Drawing

Drawing is a sheet-metal operation used to make cup-shaped.

It is performed by placing a sheet-metal blank over a die cavity and then pushing the metal into the opening with a punch as in Fig. 1. The blank must usually be held down flat against the die by a blank holder.

As the punch proceeds downward toward its final bottom position, the work experiences a complex sequence of stresses and strain as it is gradually formed into the shape defined by the punch and die cavity.

Stages in deformation of the work in deep drawing:
Lubrication is generally used to reduce friction force. The holding force applied by the blankholder is to be a critical factor in deep drawing.

- If it is too small, wrinkling occurs
- If it is too large, it prevents the metal from flowing properly toward the die cavity, resulting in stretching and possible tearing of the sheet metal.

The thinning near the base of the cup up to 25%.

DR, drawing ratio = \( \frac{D_b}{D_p} \leq 2 \)

\( r \), reduction = \( \frac{D_b - D_p}{D_b} \) less than 0.3

\( t/D_b \), thickness to diameter ratio to be greater than 0.5. As \( t/D_b \) decreases, tendency for wrinkling.

Example:

A drawing operation is used to form a cylindrical cup with inside diameter = 3 in. and height = 2 in. The starting blank \( D_b \) = 5.5 in. and the stock thickness \( = \frac{3}{32} \) in. Based on the data, is the operation feasible?

\( DR = \frac{5.5}{3.0} = 1.833 \)

\( r = \frac{5.5 - 3.0}{5.5} = 45.45 \% \)

\( t/D_b = \frac{\frac{3}{32}}{5.5} \)

As \( t/D_b \) decreases, tendency for wrinkling.

The drawing is feasible.

\( F_1 \), Force = \( \pi D_p t (TS) \left( \frac{D_b}{D_p} - 0.7 \right) \)

\( C \), constant

( Correlation factor to account for friction)

\( F_1 \), holding force = \( 0.015 \pi \sqrt{C} D_b^2 \left( D_p + 2.2 t + 2 Rd \right)^2 \)
Ex.

For the drawing operation of example.

Determine: @ drawing force and $\Sigma$ holding force, given that the tensile strength of the sheet metal = 70,000 lb/ft², and yield strength = 49,000 lb/ft².

The die corner radius = 0.75 in.

\[ F = \pi (3.0) \left( \frac{3}{32} \right) (70,000) \left( \frac{5.5}{3.0} \right) = 70.097 \text{ lb} \]

\[ F_k = 0.015(49,000) \pi \left( \frac{5.5^2}{3.0} - (3.0 + 2.2 \times \frac{3}{32} + 2 \times 0.75) \right) \]
\[ = 31.12 \text{ lb} \]

**Height of cup**

\[ T R_0^2 \] = \[ T R_i^2 \] + \[ 2 \pi T \] \[ R_i \] \[ t \]

\[ h \approx \frac{V_e}{2} \left[ \left( \frac{R_0}{R_e} \right)^2 - 1 \right]^L \]

**Other drawing operation**

Redrawing

- If the drawing radius is too high, may require more than one drawing step, referred to as redrawing.
- For the first drawing, the max reduction of the starting blank should be 40% to 45%.
- For the second draw (first redraw), $R_{max} = 30\%$.
- For the third draw (second redraw), $R_{max} = 16\%$. 
Reverse drawing

- The drawing part is positioned face down on the die so that the second drawing operation produces a configuration.

- It may seem that reverse drawing would produce a more severe deformation than redrawing, it is actually easier on the metal.

- The reason is that the sheet metal is bent in the same direction at the outside and inside corners of the die in reverse drawing. Whereas in redrawing, the metal is bent in the opposite directions at the two corners. Because of this difference, the metal experiences less than hardening in reverse drawing and the drawing force is lower.

Drawing without a blank holder

- The blank holder is to be present wrinkling of the flange while the cup is being drawn.

- Wrinkling is reduced as $t/D$ ratio increases.

- If $t/D$ is large enough, drawing can be accomplished without blank holder.

- The limiting condition for drawing without a blank holder can be estimated from eg.

