Sheet Metal Forming - 1

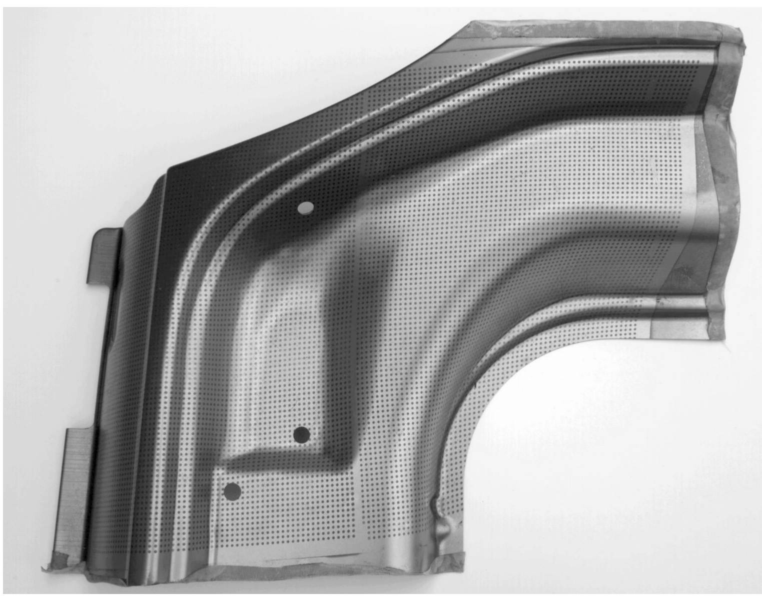
ME 230 Mechanical Processing of Materials
(lecture notes by Dr. Shreyes Melkote)

