MSE 440/540: Processing of Metallic Materials

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Lecture 11: Drawing and Forming
Wire and Bar Drawing

- Similar to extrusion except work is *pulled* through die in drawing
  - It is *pushed* through in extrusion
- Although drawing applies tensile stress, compression also plays a significant role since metal is squeezed as it passes through die opening
Area Reduction in Drawing

- Change in size of work is usually given by area reduction:

\[ r = \frac{A_o - A_f}{A_o} \]

The true drawing strain:

\[ \varepsilon = \ln \frac{A_0}{A_f} = \ln \frac{1}{1 - r} \]

\[ \sigma = \bar{\sigma}\varepsilon, \]

\[ F = A_f\sigma \quad \text{No friction, uniform deformation} \]
Practical Drawing Force

\[ \sigma_d = \bar{\sigma} \left(1 + \frac{\mu}{\tan \alpha}\right) \phi \varepsilon \]

\[ \phi = 0.88 + 0.12 \frac{D}{L_C} \]

\[ L_C = \frac{D_0 - D_f}{2 \sin \alpha} \]

\[ F = A_f \sigma_d = A_f \bar{\sigma} \left(1 + \frac{\mu}{\tan \alpha}\right) \phi \varepsilon \]
Drawing Practice and Products

• Drawing practice:
  – Usually performed as cold working
  – Most frequently used for round cross sections

• Products:
  – Wire: electrical wire; wire stock for fences, coat hangers, and shopping carts
  – Rod stock for nails, screws, rivets, and springs
  – Bar stock: metal bars for machining, forging, and other processes
Bar Drawing

- Accomplished as a *single-draft* operation - the stock is pulled through one die opening
- Requires a batch type operation

http://www.youtube.com/watch?v=ejJ6Uqs5grU
http://www.youtube.com/watch?v=QKAq1yMZIpY
Wire Drawing

- Continuous drawing machines consisting of multiple draw dies (typically 4 to 12) separated by accumulating drums
  - Each drum (*capstan*) provides proper force to draw wire stock through upstream die
  - Each die provides a small reduction, so desired total reduction is achieved by the series of dies
  - Annealing sometimes required between dies to relieve work hardening
Continuous Wire Drawing

http://www.youtube.com/watch?v=YlLWBm2e5qq&playnext=1&list=PL6DE0478CFB849C93&feature=results_main

http://www.youtube.com/watch?v=5-3ka0E-sl8
Features of a Draw Die

- Entry region - funnels lubricant into the die to prevent scoring of work and die
- Approach - cone-shaped region where drawing occurs
- Bearing surface - determines final stock size
- Back relief - exit zone - provided with a back relief angle (half-angle) of about 30°
- Die materials: tool steels or cemented carbides
Sheet Drawing

Sheet metal forming to make cup-shaped, box-shaped, or other complex-curved, hollow-shaped parts

• Products: beverage cans, ammunition shells, automobile body panels

• Also known as *deep drawing* (to distinguish it from wire and bar drawing)
Deep Drawing of Cup

- Drawing of cup-shaped part: (1) before punch contacts work, (2) near end of stroke
- Starting blank and drawn part shown in lower views
Clearance in Drawing

- Sides of punch and die separated by a clearance $c$ given by:
  \[ c = 1.1 \, t \]
  where $t = \text{stock thickness}$
- In other words, clearance is about 10% greater than stock thickness
Stages of the deformation

Figure 14.17
**Drawing Ratio \( DR \)**

- Most easily defined for cylindrical shape (e.g., cup)

\[
DR = \frac{D_b}{D_p}
\]

where \( D_b \) = blank diameter; and \( D_p \) = punch diameter

- Indicates severity of a given drawing operation
  - Upper limit: \( DR \leq 2.0 \)
Reduction $r$

- Defined for cylindrical shape:

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

- Value of $r$ should be less than 0.50
Thickness-to-Diameter Ratio $t/D_b$

Thickness of starting blank divided by blank diameter

- Desirable for $t/D_b$ ratio to be greater than 1%
- As $t/D_b$ decreases, tendency for wrinkling increases
Blank Size Determination

- For final dimensions of drawn shape to be correct, starting blank diameter $D_b$ must be right
- Solve for $D_b$ by setting starting sheet metal blank volume = final product volume
- To facilitate calculation, assume negligible thinning of part wall
Redrawing of a cup

Figure 14.18
Common defects

(a) Wrinkling in the flange  
(b) Wrinkling in the wall  
(c) Tearing  
(d) Earing  
(e) Scratches
HW assignment

- Reading assignment: Chapters 14
