3. Sheet Metal Drawing Operations

- It is used to make cup-shaped, box-shaped, or other complex-curved and concave parts.
- Figure (3-65) explains this process.
- Common parts made by sheet metal drawing include beverage cans, ammunition shells, sinks, cooking pots, and automobile body panels.

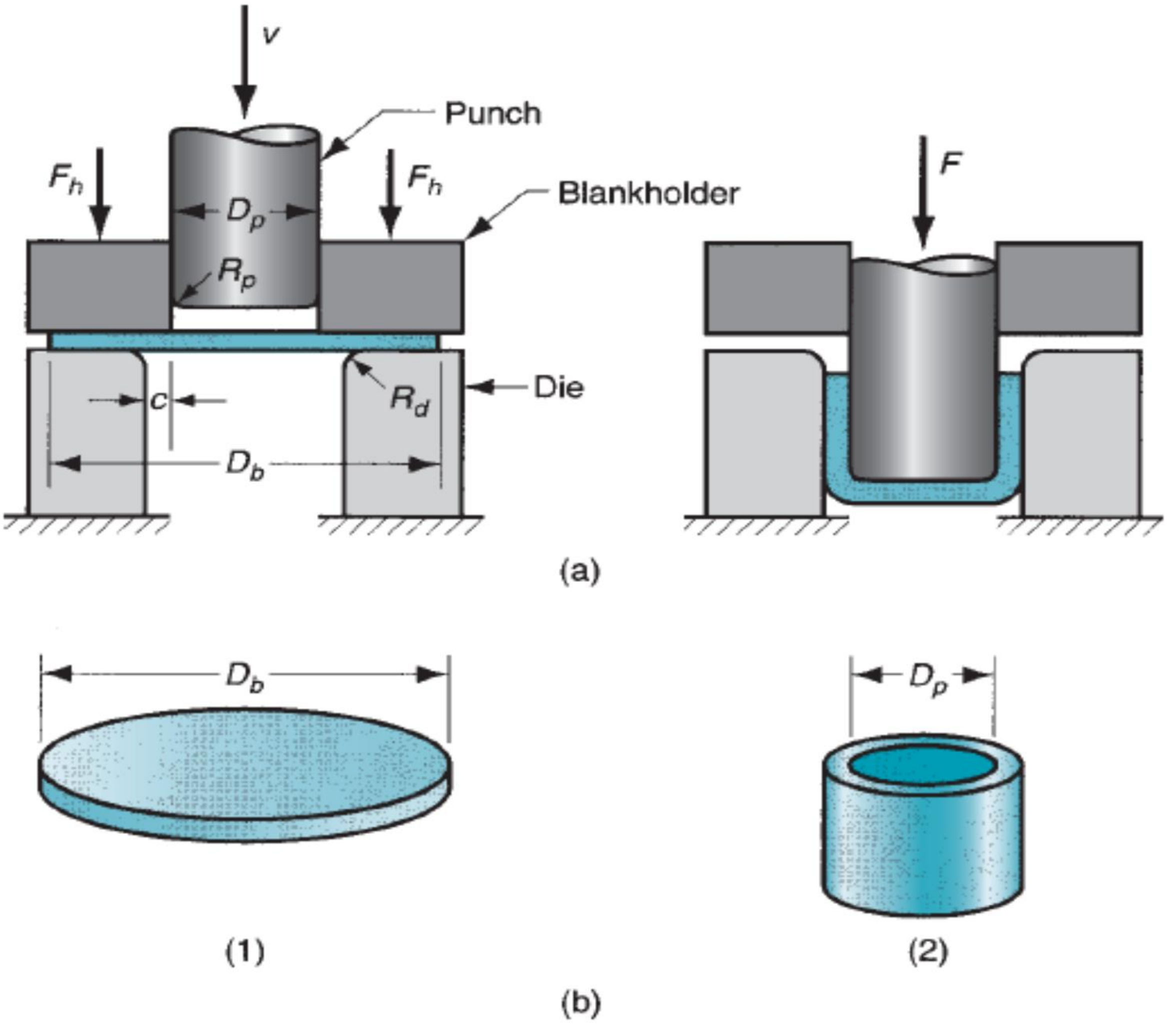

Figure (3-65): (a) drawing of a cup-shaped part: (1) start of operation, and (2) near end of stroke; and (b) corresponding workpiece: (1) starting blank, and (2) drawn part. c: clearance, D_b: blank diameter, D_p: punch diameter, R_d: die corner radius, R_p: punch corner radius, F: drawing force, F_h: holding force, v: motion of punch

Mechanics of Sheet Metal Drawing:

- Sides of punch and die are separated by a clearance *c*. It is given as:

$$c = 1.1t \qquad t\text{: stock thickness}$$

- Deformation stages in deep drawing are illustrated in figure (3-66).