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

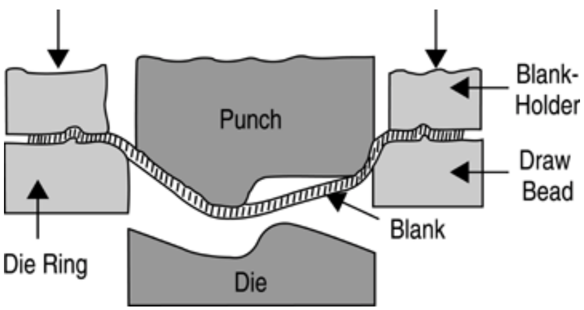


Stamped sheet metal part

Aluminum can

Introduction

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



Deep drawing

Air-Bending

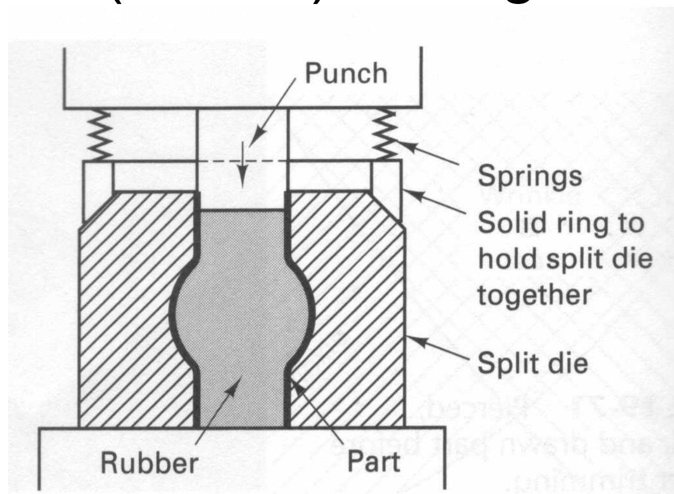
Bottoming

Metal bending machine

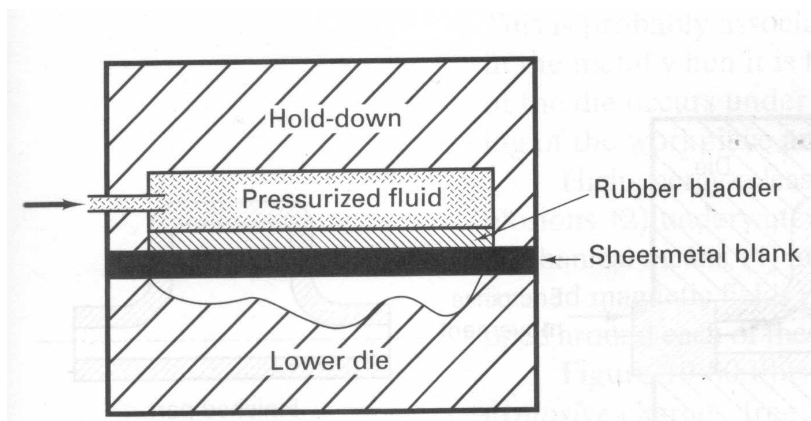
Stamping

Process Variations

- Forming with flexible (rubber) tooling



