# ***Sheet metal forming processes***

***9.1Introduction***

Products made of sheet metals are all around us. They include a very wide range of consumer and industrial products, such as **beverage cans, cookware, file cabinets, metal desks, appliances, car bodies** figure (9.1). The term **pressworking** or **press forming** is used commonly in industry to describe general sheet-forming operations, because they typically are performed on presses.

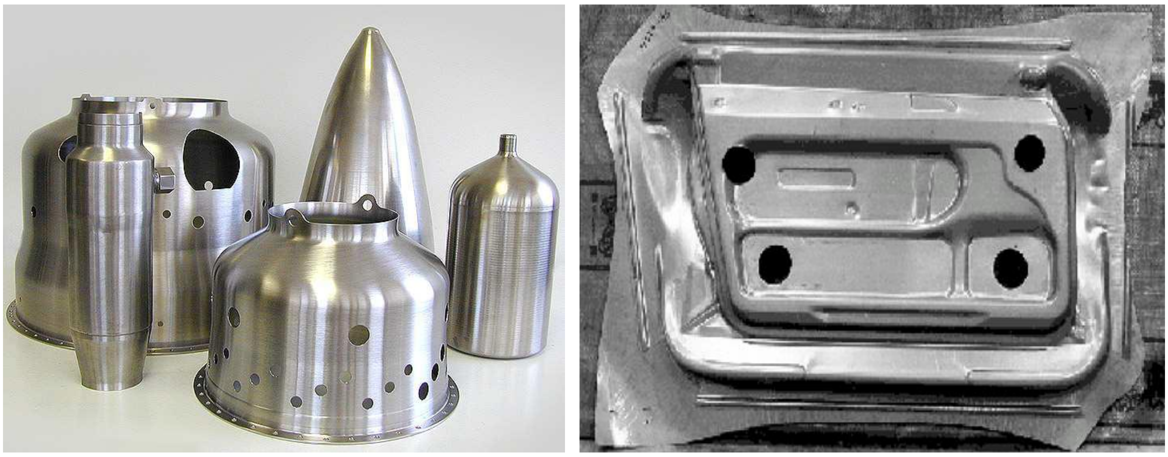


Figure (9.1) shows some sheet metal applications

**9.2 Material in sheet metal forming processes:**

Low-carbon steel is the most commonly used sheet metal because of its low cost and generally good strength and formability characteristics. Aluminum is the most common material for such sheet-metal applications as beverage cans, packaging, kitchen utensils, and applications where corrosion resistance is a concern. The common metallic materials for aircraft and aerospace applications are aluminum and titanium.

**9.3 Temperature and sheet metal forming:**

Most manufacturing processes involving sheet metal are performed at room temperature. Hot stamping is occasionally performed in order to increase formability and decrease forming loads on machinery. Typical materials in hot stamping operations are titanium alloys and various high-strength steels.

**9.4 Types of metal forming operations:**

The three major categories of sheet-metal processes are **(1) cutting, (2) bending, and (3) drawing** as shown in figure (9.2). Cutting is used to separate large sheets into smaller pieces, to cut out part perimeters, and to make holes in parts. Bending and drawing are used to form sheet-metal parts into their required shapes.

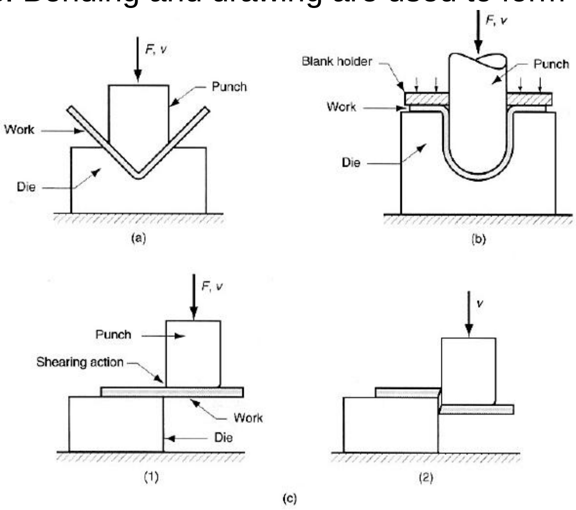
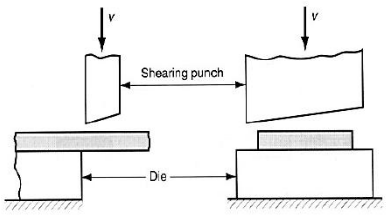