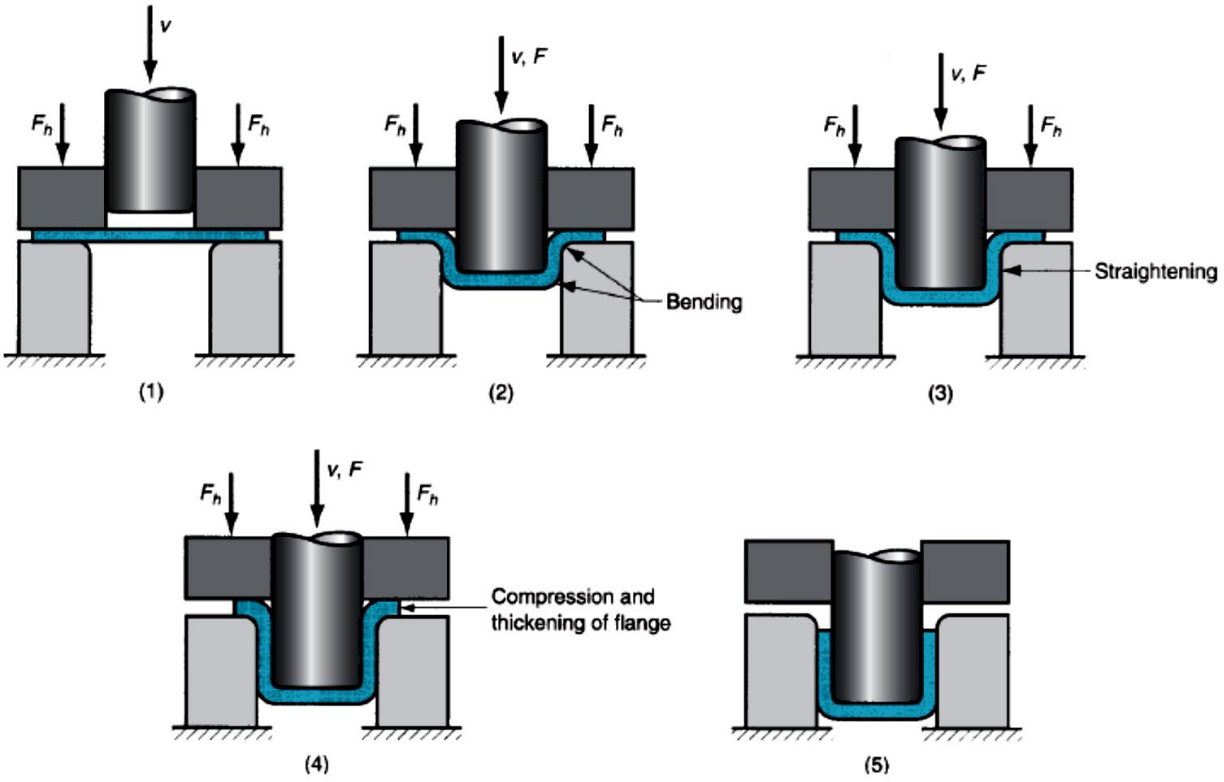

Figure (3-66) deformation stages of deep drawing

(1) Initial contact between punch and w.p.
(2) Bending: the punch proceeds to push into w.p.: the sheet is bent over the corner of the punch and the corner of the die.
(3) Straightening: As the punch moves further down. This action occurs in the metal that was previously bent over the die radius in order to be pulled into the clearance to form the wall cylinder.

 The metal in the outer portions of the blank is pulled or drawn toward the die opening, so metal flow through a constricted space gives the drawing process its name.

(4) Friction and Compression: it is occurred in the outer edge of blank (flange). The holding force and friction conditions at two interfaces are determining factors in success of this process.

 As metal in the flange region is drawn toward the center, the outer perimeter becomes smaller. Because of volume constancy, metal is squeezed and becomes thicker as perimeter is reduced (wrinkling of rest blank flange).

If holding force is too small, wrinkling occurs. If it is too large, it prevents metal flow properly toward die cavity ~~resulting~~, resulting in stretching and possible tearing in the w.p.

(5) Thinning: it is occurred in cylinder wall. As the metal is pulled over the die opening edge, the metal deformation involves stretching and thinning of the w.p.

Engineering Analysis of Sheet Metal Drawing:

Measures of Drawing:

- **Drawing Ratio (DR):** it is measure of the severity of a deep drawing operation.

$$DR = \frac{D_b}{D_p}$$

D_b: blank diameter

D_p: punch diameter

- The greater the ratio, the more severe the operation.
- *The range of* $DR \leq 2$.
- Drawing Ratio depends on: (1) R_p, (2) R_d, (3) friction conditions, (4) draw depth, (5) characteristics of sheet metal (e.g., ductility, strength properties).