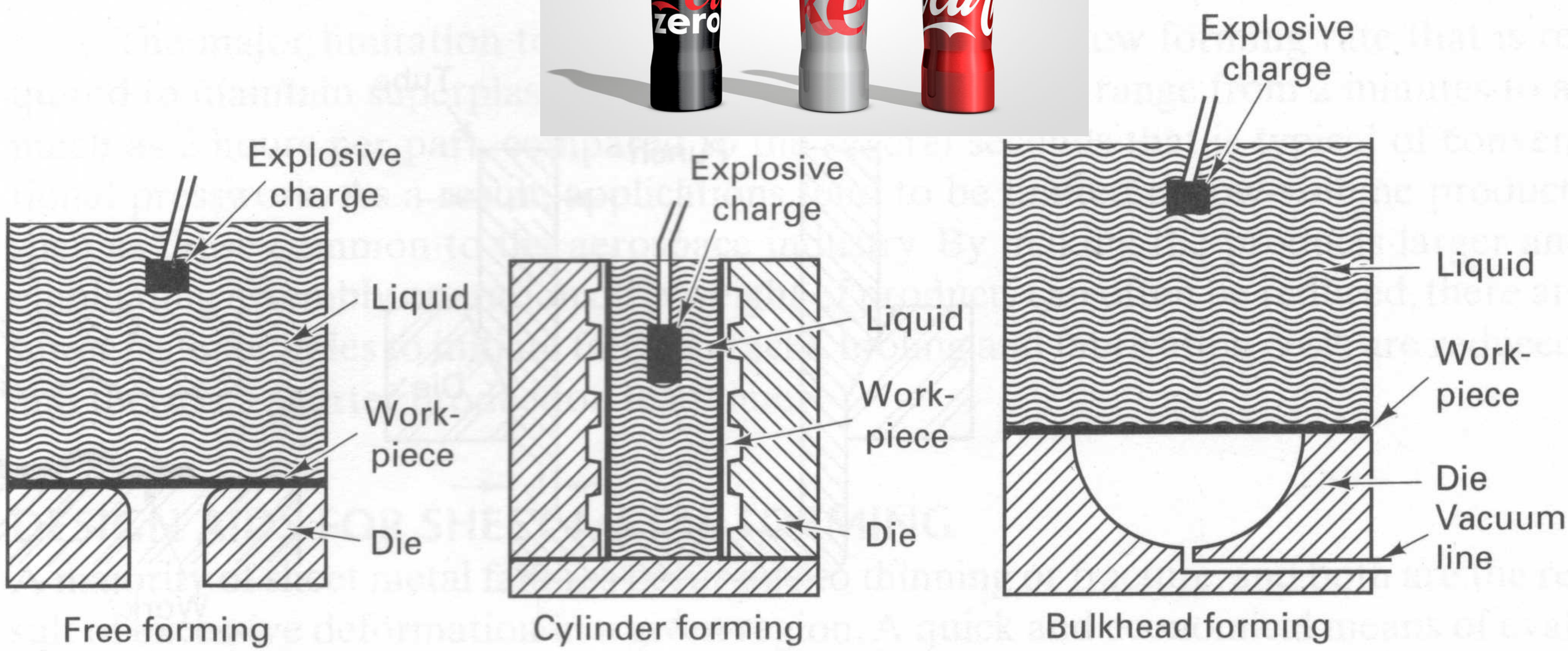
- Hydroforming



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

Process Variations

- Explosive forming



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

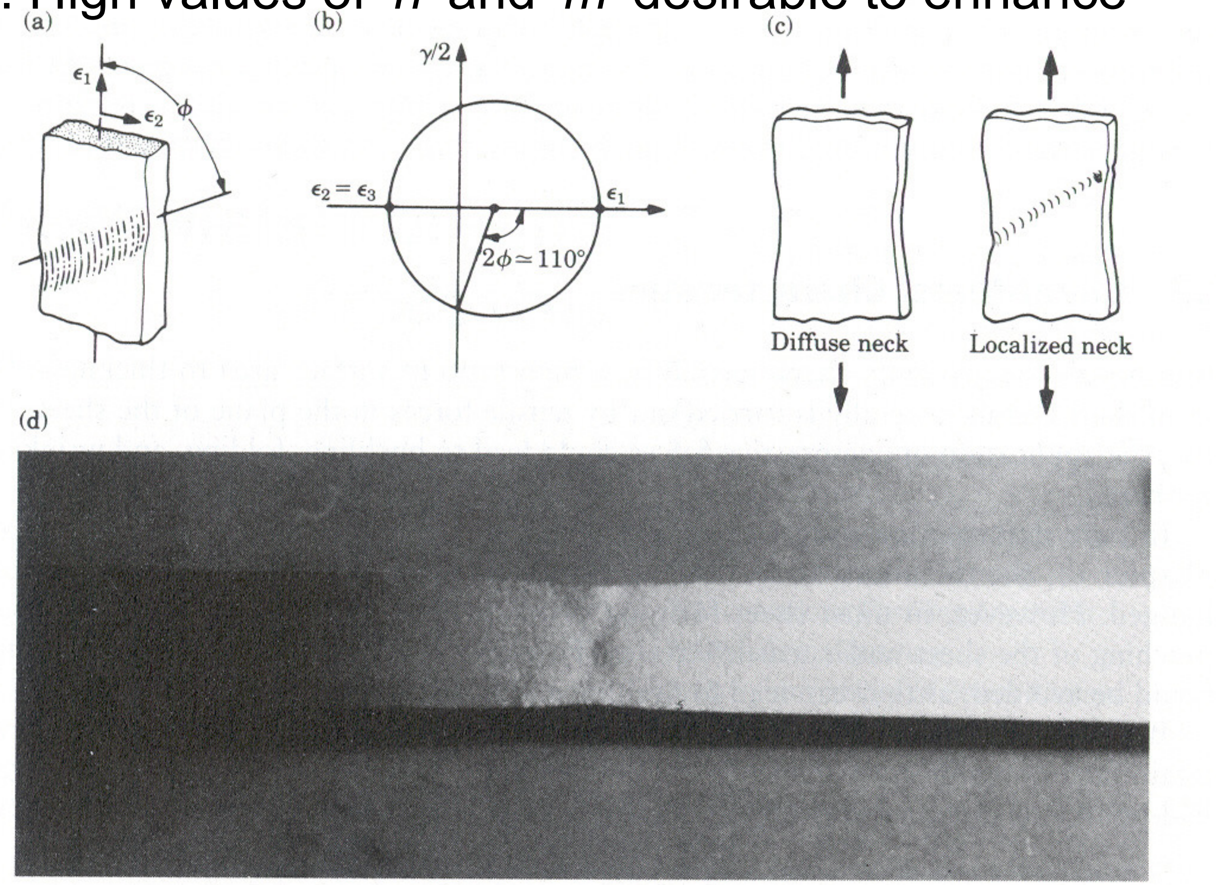
Key Factors

- Elongation: tensile loads in stretching can cause necking → 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↑ → uniform elongation↑
m↑ → post-uniform elongation↑

