Deep drawing

deep drawing is the tensile compressive forming of a sheet blank (depending on the material, also of foils or plates) to a hollow body open on one side or the forming of a pre-drawn hollow shape into another with a smaller cross-section without an intentional change in the sheet thickness,. The process limitations are laid out by the conditions required to transmit the force into the forming zone. The drawing force necessary for the forming is transmitted from the punch to the work-piece base and from there to the forming zone in the flange. The resulting limiting deformation in the force application zone has nothing to do with the depletion of the forming capacity of the material in the forming zone. The process limits are reached when the largest applied drawing force cannot be transmitted to the forming zone in the flange. From this condition, one can derive the characteristic behavior of deep drawing that a number of forming steps can be carried out consecutively without an intermediate annealing step. Subdividing the whole process into a number of drawing steps has the advantage that the tensile force acting at the force application zone can be reduced. Most special processes which have been developed, make use of this fact.

Definition of Deep Drawing

Definition: Deep drawing is defined as a tensile-compressive sheet (DIN 8584) forming process in which a plane blank is formed into a hollow part open on one side or an open hollow part is formed into another hollow part with a smaller cross-section

"Deep drawing in a single draw" or "deep drawing in one step" is the forming of a plane sheet section (blank) into an open hollow shape.

"Redrawing", is the forming of an open hollow shape into one with a smaller cross-section.

Deep Drawing with a Blank holder

The general terms and definitions of deep drawing with a blank holder are illustrated in Figure 1. The deformation in the flange is a result of tangential compressive stresses and radial tensile stresses, when the sheet blank with diameter Do is drawn through the die to a cup with the punch diameter do. The blank holder force FN prevents the formation of folds. The stress due to the blank holder pressure is small compared to the radial and tangential stresses.
Stress Zones during Deep Drawing

During the drawing process the cup can be divided into four characteristic zones, see Figure 2, with different state of stress and deformation:
- The blank holder force FN prevents folds of „type 1“.
- The forming zone is the sheet material between the flange outer edge (D) and the outlet of the material to be formed from the drawing ring radius („die shoulder“)
- The surface area of the drawn part is about the same as that of the starting blank. Consequently, the sheet thickness remains almost constant.
- The base of the drawn part is formed on the same principles that apply to mechanical drawing.

Force-Displacement Curve during Deep Drawing

During the deep drawing process, the drawing force increases from zero up to a maximum value and then falls down again to zero, see Figure 3. The base is first formed in a manner similar to the stretch forming process and then the actual drawing process follows.
Tube drawing

Definition

Tube drawing is the drawing of hollow parts, where the outside is formed by a drawing die hole and the inside by a plug or a rod

Tube drawing processes

Several manufacturing processes have been developed for drawing tubes. What the processes all have in common is that the tube to be drawn is pointed at one end (pressed between two semi-circular jaws). This pointed end is pushed through the drawing ring and then held tight by the gripper attached to the carriage of the drawing machine. The drawing carriage then pulls the tube through the stationary drawing ring.

Table. 1 shows tube drawing processes and the features which characterize them

<table>
<thead>
<tr>
<th>Drawing without a mandrel (tube sinking)</th>
<th>Drawing over a stationary mandrel (plug)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The tube is pulled through the drawing die hole with no support from inside. In this process, only the external diameter measurements are precise; the wall thickness and internal diameter deviate more. This process, known as tube sinking, is only applied to tubes with smaller internal diameters.</td>
<td>As the annular gap is smaller than the wall thickness of the tube to be drawn, the wall thickness is reduced and the tube takes on the dimensions of the drawing die hole for its external diameter, and of the plug for its internal diameter.</td>
</tr>
</tbody>
</table>

Figure 11.1 The principle of tube drawing without a mandrel. 1 Drawing die, 2 workpiece

Figure 11.2 The principle of drawing over a stationary mandrel. 1 Drawing ring, 2 workpiece, 3 mandrel, 4 plug
Principal strain and drawing force

The limits for the permissible principal strains come from the required drawing force. As the drawing force must be carried by the tube cross-section $A_x$ (Figure 8) after deformation, it must remain lower than the tensile force. $F_{dr} \leq F_{perm}$

![Figure 8 Tube cross-sections $A_0$ before and $A_1$ after the draw](image)

This provides the permissible deformations. If the required cross-sectional reduction cannot be achieved at one drawing, as $F_{dr} \leq F_{perm}$, then intermediate annealing must be carried out after the first draw.

