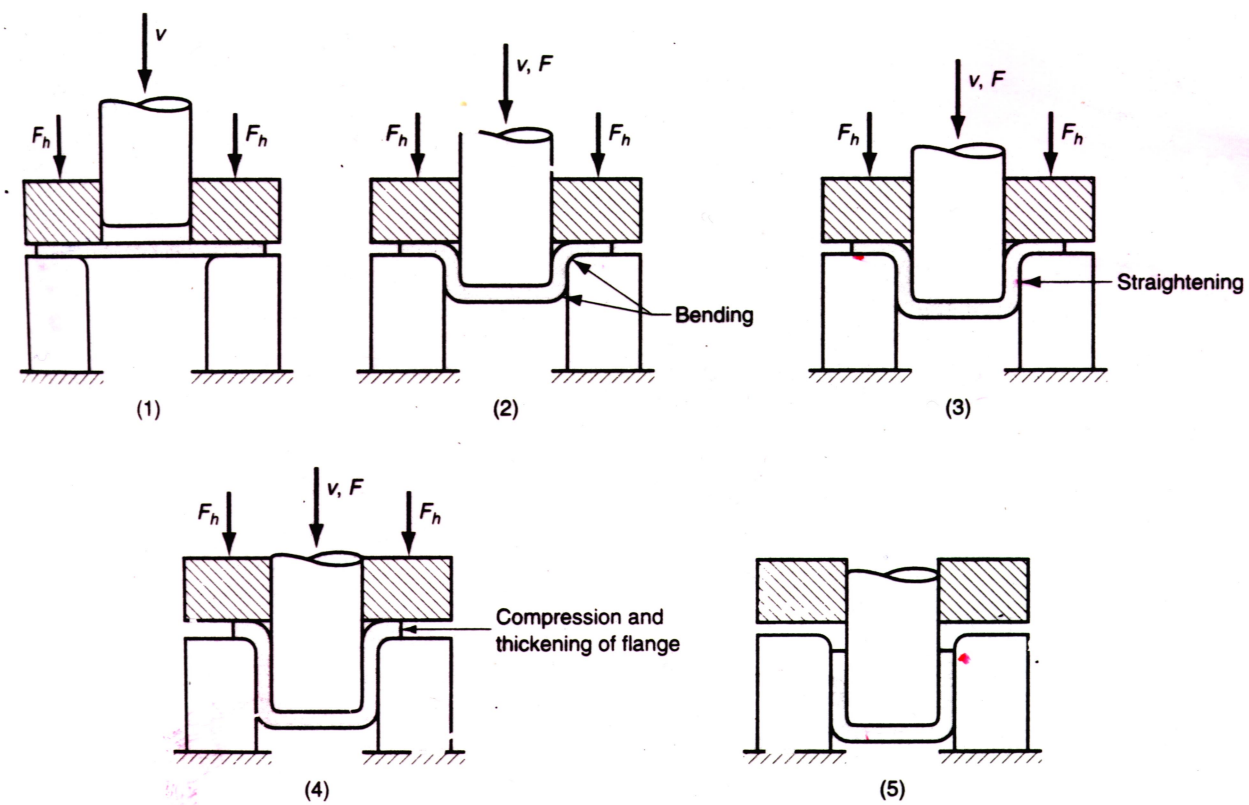
Sheet Metal Forming - 2

Outline

- Deep Drawing Basics
- Limiting Drawing Ratio (LDR)
- Forming Limit Diagram

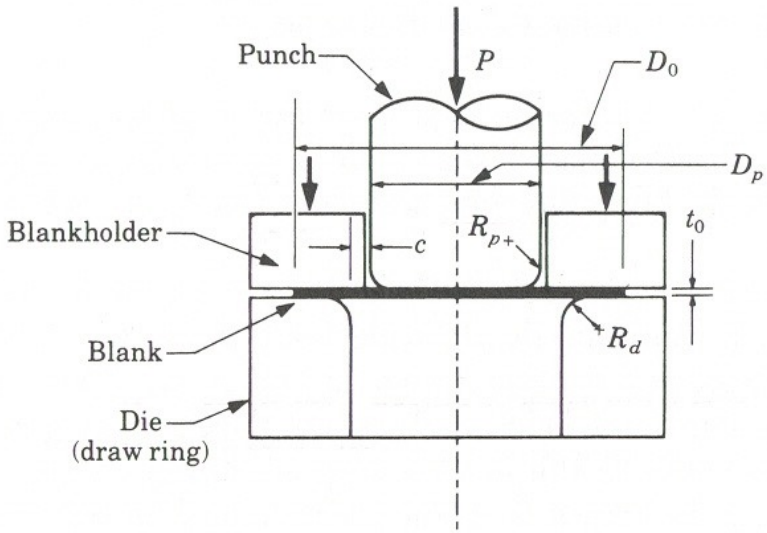
Deep Drawing Basics



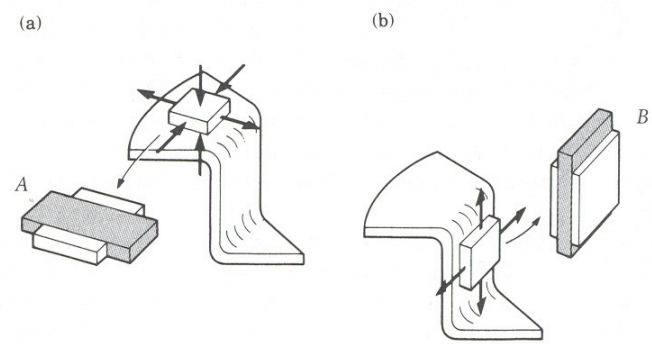
- Flat sheet-metal blank is formed into a cylindrical or box-shaped part by means of a punch that presses the blank into the die cavity