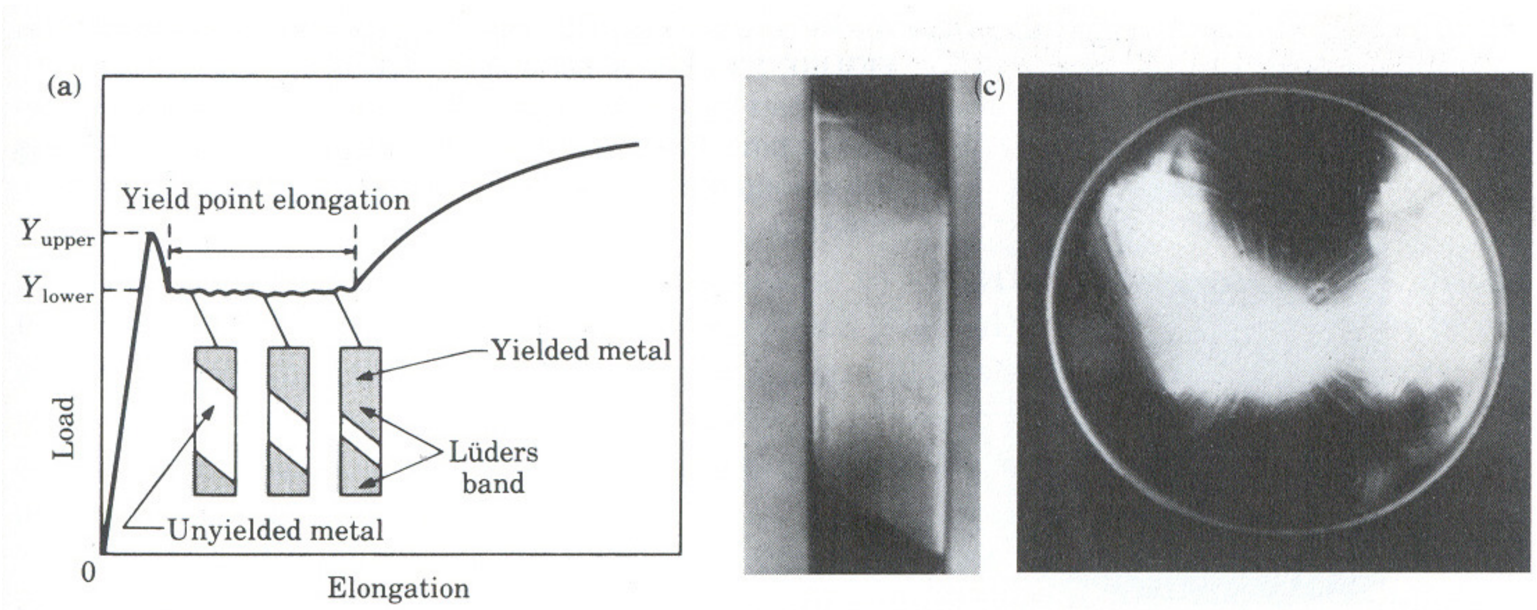


Source: Kalpakjian & Schmidt, 4th Ed., 2003

Key Factors

- Yield-Point Elongation: Yield point elongation is a function of the strain-rate and the grain size; increases as strain-rate↑ and grain size↓

