Problem: A symmetrical cup workpiece is made of cold rolled steel with a thickness of 2 mm. Determine the following:

1. Blank size (D)
2. Percentage Reduction
3. Number of draws
4. Punch and die corner radii
5. Die clearance, punch & die dimensions
6. Drawing force
7. Blank holding force

$\sigma_{ut} = 340 \text{ MPa}$
(i) Blank size $(D)$

\[ d_{\text{shell}} = 45 \text{mm}, \quad h = 75 \text{mm}, \quad \sigma = 1.8 \text{mm} \]

\[ \frac{d}{\sigma} = \frac{45}{1.8} = 25 \]

Therefore \[ D = \sqrt{d^2 + 4dh} = 124.6 \text{ mm} \]

$D = 124.6$ mm is a theoretical blank diameter. To get finished edges, a small edge trimming is required. Therefore as a rule of thumb 0.05 mm trimming allowance is given per mm of blank diameter. Thus the trimming allowance in this case is 0.623 mm.

Hence the blank dia $D = 124.6 + 0.623 = 125.23$ mm

(ii) Percentage reduction \[ P = 100 \left( 1 - \frac{41}{125.23} \right) = 67.26\% \]

Since a maximum of 50% is achieved in first draw hence redraws are required.

(iii) Number of redraws \[ \frac{h}{d_8} = \frac{75}{41} = 1.8 \quad \text{i.e.} \quad 1.5 < 1.8 < 3 \]

Therefore at least three redraws are needed to achieve a cup dia 41 mm.

<table>
<thead>
<tr>
<th>draw</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40 - 50%</td>
</tr>
<tr>
<td>2</td>
<td>25 - 30%</td>
</tr>
<tr>
<td>3</td>
<td>15 - 20%</td>
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<tr>
<td>4</td>
<td>10 - 15%</td>
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</tbody>
</table>
First Iteration

First draw: Assume 45\% reduction and cup ID after reduction is \( r \)

\[ P_1 = 0.45 = 1 - \frac{d_1}{125.23} \Rightarrow d_1 = 68.88 \text{ mm} \]

Second draw: Assume 30\% reduction and cup ID after reduction is \( d_2 \)

\[ P_2 = 0.3 \]

Here \( D = 68.88 + 2t = 72.88 \text{ mm} \)

\[ 0.3 = (1 - \frac{d_2}{72.88}) \Rightarrow d_2 = 51.02 \text{ mm} \]

Third draw: Final cup ID is 41 mm. The \( \% \) reduction in this draw with \( D = 51.02 + 2t = 55.02 \text{ mm} \)

\[ P_3 = 100 \left(1 - \frac{41}{55.02}\right) \]

\[ = 25.48 \% \]  

( Going beyond the reduction limit in 2nd draw ) \( \Rightarrow \) 2nd Iteration is needed

Second Iteration

First draw: Assume 50\% reduction

\[ P_1 = 0.5 = 1 - \frac{d_1}{125.25} \Rightarrow d_1 = 62.62 \text{ mm} \]

Second draw: Assume 30\% reduction

\[ D = 62.62 + 4 = 66.62 \text{ mm} \]

\[ P_2 = 0.3 = 1 - \frac{d_2}{66.62} \Rightarrow d_2 = 46.63 \text{ mm} \]

Third draw: Final cup dia (i.e. ID) = 41 mm

\[ D = 46.63 + 4 = 50.63 \]

\[ P_3 = 100 \left(1 - \frac{41}{50.63}\right) = 19 \% \]
(iv) Calculation for punch and die corner radius

Punch corner radius \( r_p \)
- First draw \( r_p = 4t = 8\text{mm} \)
- Second draw \( r_p = 3t = 6\text{mm} \)
- Third draw \( r_p = 1.8\text{mm} \)

Die corner radius \( r_d = 4t = 8\text{mm} \)

(v) Die clearance, \( t = 2\text{mm}, 1.3 < t < 3.18 \)

- Clearance for first draw = \( 1.1 \times t = 1.1 \times 2 = 2.2\text{mm} \)
- Clearance for second draw = \( 1.12 \times 2 = 2.24\text{mm} \)
- Clearance for third draw = \( 1.12 \times 2 = 2.24\text{mm} \)

Calculation of punch and die diameters

First draw

Punch dia. = \( ID \) of cup = 41\text{mm} \\
Die dia = punch dia. + 2 \times \text{clearance in 3rd draw} \\
= 41 + 2 \times 2.24 = 45.48\text{mm} \\

Second draw

Punch dia = 46.63\text{mm} \\
Die dia = 46.63 + 2 \times 2.24 = 51.11\text{mm} \\

Third draw

Punch dia = 62.62\text{mm} \\
Die dia = 62.62 + 2 \times 2.2 = 67.02\text{mm} \\

First draw

(vi) Drawing force

\[ P = \pi d t \sigma_u \left( \frac{D}{d} - 1 \right) \]

where \( d \) = shall OD
\( D \) = Blank dia (OD)
\( \sigma_u \) = Ultimate tensile strength of sheet material
\( C \) = Constant to cover friction and bending
\( \approx 0.6 \) to 0.7 for ductile material

For first draw, shall OD = \( d = \frac{62.62 + 4}{12.8} = 66.62 \) mm
\[ P_1 = \pi \times 66.62 \times 2 \times 340 \left( \frac{125.23}{66.62} - 0.6 \right) \]
\[ P_1 = 182.135 \text{ KN} \]

For second draw \( d = \frac{50.63 + 4}{66.62} = 50.63 \) mm
\[ P_2 = \pi \times 50.63 \times 2 \times 340 \left( \frac{66.62}{50.63} - 0.6 \right) \]
\[ P_2 = 77.423 \text{ KN} \]

For third draw \( d = 45 \) mm, \( D = 50.63 \) mm
\[ P_3 = \pi \times 45 \times 2 \times 340 \left( \frac{50.63}{45} - 0.6 \right) \]
\[ P_3 = 50.480 \text{ KN} \]

(vii) Blank holding force \( P_h = \frac{1}{3} \times \text{Drawing force} \)

First draw \( P_{h1} = \frac{1}{3} \times 182.135 = 60.71 \) KN
Second draw \( P_{h2} = \frac{1}{3} \times 77.423 = 25.81 \) KN
Third draw \( P_{h3} = \frac{1}{3} \times 50.48 = 16.83 \) KN
Blank holding force:

\[ F_b = A_c \times \bar{p} \]

where \( A_c = \frac{\pi}{4} \left( D^2 - (d + 2 \cdot \beta d)^2 \right) \)

\( D = \) blank diameter
\( d = \) punch diameter
\( \beta d = \) die profile radius

\[ \bar{p} = \frac{k}{t} \left( \left( \frac{D}{d} - 1 \right)^3 + 0.005 \frac{D}{t} \right) \] \text{bar N/mm}^2

\( t = \) sheet thickness

\( k = 0.005 \) to \( 0.007 \)