- Applications: beverage cans, utensils, sinks

Deep Drawing Basics

- Basic deformation modes: bending and stretching
- Key variables: punch diameter (D_p), blank diameter (D_0), blank thickness (t), punch force (P), punch radius (R_p), die radius (R_d), punch-die clearance (c), blankholder force



Deep drawing



Stress States

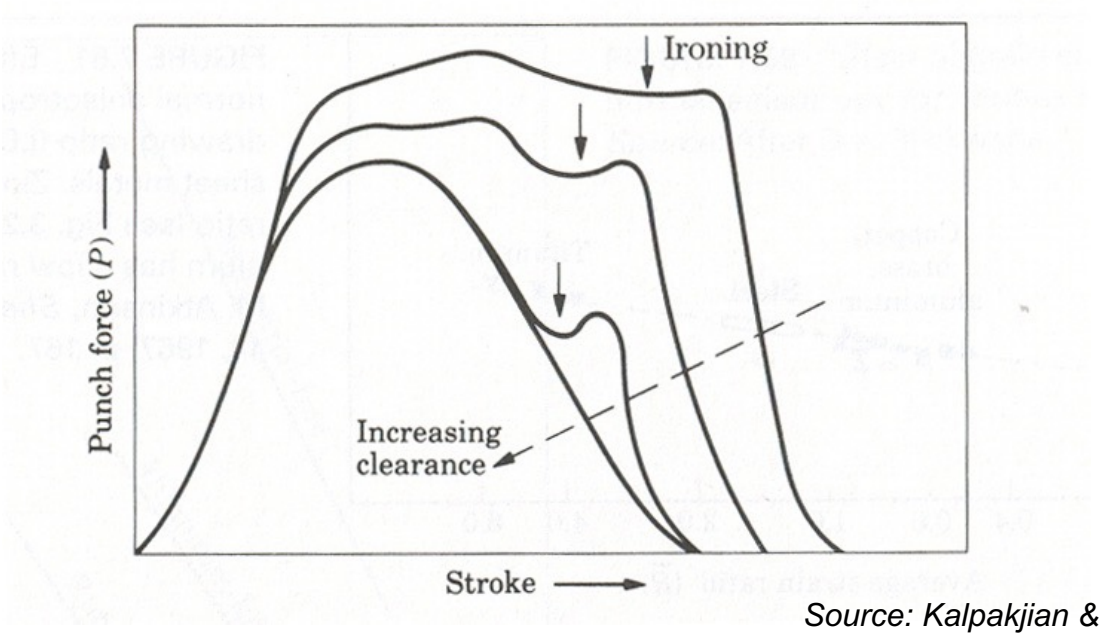
Source: Kalpakjian & Schmidt, 4th Ed., 2003