- **Reduction (r):** another ratio to characterize the deep drawing operation.

$$r = \frac{D_b - D_p}{D_b}$$

- *The range of reduction* $r \leq 0.5$.

- **Thickness to Blank Diameter Ratio (t/D_b)**

- *It is desirable for* t/D_b *to be greater than 1%* ($t/D_b > 0.01$).
- As t/D_b decreases, tendency for wrinkling increases.

Sheet Metal Drawing Force (F_{smd}):

- The sheet metal drawing force required to perform a given operation can be estimated roughly by the formula:

$$\boldsymbol{F_{smd} = \pi D_p t(TS)[DR - C]}$$

F_{smd}: sheet metal drawing force (N), maximum force in operation
D_p: punch diameter (mm),
t: stock thickness (mm),
TS: tensile strength (MPa),
DR: drawing ratio,
C: correction factor to account for friction usually = 0.7.

Sheet Metal Holding Force (F_h):

- It is important factor in sheet metal drawing operation.
- The holding pressure can be set at a value=0.015 Y (yield strength).
- The holding pressure is then multiplied by the blank starting area that is to be in contact with the blankholder.

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

F_h: holding force (N),
Y: yield strength (MPa),
t: stock thickness (mm),
R_d: die corner radius (mm)

Blank Size Determination:

- The following is reasonable method for estimating the starting blank diameter in a deep drawing to produce a round part (e.g., cylindrical cup and more complex shapes so long as they are axisymmetric).
- **By setting: *volume of final product = starting blank volume* and solving for diameter *D_b*.**
- To facilitate the calculation, it is often assumed that wall thinning is neglected.

Sheet Metal Drawing Without a Blankholder:

- One of blankholder functions is to prohibit wrinkling of sheet flange while the cup is being drawn.
- Tendency for wrinkling is reduced as t/D_b increases.
- If t/D_b ratio is large enough, sheet metal drawing can be accomplished without using a blankholder as shown in figure (3-67).
- The limiting condition for sheet metal drawing without a blankholder is:

$$D_b - D_P < 5t$$

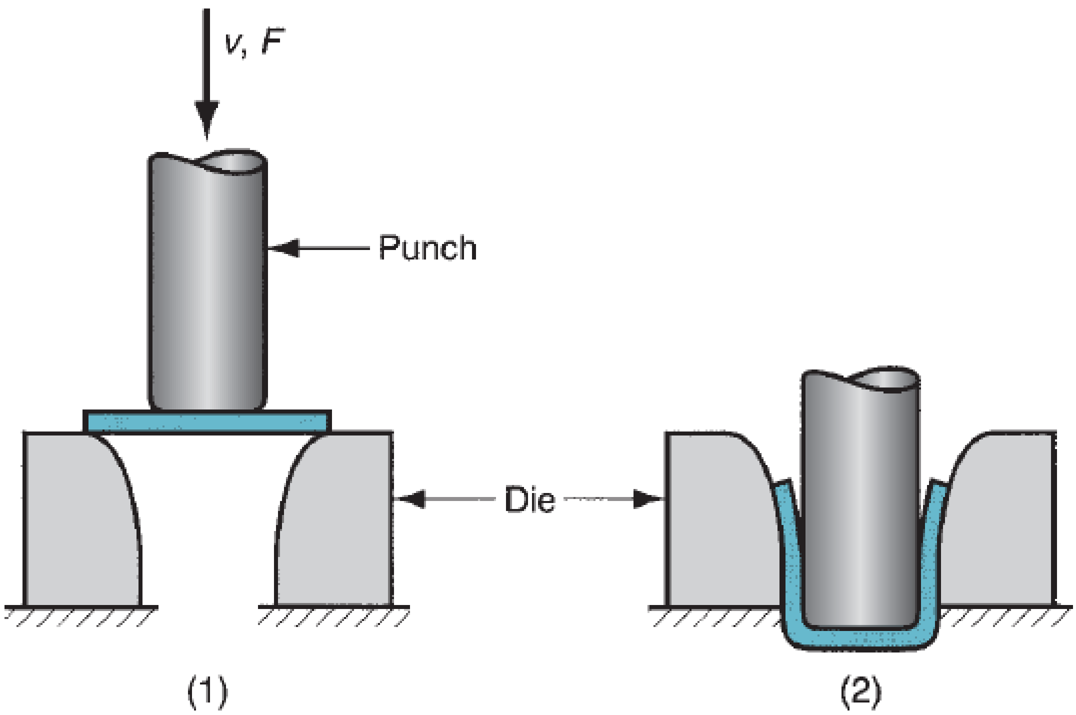

Figure (3-67) sheet metal drawing without blankholder. ***The draw die must have the shape of a funnel or cone to permit the sheet metal to be drawn properly into the die cavity.***

Example (24):

A sheet metal drawing operation is used to form a cylindrical cup with inside diameter = 75mm and height = 50mm. The starting blank size = 138mm and stock thickness = 2.4mm. Based on these data, (a) is the operation feasible? (b) determine the sheet metal drawing force and holding force.

