



# LECTURE FIFTEEN

DEEP DRAWING ANALYSIS

**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:

$$DR = D_b / D_p \quad 15.1$$

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 ( $R_p$  and  $R_d$ ), 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

$$r = \frac{D_b - D_p}{D_b} \quad 15.2$$

It is very closely related to drawing ratio. Consistent with the previous limit on DR ( **$DR \leq 2.0$** ), 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 = 138mm and 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:

$$F = \pi D_p t (TS) \left( \frac{D_b}{D_p} - 0.7 \right) \quad 15.3$$

Where  $F$  = drawing force, N (lb);  $t$  = original blank thickness, mm (in);  $TS$  = tensile strength, MPa (lb/in<sup>2</sup>); 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

$$F_h = 0.015Y\pi\{D_b^2 - (D_p + 2.2t + 2R_d)^2\} \quad 15.4$$

Where  $F_h$  = holding force in drawing, N (lb);  $Y$  = yield strength of the sheet metal, MPa (lb/in<sup>2</sup>);  $t$  = 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.

SOL:

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

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

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

# Defect in deep drawing

- (a) **Wrinkling** in the flange. Wrinkling in a drawn part consists of a series of ridges that form radially in the undrawn flange of the workpart due to compressive buckling.
- (b) **Wrinkling** in the wall. If and when the wrinkled flange is drawn into the cup.
- (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.

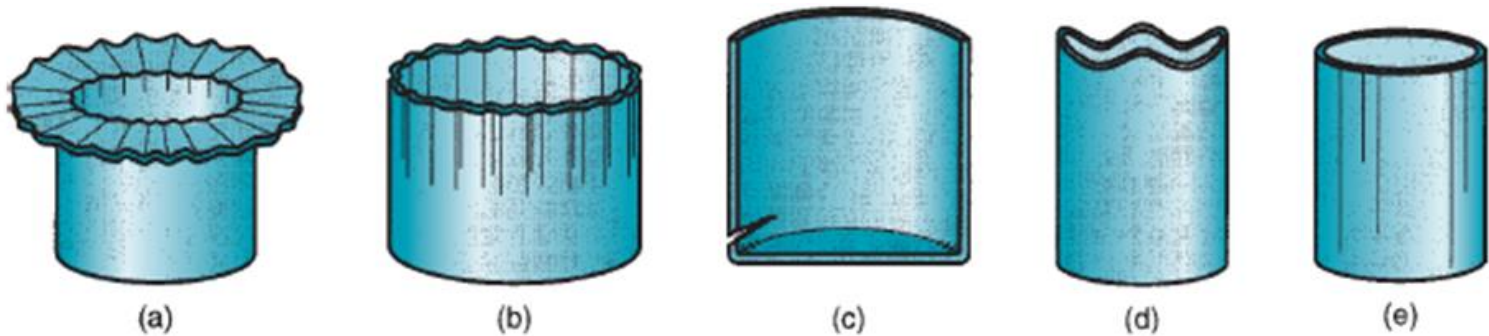


Figure 15.1 Common defects in drawn parts: (a) wrinkling can occur either in the flange or (b) in the wall, (c) tearing, (d) earring, and (e) surface scratches.