- Characteristic of low carbon steels

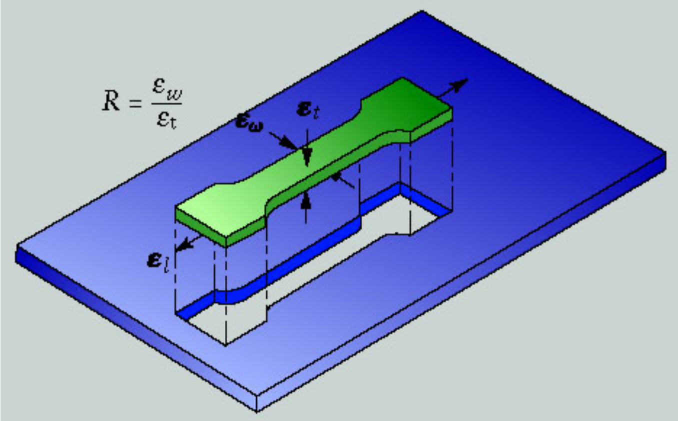


Source: Kalpakjian & Schmidt, 4th Ed., 2003

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

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

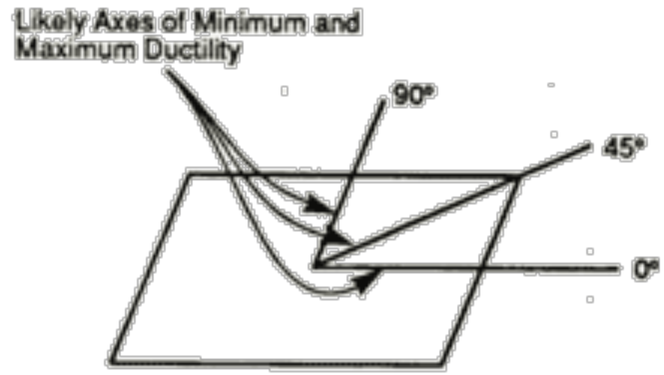


Key Factors

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

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

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



Directionality In Properties of a Rolled Sheet

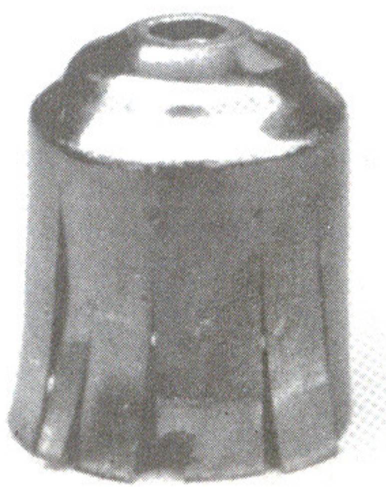
- Planar anisotropy, ΔR

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

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

Key Factors

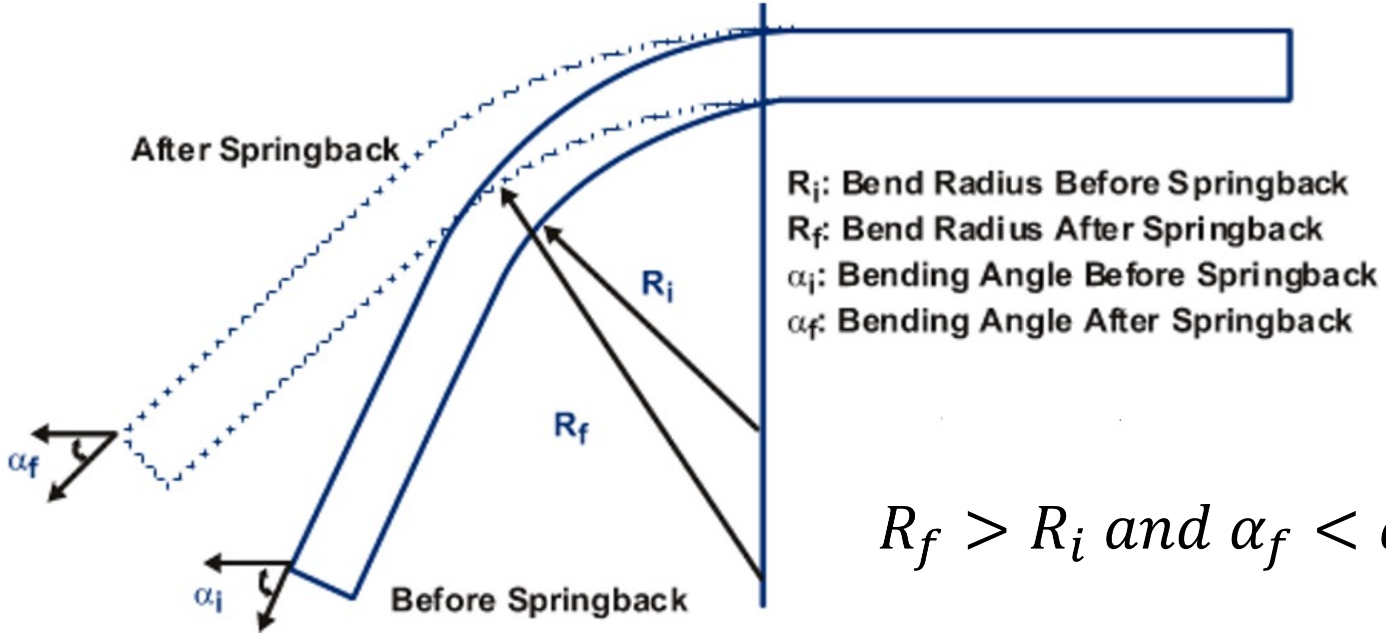
- Grain size: impacts mechanical properties and appearance of surface of sheet
  - Finer grain size → stronger the sheet, smoother surface
- Residual stresses: due to non-uniform deformation
  - Tensile stresses → stress corrosion cracking, part distortion