Figure (9.2) Basic sheet metalworking operations:
(a) bending, (b) drawing, and (c) Shearing;
(1) as punch first contacts sheet and (2) after cutting. Force and relative motion are indicated by F and v

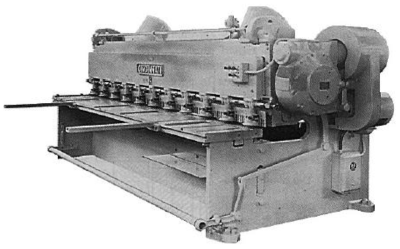
### *9.4.1 Cutting operations:*

The three most important operations in pressworking that cut metal by the shearing mechanism just described are shearing, blanking, and punching.

**A)Shearing: Shearing is a sheet metal cutting operation along a straight line between two cut-ting edges by means of a power shear** see figure (9.3).




Shearing operation



3-m power shear for 6.5-mm steel

Figure (9.3) show the shearing operation and its equipment

### B) Blanking and punching

Blanking and punching are similar sheet metals cutting operations that involve cutting the sheet metal along a closed outline. **If the part that is cut out is the desired product, the operation is called *blanking* and the product is called *blank*. If the remaining stock is the desired part, the operation is called *punching*** as shown in figure (9.4). Both operations are illustrated on the example of producing a washer:

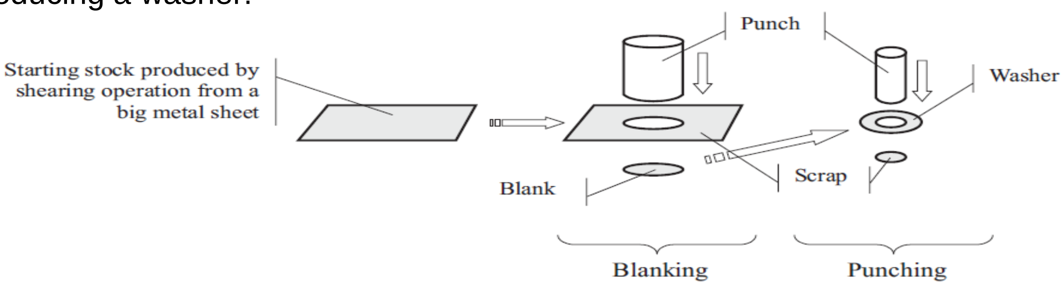
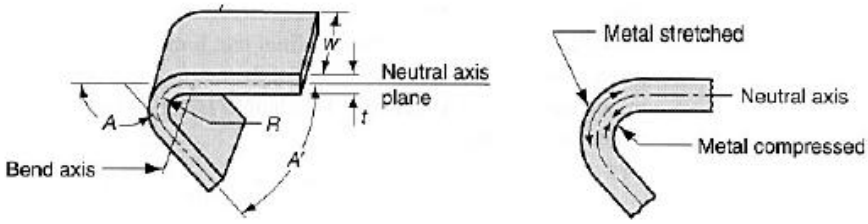



Figure (9.4) shows the blanking and punching operations

### *9.4.2 Bending operation:*

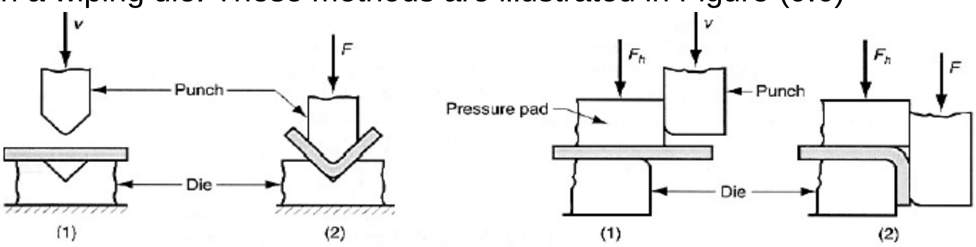
**Bending in sheet-metalwork is defined as the straining of the metal around a straight axis**, as in Figure (9.5)