Table 2 shows how the drawing force $F_{dr}$ and the tensile force $F_{perm}$ can be calculated mathematically.
### Table 2: Calculating principal strain and drawing force

<table>
<thead>
<tr>
<th>Type of drawing</th>
<th>Permissible deformation $\varphi_{perm}$ in % (from drawing force)</th>
<th>Principal strain $\varphi_p$ (-)</th>
<th>Drawing force in N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube sinking</td>
<td>20 – 50</td>
<td>$\varphi_p = \ln \frac{d_0}{d_1}$</td>
<td>$F_{dr} = \frac{A_t \cdot k_{st,\varphi_p} \cdot \varphi_p}{\eta_F}$ for $2 \varphi = 16^\circ$ (optimum opening angle):</td>
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<tr>
<td></td>
<td></td>
<td>$\varphi_{perm} = \varphi_p \cdot 100$ (%)</td>
<td>$\eta_F = 0.4 - 0.6$ for $\varphi_p = 15$ %, $\eta_F = 0.7 - 0.8$ for $\varphi_p = 50$ %</td>
</tr>
<tr>
<td>Plug drawing</td>
<td>30 – 50</td>
<td>$\varphi_p = \ln \frac{A_0}{A_t}$</td>
<td>$F_{perm} = A_t \cdot R_m$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\varphi_p = \ln \frac{d_2^2 - d_1^2}{D_1^2 - d_1^2}$</td>
<td>$F_{dr}$ must be lower than $F_{perm}$ however, or the tube breaks off.</td>
</tr>
<tr>
<td>Rod drawing</td>
<td>40 – 60</td>
<td>$\varphi_{perm} = \varphi_p \cdot 100$ (%)</td>
<td></td>
</tr>
</tbody>
</table>

- $\varphi_p$: principal strain
- $D_0$ in mm: external diameter before drawing
- $d_0$ in mm: internal diameter before drawing
- $A_0$ in mm$^2$: tube cross-section before drawing
- $D_1$ in mm: external diameter after drawing
- $d_1$ in mm: internal diameter after drawing
- $A_1$ in mm$^2$: tube diameter after drawing
- $k_{st,\varphi_p}$ in N/mm$^2$: mean flow stress
- $R_m$ in N/mm$^2$: tensile strength of the tube material
- $F_{dr}$ in N: drawing force
- $F_{perm}$ in N: maximum force which can be carried into the tube cross-section
- $\eta_F$: deformation resistance
11.5 Example

The aim is to draw a tube made of Ck 45 (\(R_{m} = 800\) N/mm\(^2\)) with initial dimensions of \(D_0 = 45\), \(d_0 = 30\), bringing it to \(D_1 = 40\) und \(d_1 = 28\).

Find:
1. Drawing force
2. Permissible limiting force
3. Can the cross-sectional reduction be achieved in one drawing?

Solution:

\[
\varphi_p = \ln \frac{D_0^2 - d_0^2}{D_1^2 - d_1^2} = \ln \frac{45^2 - 30^2}{40^2 - 28^2} = 0.32 \rightarrow 32\%
\]

\(k_{st}\alpha = 390, \quad k_{st\eta} = 840, \quad k_{str} = 615\) N/mm\(^2\)

\[
F_{dr} = \frac{A_t \cdot k_{str}}{\eta_{F}} \cdot \varphi_p = \frac{(40^2 - 28^2) \cdot \pi \cdot mm^2 \cdot 615 \cdot 0.32}{4 \cdot 0.7 \cdot mm^2}
\]

\(F_{dr} = 180178\) N \(\equiv 180\) kN

\[
F_{perm} = \frac{A_t \cdot R_{m}}{10^3 \cdot N/kN \cdot mm^2} = \frac{640.9 \cdot mm^2 \cdot 800}{10^3 \cdot N/kN} = 512.7\) kN

As \(F_{dr}\) is considerably smaller than \(F_{perm}\), this deformation can take place in one drawing.