$D_0 - D_f < \text{st.}$

Advantages

1. Lower cost
2. Simple press
1. Derive an expression for the reduction $r$ in drawing as a function of drawing ratios $DR$

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

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

$$r = \frac{D}{D} - \frac{D_p}{D} = 1 - \frac{D_p}{D} = 1 - \frac{1}{DR}$$

From 2:

$$D_p = \frac{A_{AR}}{HR}$$

Substitute into 0:

$$r = \frac{D - D_p}{D} = \frac{D DR - D}{D} = \frac{D DR - D}{D} \times \frac{1}{DR}$$

$$r = \frac{D DR - D}{D DR} = 1 - \frac{1}{DR}$$

2. A cup is to be drawn in a deep drawing operation. The height of the cup is 75 mm and its inside diameter is 100 mm. The sheet metal thickness is 2 mm. If the blank diameter is 225 mm, determine the drawing ratio, $DR$, reduction, $r$, and thickness-to-diameter ratio, $t/D_b$, does the operation seem feasible?

Solution:

$$\frac{DR \cdot D_b}{D_p} = \frac{225}{100} = 2.25$$

$$r = \frac{D_b - D_p}{D_p} = \frac{225 - 100}{225} = 0.555 \text{ or } 55.5\%$$

$$\frac{t}{D_b} = \frac{2}{225} = 0.889\%$$

C) Feasibility: No! $DR$ is too large (greater than 2.0), and $t/D_b$ is small (less than 1%).
3. Solve problem 2 except that the starting blank size = 175 mm.

A) \( DR = 1.75 \)

B) \( r = 62.9\% \)

C) \( \frac{t}{D} = 1.14\% \)

Feasibility? \( DR < 2.0, r < 50\%, \text{ and } \frac{t}{D} > 1\% \).

However, the operation is not feasible because the 175 mm diameter blank size does not provide sufficient metal to draw a 75 mm cup height.

Blank area = \( \pi D^2/4 = 24.053 \text{ mm}^2 \)

Cup area = \( \pi D h + \pi D^2/4 = 100 \pi h + \pi (100\text{ mm})^2/4 \)

Area of wall = \( 314.16 h = 78.54 \text{ mm}^2 \)

Area of cup = area of blank

\( 314.16 h + 78.54 = 24.053 \)

\( \Rightarrow h = 51.56 \text{ mm} \)

This is less than the specified 75 mm height.

4. A deep drawing operation is performed in which the inside of the cylindrical cup has a diameter = 4.0 in. and a height = 2.5 in. The stock thickness = \( \frac{1}{8} \) in. and the starting blank diameter = 3.5 in. punch and die radii = \( \frac{5}{32} \) in. The metal has tensile strength = 60,000 lb/in. and yield strength = 30,000 lb/in. Determine: A) drawing radius, B) reduction, C) drawing force, and D) blank holder force.

A) 1.875, B) 1.667\%, C) 110,756 lb, D) 49,770 lb.
6. Solve the previous problem except \( t = \frac{3}{16} \) in. Estimate \( F_h \) then compare with Ex. 4.

6. A cup drawing operation is performed in which the inside diameter is 80 mm and the height is 50 mm. The stock thickness is 3.0 mm, and the starting blank diameter is 150 mm. Punch and die radii are 4 mm. Tensile strength is 400 MPa and a yield strength is 180 MPa for this sheet metal. Determine:
   (a) drawing ratios, (b) reduction, (c) drawing force, and (d) blankholder force.

7. A deep drawing operation is to be performed on a sheet metal blank that is \( \frac{1}{8} \) in. thick. The height (inside dimension) of the cup is 3.8 in., and the diameter (inside dimension) is 5.0 in. Assuming the punch radius is 0, compute the starting diameter of the blank to complete the operation with no material left in the flange. Is the operation feasible (ignoring the fact the punch radius is too small)?

It is constant (deep drawing):

\[
\text{Cup area} = \text{well area} + \text{base area} = \pi D h + \pi D^2/4 = 25.25 \pi \text{ in}^2.
\]

\[
\text{Blank area} = \pi D^2/4 = 0.25 \pi D^2.
\]

\[
\text{Blank area} = \text{cup area} - 0.25 \pi D^2 = 25.25 \pi - 79.32 \text{ in}^2.
\]

\[D = 10.050 \text{ in.}\]

\[
DR = \frac{D_p}{D} = \frac{10.050}{5.0} = 2.01 > 2.0
\]

For feasibility, test \( DR \) is No.