Deep Drawing

- Punch force can be estimated by:

$$P_{max} = \pi D_p t_o \left(UTS\right)\left(\frac{D_o}{D_p} - 0.7\right)$$

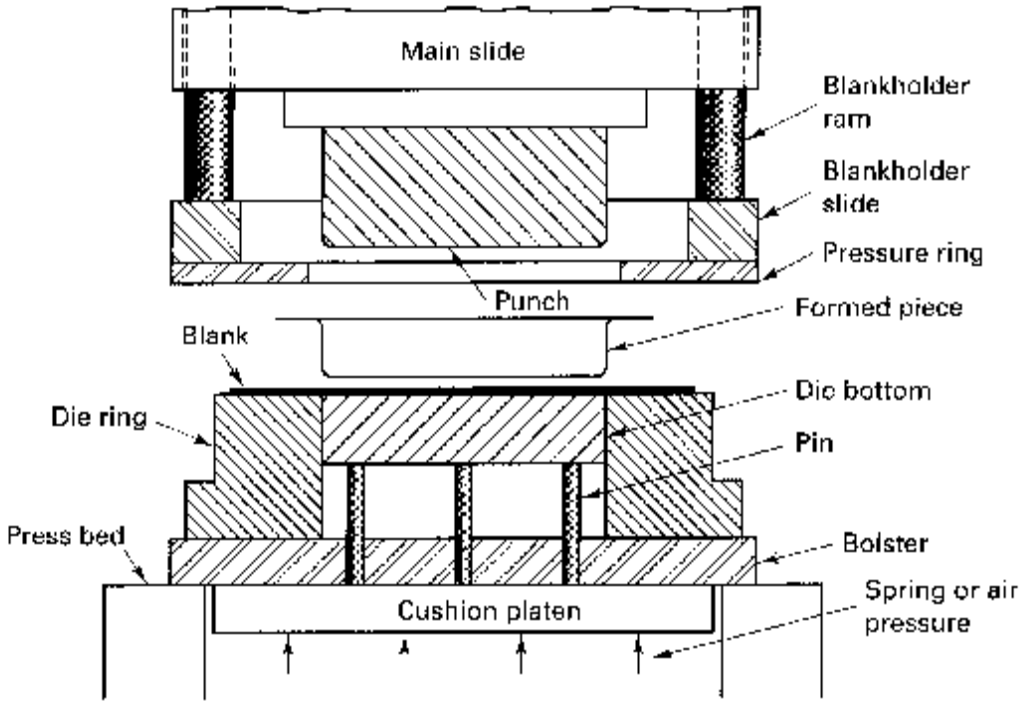
- Punch-die clearance affects "ironing"