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

Key Factors

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



$$R_f > R_i \text{ and } \alpha_f < \alpha_i$$

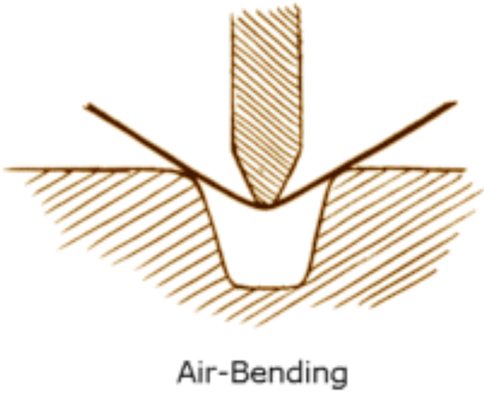
Key Factors

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

Source: www2.thefabricator.com

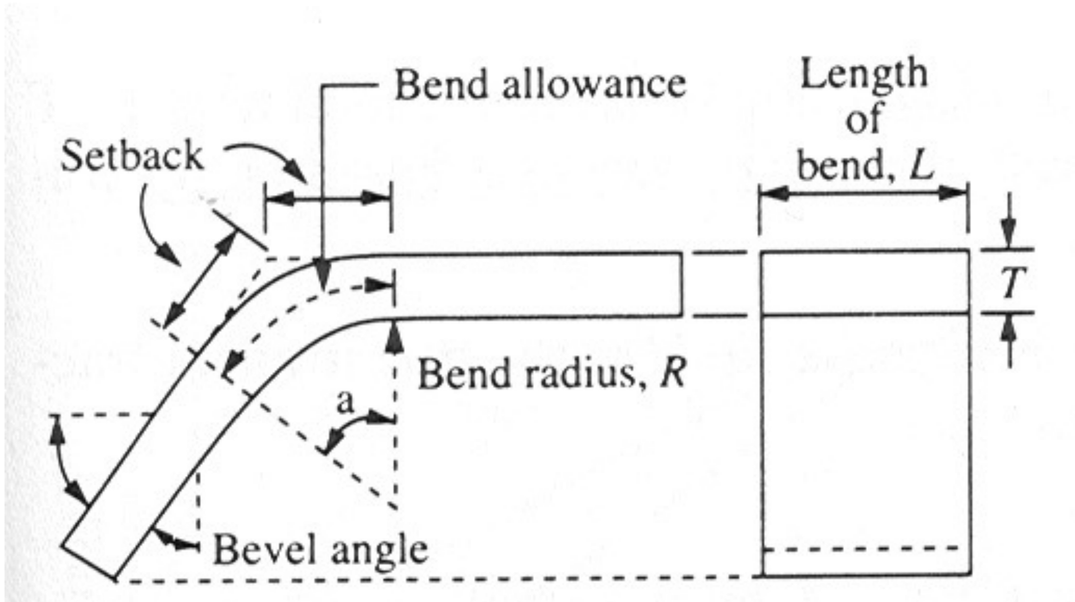
Sheet Metal Bending

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



Metal bending machine

Sheet Metal Bending



Engineering strains (theoretical):

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

e_i = strain in inner fiber; e_o= strain in outer fiber

$$\therefore \text{ as } \frac{R}{T}\downarrow \;\; e_o \uparrow \;\rightarrow \text{ cracking on outer bend surface}$$