Bending of sheet metal

Figure (9.5) show bending of sheet metal

Bending operations are performed using punch and die tooling. The two common bending methods and associated tooling are V-bending, performed with a V-die; and edge bending, performed with a wiping die. These methods are illustrated in Figure (9.6)




(*Left*) V-bending, and (*Right*) edge bending; (1) before and (2) after bending

Figure (9.6) types of bending operations

**In V-bending**, the sheet metal is bent between a V-shaped punch and die. Included angles ranging from very obtuse to very acute can be made with V-dies. It is often performed on a press brake, and the associated V-dies are relatively simple and inexpensive.
**Edge bending** involves cantilever loading of the sheet metal. A pressure pad is used to apply a force to hold the base of the part against the die, while the punch forces the part to yield and bend over the edge of the die. In the setup shown in Figure (9.6 right), edge bending is limited to bends of 90° or less. More complicated wiping dies can be designed for bend angles greater than 90°. Because of the pressure pad, wiping dies are more complicated and costly than V-dies and are generally used for high-production work.

**Springback** When the bending pressure is removed at the end of the deformation operation, elastic energy remains in the bent part, causing it to recover partially toward its original shape. This elastic recovery is called springback, defined as the increase in included angle of the bent part relative to the included angle of the forming tool after the tool is removed. This is illustrated in Figure (9.7)

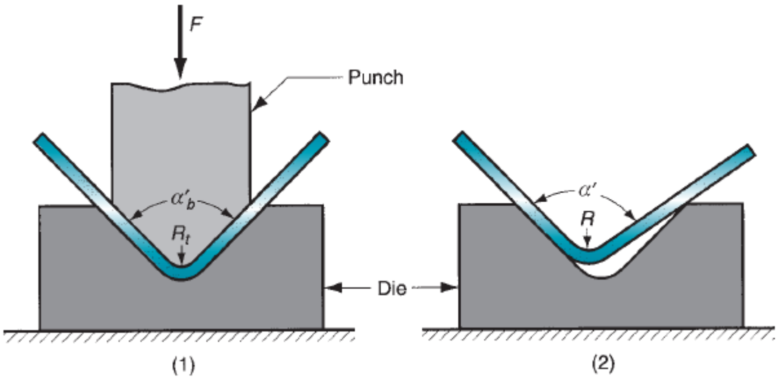



Figure (9.7) Springback in bending shows itself as a decrease in bend angle and an increase in bend radius: (1) during the operation, the work is forced to take the radius $R_t$ and included angle $\alpha'_t$ = determined by the bending tool (punch in V-bending); (2) after the punch is removed, the work springs back to radius $R$ and included angle $\alpha'$. Symbol: $F$ = applied bending force.

Compensation for springback can be accomplished by several methods. Two common methods are overbending and bottoming.

***Overbending***—the punch angle and radius are smaller than the final ones.
***Bottoming***—squeezing the part at the end of the stroke.

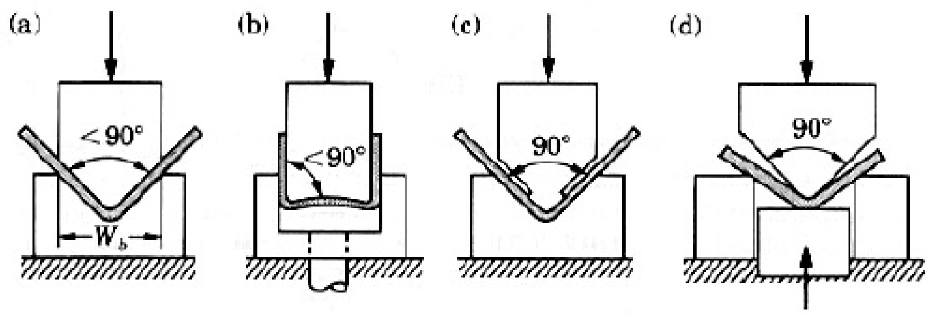



Figure 9.8 Compensation of springback by:
(a) and (b) overbending; (c) and (d) bottoming

***9.4.3 Drawing operation:***

Drawing is a sheet-metal-forming operation used to make cup-shaped, box-shaped, or other complex-curved and concave parts. It is performed by placing a piece of sheet metal over a die cavity and then pushing the metal into the opening with a punch, as in Figure 9.9. The blank must usually be held down flat against the die by a blankholder.
Common parts made by drawing include beverage cans, ammunition shells, sinks, cooking pots, and automobile body panels.

