpiece, Tool, Stretch gripper
(b) Crosshead, Ram, Upper tool, Clamping fixture, Workpiece, Lower tool, Bed

1. Stretching
2.
3.
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
   - Punch
   - Stock
   - Die
   - Blank

2. Deep drawing
   - Punch
   - Blank
   - Blank-holder
   - Die

3. Redrawing
   - Punch
   - Deep-drawn cup
   - Hold down
   - Die

4. Ironing
   - Punch
   - Redrawn cup
   - Ironing ring
   - Die

5. Doming
   - Punch
   - Ironed cup
   - Die

6. Necking
   - Domed can
   - Spinning tools
   - Support

7. Seaming
   - Chuck
   - Lid
   - Before
   - After
   - Roller
   - Can body
Deep Drawing

Wrinkling can be reduced if a blankholder is loaded by maximum punch force

\[ F_{\text{max}} = \pi D_p T(UTS) \left[ \left( \frac{D_o}{D_p} \right) - 0.7 \right] \]

The force increases with increasing blank diameter, thickness, strength and the ratio (Do/Dp)

The wall of the cup is subjected principally to a longitudinal (vertical) tensile stress due to the punch force
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

$$R = \frac{\text{Width strain}}{\text{Thickness strain}} = \frac{\varepsilon_w}{\varepsilon_t}$$
R value depend on its orientation with respect to the rolling direction of the sheet

Thus the average is

\[ R_{avg} = \frac{R_0 + 2R_{45} + R_{90}}{4} \]

| Typical Ranges of Average Normal Anisotropy, \( R_{avg} \), for Various Sheet Metals |
|---------------------------------|-------------|
| Zinc alloys                     | 0.4–0.6     |
| Hot-rolled steel                | 0.8–1.0     |
| Cold-rolled, rimmed steel       | 1.0–1.4     |
| Cold-rolled, aluminum-killed steel | 1.4–1.8    |
| Aluminum alloys                 | 0.6–0.8     |
| Copper and brass                | 0.6–0.9     |
| Titanium alloys (α)             | 3.0–5.0     |
| Stainless steels                | 0.9–1.2     |
| High-strength, low-alloy steels | 0.9–1.2     |
Earing

In deep drawing, the edges of cups may become wavy and the phenomenon is called earring.

Earing is caused by the planar anisotropy.

Planar anisotropy of the sheet is indicated by

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

Include dies produced from ductile-iron castings made by the lost-foam process
Deep Drawing: Deep-drawing Practice

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.
Rubber Forming and Hydroforming

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.
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:

- Capability to form complex shapes
- Flexibility and ease of operation
- Low tooling cost
Rubber Forming and Hydroforming

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
Rubber Forming and Hydroforming

Tube Hydroforming of an Automotive Radiator Closure

Conventional hydroforming involves the following:
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.

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(b)  
(c)
Spinning

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
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:
- Complex shapes can be formed
- Weight and material savings
- Little residual stresses
- Tooling costs are lower
Superplastic Forming

Limitations of superplastic forming:

Part will undergo shape changes

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
Specialized Forming Processes

Explosive Forming

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

The explosive generates a shock wave with a pressure that is sufficient to form sheet metals.

The peak pressure, $p$, generated in water is given by the expression:

$$p = K \left( \frac{\sqrt[3]{W}}{R} \right)^a$$
Specialized Forming Processes

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
Specialized Forming Processes

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

Used by the aircraft industry to generate smooth and complex curvatures on aircraft wing skins.
Specialized Forming Processes

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
Specialized Forming Processes

**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
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.
Design Considerations in Sheet-metal Forming

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.

Design Considerations in Sheet-metal Forming
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.
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.
Economics of Sheet-forming Operations

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.