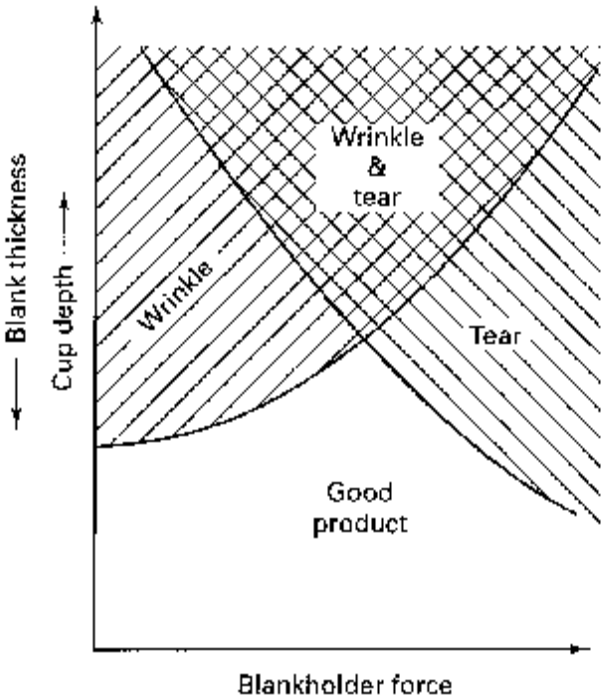


Source: Kalpakjian & Schmidt, 4th Ed., 2003

Deep Drawing

- Effect of blankholder force





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

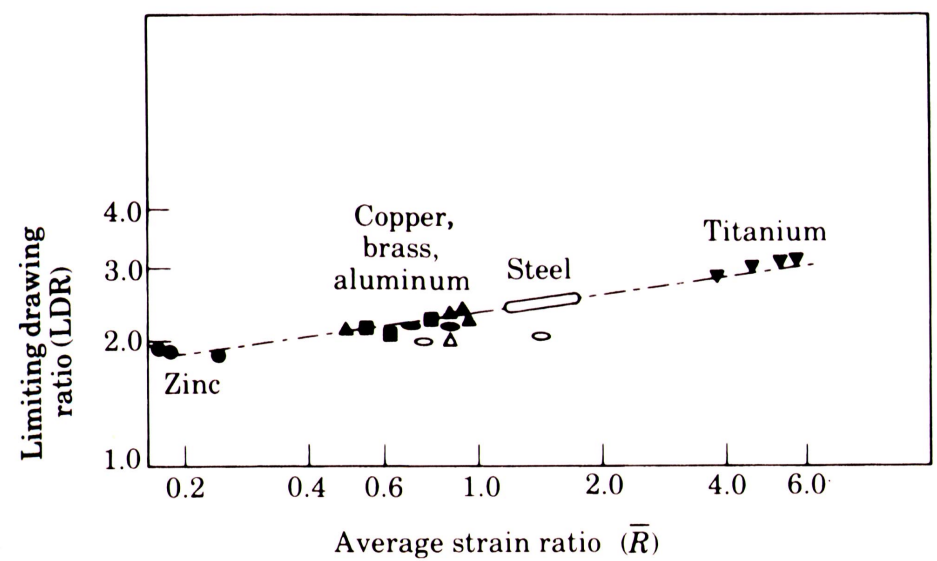
Limiting Drawing Ratio (LDR)

- **LDR** - the maximum ratio of blank diameter to punch diameter that can be drawn without failure ($=D_o/D_p$)

- LDR is affected by normal anisotropy, $\overline{R}$

$$R = \frac{\varepsilon_w}{\varepsilon_t} = \frac{\ln\left(\frac{w_o}{w_f}\right)}{\ln\left(\frac{t_o}{t_f}\right)} = \frac{\ln\left(\frac{w_o}{w_f}\right)}{\ln\left(\frac{w_f l_f}{w_o l_o}\right)}$$

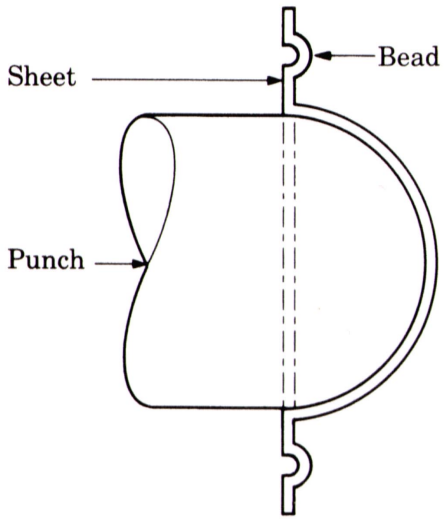
$$\overline{R} = \frac{R_o + 2R_{45} + R_{90}}{4}$$