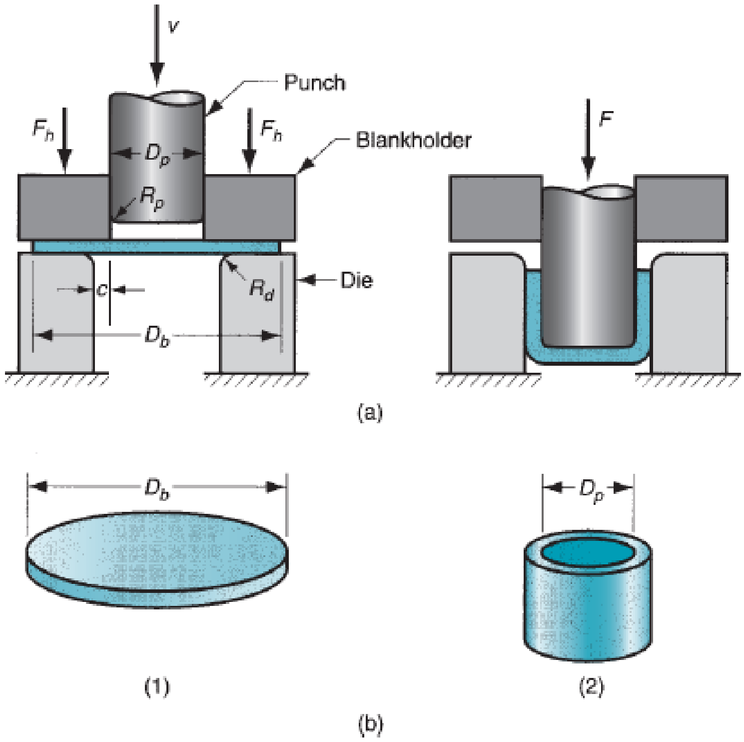



Figure 9.9

(a) Drawing of a cup-shaped part: (1) start of operation before punch contacts work, and (2) near end of stroke; and (b) corresponding workpart: (1) starting blank, and (2) drawn part. Symbols: $c$ = 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.

**9.4.3.1 Mechanic of drawing:**

Drawing of a cup-shaped part is the basic drawing operation, with dimensions and parameters as pictured in Figure 9.9. A blank of diameter $D_b$ is drawn into a die cavity by means of a punch with diameter $D_p$. The punch and die must have corner radii, given by $R_p$ and$R_d$. If the punch and die were to have sharp corners ($R_p$ and$R_d$=0), a hole-punching operation (and not a very good one) would be accomplished rather than a drawing operation. The sides of the punch and die are separated by a clearance c. **This clearance in drawing is about 10% greater than the stock thickness**:

$$c=1.1t \qquad 9.1$$

The punch applies a downward force F to accomplish the deformation of the metal, and a downward holding force $F_h$ is applied by the **blankholder**, as shown in the sketch.

**9.4.3.2 ENGINEERING ANALYSIS OF DRAWING:**

**Measures of Drawing**:

One of the measures of the severity of a deep drawing operation is the **drawing ratio DR**. This is most easily defined for a cylindrical shape as the ratio of blank diameter $D_b$ to punch diameter $D_p$. In equation form:

$$DR= D_b/D_P \qquad 9.2$$

The drawing ratio provides an indication of the severity of a given drawing operation. The greater the ratio, the more severe the operation. An approximate upper limit on the drawing ratio is a value of **2.0**. The actual limiting value for a given operation **depends on punch and die corner radii**

**(Rp and Rd), friction conditions, depth of draw, and characteristics of the sheet metal (e.g., ductility, degree of directionality of strength properties in the metal).**
Another way to characterize a given drawing operation is by the **reduction r**, where

$$r = \frac{D_b - D_p}{D_b} \qquad \textbf{9.3}$$

It is very closely related to drawing ratio. Consistent with the previous limit on DR (**DR ≤ 2.0**), the value of reduction **r** should be less than **0.50**.
A third measure in deep drawing is the **thickness-to-diameter ratio** $t/D_b$ (thickness of the starting blank t divided by the blank diameter $D_b$). Often expressed as a percentage, it is desirable for the $t/D_b$ ratio to be greater than **1%**. **As $t/D_b$ decreases, tendency for wrinkling increases.**
In cases where these limits on drawing ratio, reduction, and $t/D_b$ ratio are exceeded by the design of the drawn part, the blank must be drawn in two or more steps, sometimes with annealing between the steps.