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

Sheet Metal Bending

- <u>Minimum bend radius</u>: 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

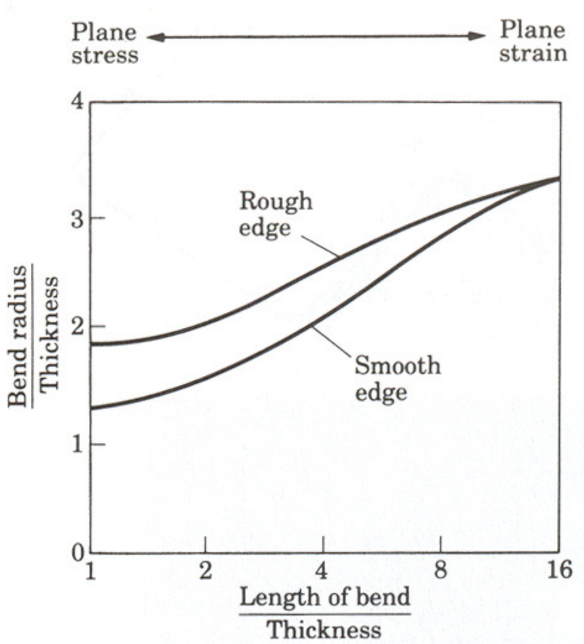
Expression for min. bend radius derived by equating true strain at fracture in tension, $\varepsilon_f = \varepsilon_o$, true strain in outer fiber of bent sheet

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

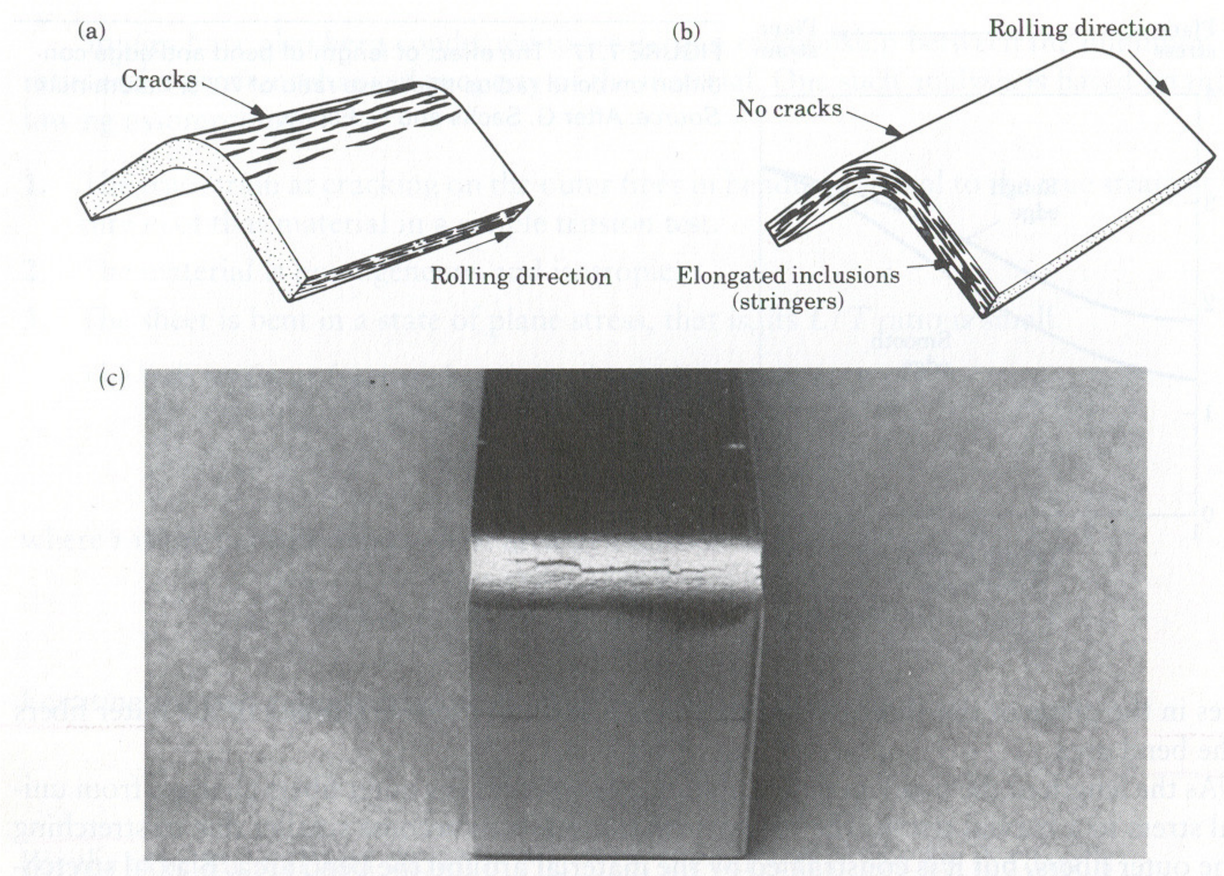
- Bendability can be enhanced by heating, applying compressive stresses in plane of sheet
- As L $\uparrow$ $\rightarrow$ state of strain in outer fiber changes from uniaxial to biaxial $\rightarrow$ decreases ductility and the Min. R/T ratio $\uparrow$