The sheet metal is low carbon steel having tensile strength = 300 MPa, and yield strength = 175 MPa. Take the die corner radius = 6mm.

Solution:

(a) To assess feasibility, determining the drawing ratio *DR*, reduction *r*, and thickness to blank diameter ratio are necessary:

D_p = 75mm, D_b = 138mm

DR = D_b / D_p = 138 / 75 = **1.84** < **2** **Answer**

r = (D_b – D_p) / D_b = (138-75)/138 = **0.457** < **0.5** **Answer**

t/D_b = 2.4 / 138 = **0.0174** > **0.01** **Answer**

Thus the sheet metal drawing operation is feasible.

(b)

$F_{smd} = \pi D_p t(TS)[DR - C] = \pi(75)(2.4)(300)[1.84 - 0.7] = \mathbf{193.4KN}$ **Answer**

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

$$= 0.015(175)\pi\{138^2 - (75 + 2.2x2.4 + 2x6)^2\} = \mathbf{86.8KN}$$ **Answer**

Example (25):

A drawing operation is performed on 3 mm stock. The part is a cylindrical cup with height = 50 mm and inside diameter = 70 mm. Assume the corner radius on the punch is zero. (a) Find the required starting blank size D_b. (b) Is the sheet metal drawing operation feasible?

Solution:

(a) *volume of final product = starting blank volume*

volume of final product = cup wall volume + cup base volume

assume thickness is remain constant during drawing operation.

$$volume\ of\ final\ product = \frac{\pi}{4}[76^2 - 70^2]50 + \frac{\pi}{4}(70^2)3 = 45945.8mm^3$$

$$starting\ blank\ volume = \frac{\pi}{4}D_b^2(3) = 2.356D_b^2 mm^3$$

$$\therefore 45945.8 = 2.356D_b^2 \Longrightarrow \therefore D_b = \mathbf{139.6mm}$$ **Answer**

(b) To check feasibility, determining the drawing ratio *DR*, reduction *r*, and thickness to blank diameter ratio are necessary:

D_p = 70mm, D_b = 139.6mm

DR = D_b / D_p = 139.6 / 70 = **1.994** < **2** **Answer**

r = (D_b – D_p) / D_b = (139.6-70)/139.6 = **0.498** < **0.5** **Answer**

t/D_b = 3 / 139.6 = **0.0215 > 0.01** **Answer**

Thus the sheet metal drawing operation is feasible.

Example (26):

A cup is to be drawn in a deep drawing operation. The height of the cup is 75 mm and its inside diameter = 100 mm. The sheet-metal thickness = 2 mm. If the blank diameter = 225 mm. (a) does the operation seem feasible? (b) if the blank diameter = 175 mm, does that blank diameter provide sufficient metal to draw a 75mm cup height? is the operation feasible also? Assuming the corner radius on the punch has a negligible effect on drawing operation.

Solution:

(a) D_p = 100mm, D_b = 225mm

DR = D_b / D_p = 225 / 100 = **2.25 > 2 (not in range)** **Answer**

r = (D_b – D_p) / D_b = (225-100)/225 = **0.555 > 0.5 (not in range)** **Answer**

t/D_b = 2 / 225 = **0.00888 < 0.01 (not in range)** **Answer**

Thus the sheet metal drawing operation is NOT feasible.

(b) We must calculate the cup height with blank diameter=175mm, if the cup height equal to 75mm, then that blank diameter provide sufficient metal for drawing process:

volume of final product = starting blank volume

volume of final product = cup wall volume + cup base volume

assume thickness is remain constant during drawing operation.

$$\text{volume of final product} = \frac{\pi}{4}[104^2 - 100^2]h + \frac{\pi}{4}(100^2)2 = 640.9h + 15707.9$$

$$\text{starting blank volume} = \frac{\pi}{4}175^2(2) = 48105.6mm^3$$

$$\therefore 640.9h + 15707.9 = 48105.6$$

$$\therefore h = \mathbf{50.55mm}, \text{ it is less than 75mm}$$

D_p = 100mm, D_b = 175mm

DR = D_b / D_p = 175 / 100 = **1.75 < 2 (in range)** **Answer**

r = (D_b – D_p) / D_b = (175-100)/175 = **0.429 < 0.5 (in range)** **Answer**

t/D_b = 2 / 175 = **0.0114 > 0.01 (in range)** **Answer**

Although the DR, r and t/D_b are in the acceptable range but still the drawing operation infeasible because of blank diameter 175mm doesn't provide the sufficient material for drawing operation since new height ≠ 75mm.