**Example:**
A drawing operation is used to form a cylindrical cup with inside diameter = 75 mm and height = 50mm. The starting blank size = 138mmand the stock thickness = 2.4mm. Based on these data, is the operation feasible?

**Solution:** To assess feasibility, we determine the drawing ratio, reduction, and thickness-to-diameter ratio.

$$DR = 138/75 = 1.84$$
$$r = (138 - 75)/138 = 0.4565 = 45.65\%$$
$$t/D_b = 2.4/138 = 0.017 = 1.7\%$$

**Forces**
The drawing force required to perform a given operation can be estimated roughly by the formula:

$$F = \pi D_p t(TS)\left(\frac{D_b}{D_p} - 0.7\right) \qquad 9.4$$

Where F = drawing force, N (lb); t = original blank thickness, mm (in); TS = tensile strength, MPa (lb/in2); and $D_b$ and $D_p$ are the starting blank diameter and punch diameter, respectively, mm (in). The constant 0.7 is a correction factor to account for friction.

**The holding force is an important factor in a drawing operation**. As a rough approximation, the holding pressure can be set at a **value = 0.015 of the yield strength of the sheet metal**. This value is then multiplied by that portion of the starting area of the blank that is to be held by the blankholder. In equation form

$$F_h = 0.015Y\pi\left\{D_b^2 - \left(D_p + 2.2t + 2R_d\right)^2\right\} \qquad 9.5$$

Where $F_h$ = holding force in drawing, N (lb); Y = yield strength of the sheet metal, MPa (lb/in2); t = starting stock thickness, mm (in); $R_d$ = die corner radius, mm (in); and the other terms have been previously defined. The holding force is usually about one-third the drawing force.

Example:
For the drawing operation of Example above, determine (a) drawing force and
(b) Holding force, given that the tensile strength of the sheet metal (low-carbon steel) = 300 MPa and yield strength = 175 MPa. The die corner radius = 6 mm.

Solution:

$$F = \pi(75)(2.4)(300)\left(\frac{138}{75} - 0.7\right) = 193{,}396\ \text{N}$$

(b) Holding force is estimated by Eq. (20.13):

$$F_h = 0.015(175)\,\pi(138^2 - (75 + 2.2 \times 2.4 + 2 \times 6)^2) = 86{,}824\ \text{N}$$

**9.4.3.3 D**

(a) **Wrink** ... that form radially ir ...

(b) **Wrinkling** in the wall. If and when the wrinkled flange is drawn into the cup, these ridges appear in the vertical wall.

(c) **Tearing**. Tearing is an open crack in the vertical wall, usually near the base of the drawn cup, due to high tensile stresses that cause thinning and failure of the metal at this location. This type of failure can also occur as the metal is pulled over a sharp die corner.

(d) **Earing**. This is the formation of irregularities (called ears) in the upper edge of a deep drawn cup, caused by anisotropy in the sheet metal. If the material is perfectly isotropic, ears do not form.

(e) **Surface scratches**. Surface scratches can occur on the drawn part if the punch and die are not smooth or if lubrication is insufficient.

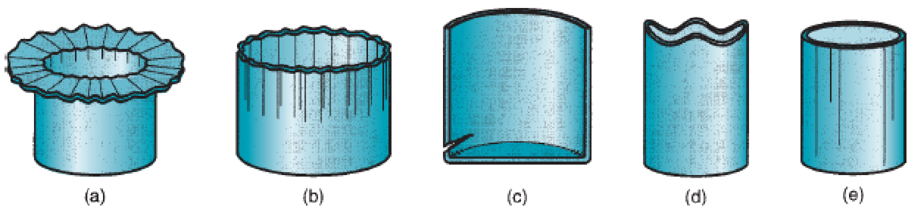



Figure 9.10 Common defects in drawn parts: (a) wrinkling can occur either in the flange or (b) in the wall, (c) tearing, (d) earing, and (e) surface scratches.