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

Factors Affecting Bendability

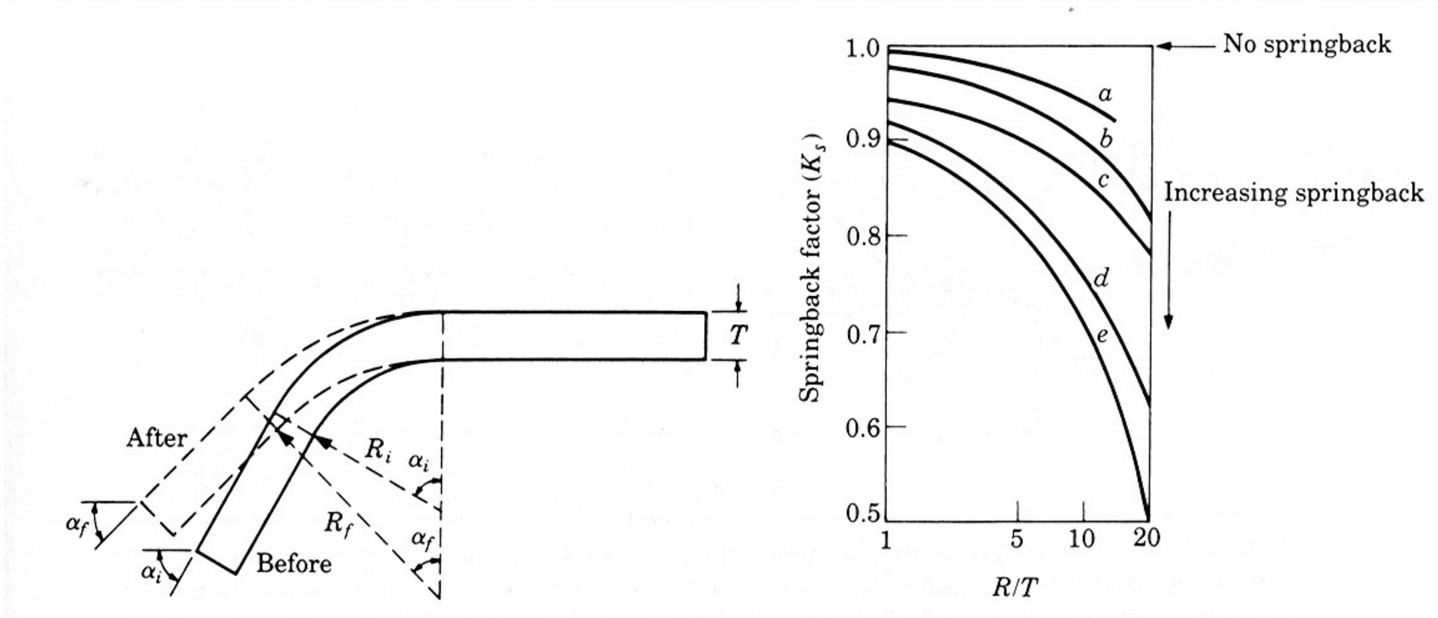
- Direction of Anisotropy



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

Factors Affecting Bendability

- Springback: results in larger bend radius and smaller bend angle, α



Springback factor, K_s

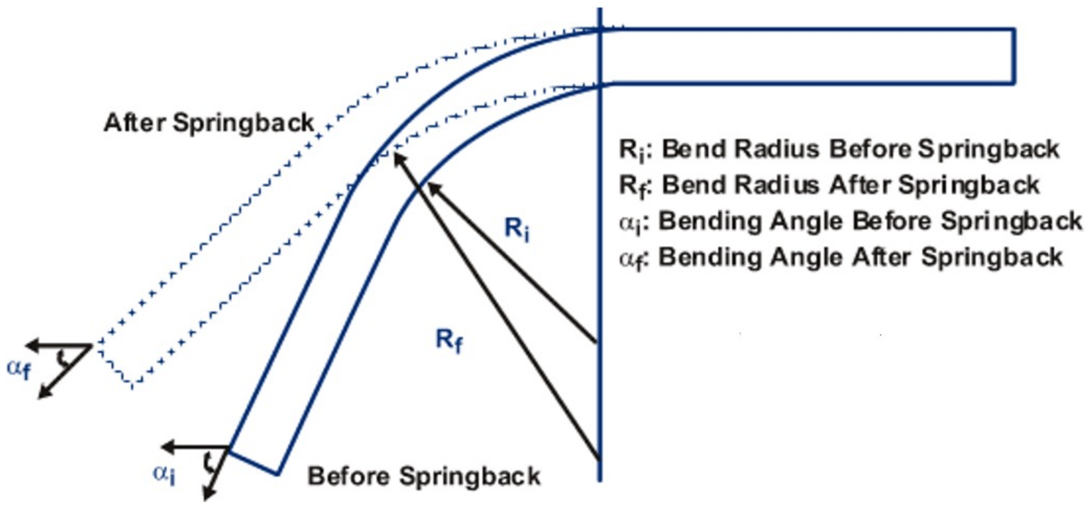
$$K_s = \frac{\alpha_f}{\alpha_i} = \frac{(2R_i/T)+1}{(2R_f/T)+1} \qquad \frac{R_i}{R_f} = 4\left(\frac{R_iY}{ET}\right)^3 - 3\left(\frac{R_iY}{ET}\right) + 1$$

Where *Y* is the yield strength and *E* is the Young's modulus

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

Factors Affecting Bendability

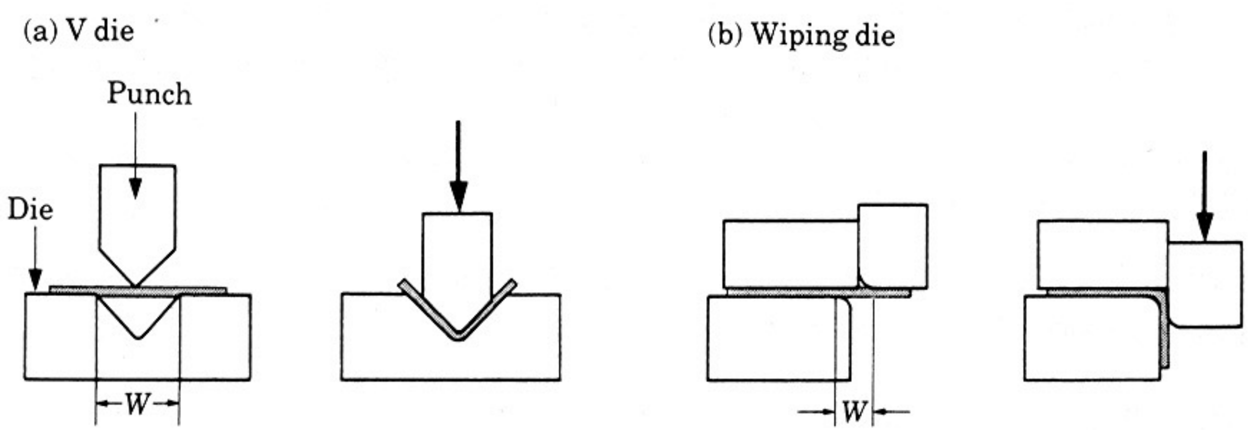
- Springback compensation methods
  - Overbending
  - Heating → lowers yield strength
  - Coining
  - Stretch bending



Coining

$$R_f > R_i \; and \; \alpha_f < \alpha_i$$

Bending Force Calculation



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

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

k =1.2~1.3 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