Sheet Metal Forming - 1
Outline

• Introduction
• Key Factors
• Sheet Bending
Introduction

- **Sheet metal**: metallic sheet typically < 6 mm thick
- **Large surface area/volume ratio**
- **Applications**: auto body parts, beverage cans, utensils
Introduction

- Sheet forming processes: sheet bending, stamping, deep drawing, shearing, etc.
- Constant volume processes
- Basic deformation modes: bending and stretching

Deep drawing

Metal bending machine
Stamping

http://video.google.com/videoplay?docid=-6082773547960703710&q=metal+stamping&total=70&start=0&num=10&so=0&type=search&plindex=4
Process Variations

• Forming with flexible (rubber) tooling

• Hydroforming

Source: DeGarmo, Black, Kohser, 9th Ed., 2003
Process Variations

- Explosive forming

Source: DeGarmo, Black, Kohser, 9th Ed., 2003
Key Factors

- **Elongation**: tensile loads in stretching can cause necking \( \rightarrow \) limits uniform elongation. Sheet metal specimens tend to undergo “localized necking”. High values of ‘\( n \)’ and ‘\( m \)’ desirable to enhance total elongation.

\[
\sigma = K \varepsilon^n \\
\sigma = C \dot{\varepsilon}^m
\]

\( n \uparrow \rightarrow \) uniform elongation\( \uparrow \)

\( m \uparrow \rightarrow \) post-uniform elongation\( \uparrow \)

Source: Kalpakjian & Schmidt, 4th Ed., 2003
Key Factors

- **Yield-Point Elongation**: Yield point elongation is a function of the strain-rate and the grain size; increases as strain-rate $\uparrow$ and grain size $\downarrow$

- **Characteristic of low carbon steels**

Source: Kalpakjian & Schmidt, 4th Ed., 2003
Key Factors

- **Anisotropy**: directional properties (of rolled sheet)

- **Causes**
  - crystallographic (from preferred grain orientation)
  - mechanical fibering (impurities, inclusions, etc. aligned in one direction)

- **Significance**: can lead to defects such as earing, wrinkling, or fracture

- **Severity of directionality measured by plastic strain ratio, \( R \), or normal anisotropy**

\[
R = \frac{\text{width strain}}{\text{thickness strain}} = \frac{\varepsilon_w}{\varepsilon_t} = \frac{\ln \left( \frac{w_0}{w_f} \right)}{\ln \left( \frac{t_0}{t_f} \right)} = \frac{\ln \left( \frac{w_0}{w_f} \right)}{\ln \left( \frac{w_f l_f}{w_0 l_0} \right)}
\]
Key Factors

- $R$ varies with direction of tensile stress application relative to sheet rolling direction

- Average normal anisotropy, $\bar{R}$

$$\bar{R} = \frac{R_{0^\circ} + 2R_{45^\circ} + R_{90^\circ}}{4}$$

- Planar anisotropy, $\Delta R$

$$\Delta R = \frac{R_{0^\circ} - 2R_{45^\circ} + R_{90^\circ}}{2}$$

$R_{\theta = 0, 45, 90}$ are the normal anisotropies in the sheet at the specified angles relative to the rolling direction of sheet.
Key Factors

- **Grain size**: impacts mechanical properties and appearance of surface of sheet
  - Finer grain size $\rightarrow$ stronger the sheet, smoother surface

- **Residual stresses**: due to non-uniform deformation
  - Tensile stresses $\rightarrow$ stress corrosion cracking, part distortion

*Source: Kalpakjian & Schmidt, 4th Ed., 2003*
Key Factors

- **Springback**: elastic recovery of sheet; common in bending operations

\[ R_f > R_f \text{ and } \alpha_f < \alpha_i \]
Key Factors

- **Wrinkling**: due to compressive stresses acting in the plane of the sheet (common in deep drawing)

Source: [www2.thefabricator.com](http://www2.thefabricator.com)
Sheet Metal Bending

- Process used to create parts with bends in them
- Bending also enhances rigidity of part
- Process carried out on a press brake machine
Sheet Metal Bending

Engineering strains (theoretical):

\[ e_o = e_i = \frac{1}{\left(\frac{2R}{T}\right) + 1} \]

\[ e_i = \text{strain in inner fiber}; \quad e_o = \text{strain in outer fiber} \]

\[ \therefore \text{as } \frac{R}{T} \downarrow \quad e_o \uparrow \quad \rightarrow \text{cracking on outer bend surface} \]

Source: Kalpakjian & Schmidt, 4th Ed., 2003
Sheet Metal Bending

- **Minimum bend radius**: expressed as an integer \((n)\) multiple of the sheet thickness \(T\) i.e. \(nT\)
- Determined experimentally
- Theoretically, 
  \[
  \text{Min. } \frac{R}{T} = \frac{50}{r} - 1
  \]
  \(r = \%\) reduction in area in a tension test

Expression for min. bend radius derived by equating true strain at fracture in tension, \(\varepsilon_f = \varepsilon_o\), true strain in outer fiber of bent sheet

Note that 
\[
\varepsilon_f = \ln \left( \frac{A_0}{A_f} \right) = \ln \left( \frac{100}{100 - r} \right)
\]

and 
\[
\varepsilon_0 = \ln (1 + e_0) = \ln \left( \frac{R + T}{R + 0.5T} \right)
\]
Factors Affecting Bendability

- Bendability can be enhanced by heating, applying compressive stresses in plane of sheet
- As $L \uparrow \rightarrow$ state of strain in outer fiber changes from uniaxial to biaxial $\rightarrow$ decreases ductility and the Min. R/T ratio $\uparrow$

Source: Kalpakjian & Schmidt, 4th Ed., 2003
Factors Affecting Bendability

• Direction of Anisotropy

Source: Kalpakjian & Schmidt, 4th Ed., 2003
Factors Affecting Bendability

- Springback: results in larger bend radius and smaller bend angle, \( \alpha \)

Springback factor, \( K_s \)

\[
K_s = \frac{\alpha_f}{\alpha_i} = \frac{\left(2R_i/T\right)+1}{\left(2R_f/T\right)+1}
\]

\[
\frac{R_i}{R_f} = 4\left(\frac{R_iY}{ET}\right)^3 - 3\left(\frac{R_iY}{ET}\right) + 1
\]

Where \( Y \) is the yield strength and \( E \) is the Young’s modulus

Source: Kalpakjian & Schmidt, 4th Ed., 2003
Factors Affecting Bendability

- Springback compensation methods
  - Overbending
  - Heating $\rightarrow$ lowers yield strength
  - Coining
  - Stretch bending

\[ R_f > R_f \text{ and } \alpha_f < \alpha_i \]
Bending Force Calculation

- Max. bending force, $P_{\text{max}}$ (neglecting friction)

$$P_{\text{max}} = \frac{kYLT^2}{W} \approx k \frac{(UTS)LT^2}{W}$$

$k = 1.2 \sim 1.3$ for V dies

$k = 0.3$ for wiping

$k = 2.4$ for U dies

Source: Kalpakjian & Schmidt, 4th Ed., 2003
Summary

• Sheet metal basics
• Key factors
• Sheet metal bending