8. Solve Ex. 7 except use a punch radius of 0.375 inch.
8. The surface area of the cup

\[ h = 3.80 \times 0.375 = 3.425 \text{ in} \text{, then } \]

A quarter toroid formed by 0.375 radius of the base of the cup, base, which has a diameter base: \(5.0 - 2 \times 0.375 = 4.25 \text{ in}\)

\[ A_1 = \pi D h = \pi (5.0) (3.425) = 53.807 \text{ in}^2 \]

\[ A_2 = \frac{\pi D^2}{4} = 0.25 \pi (2 \times 0.375)^2 = 0.589 \text{ in}^2 \]

The centroid is located at the center of the arc which is

0.375 \ sin 45° = 0.265 beyond the center of the 0.375 in.

Thus the diameter of the circle described by the centroid is

4.25 \+ 2 \times 0.265 \= 4.780 \text{ in}

\[ A_2 = \pi (4.78 \times 0.589) = 8.847 \text{ in}^2 \]

\[ A_3 = \frac{\pi (4.25)^2}{4} = 14.188 \text{ in}^2 \]

Total area of cup = 53.807 + 14.188 + 8.847 = 76.842 \text{ in}^2

Blank area = \(\frac{\pi D^2}{4} = 0.7855 D^2 = 76.842 \text{ in}^2\)

D = 9.89 in

\[ DR = 1.978 \]

\[ HD = 0.125/9.89 = 0.0126 \leq 1.26\% \Rightarrow \text{The operation is feasible} \]

Previous problem

\[ A = 25.25 \times \pi = 79 \text{. Compare with } 76.842 \]
9. A drawing operation is performed on 3.0 mm stock. The part is a cylindrical cup with a height of 50 mm and inside diameter 70 mm. Assume the corner radius on the punch = zero. a) Find the required starting blank size D₀. b) Is the drawing operation feasible?

Cup area = wall area + base area

= \pi \frac{D^2}{4} + \pi D h = \pi (70)(50) + 0.25 \pi (70)^2 = 14.846 \text{ mm}^2

Blank area = \pi \frac{D^2}{4} = 0.7855 D = 14.846

D = 137.48 \text{ mm}

DR = 1364, \frac{t}{D} = 2.18\% (feasible) but Rp = 0 (the shape would be difficult to draw like blanlking punch)

10. Solve Ex. 9: take h = 60 mm.

11. Solve Ex. 10: take Rp = 10 mm, answer D = 143.28 mm and the operation infeasible.
12. A cup shaped part is to be drawn without a blank holder from sheetmetal whose thickness = 0.25 inches. The inside diameter of the cup = 2.5 inches, its height = 1.5 inches, and the corner radius at the base = 0.375 inch. (a) What is the min starting blank diameter that can be used, according to \( D_0 - D_p < 5t \)? (b) Does this blank diameter provide sufficient material to complete the cup?

\[
D < 5t + D_p = 5(0.25) + 2.5 = 3.75 \text{ in}
\]

Volume of walls: \( V_1 = (1.5 - 0.375) \pi [ (2.5 + 2 \times 0.25)^2 - (2.5)^2 ] = 2.430 \text{ in}^3 \)

\( V_2 \): (cross-section of quarter toroid) \( \times \) (Circle made by sweep of centroid)

Cross-section of quarter toroid = \( 0.25 \pi \left[ (0.375 + 0.25)^2 - (0.375)^2 \right] = 0.1964 \text{ in}^2 \)

Circle made by centroid sweep has diameter:

\[
(2.5 - 2 \times 0.25) \times 2(0.375 + 0.25) = 2.457 \text{ in}
\]

\[ V_2 = 2.457 \pi (0.1964) = 1.516 \text{ in}^3 \]

\[ V_3 = (2.5 - 2 \times 0.375)^2 \pi (0.25)/4 = 0.601 \text{ in}^2 \]

\[ V_t = V_1 + V_2 + V_3 = 4.547 \text{ in}^3 \]

\[ V_{o blank} = \pi (0.25)^2 / 4 = \pi (0.25)^2 / 4 = 4.547 \text{ in}^3 \]

\[ D = 4.81 \text{ in} \]

The diameter \( 4.75 \) computed in (a) does not provide sufficient metal to complete the drawing.