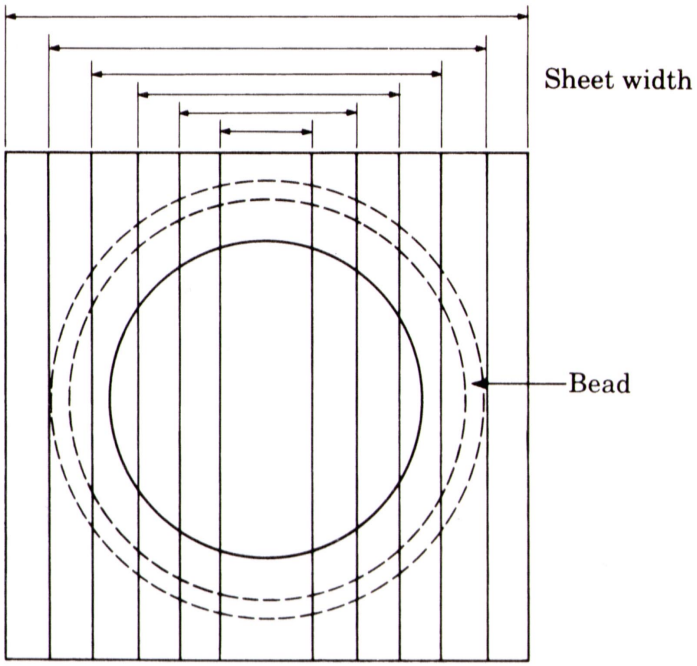


Source: Kalpakjian & Schmidt, 4th Ed., 2003

Forming Limit Diagram (FLD)

- Formability: ability of sheet metal to undergo the desired deformation without failures such as necking and tearing
- FLD used to estimate formability of sheet metal in deep drawing

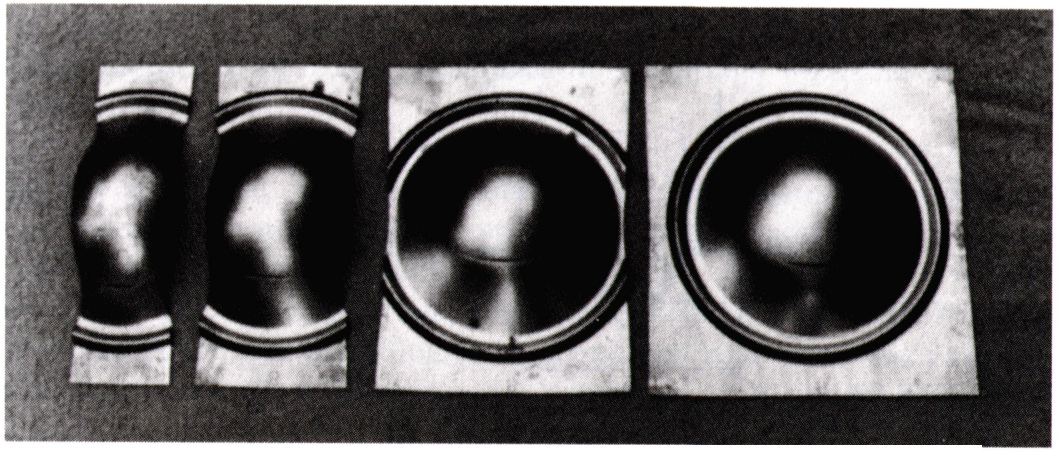




Source: Kalpakjian & Schmidt, 4th Ed., 2003

Forming Limit Diagram (FLD)

- Bulge tests performed for various sheet widths
- Each sheet has circular grid marks etched on it



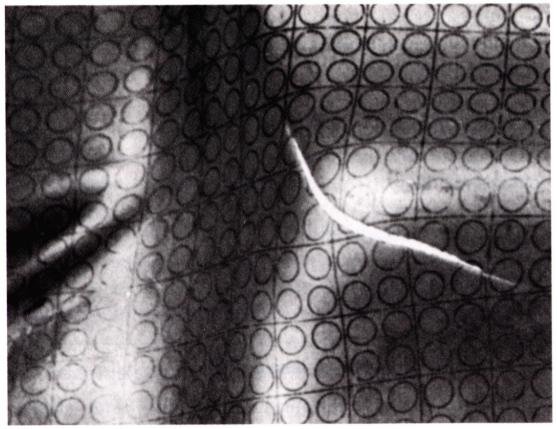
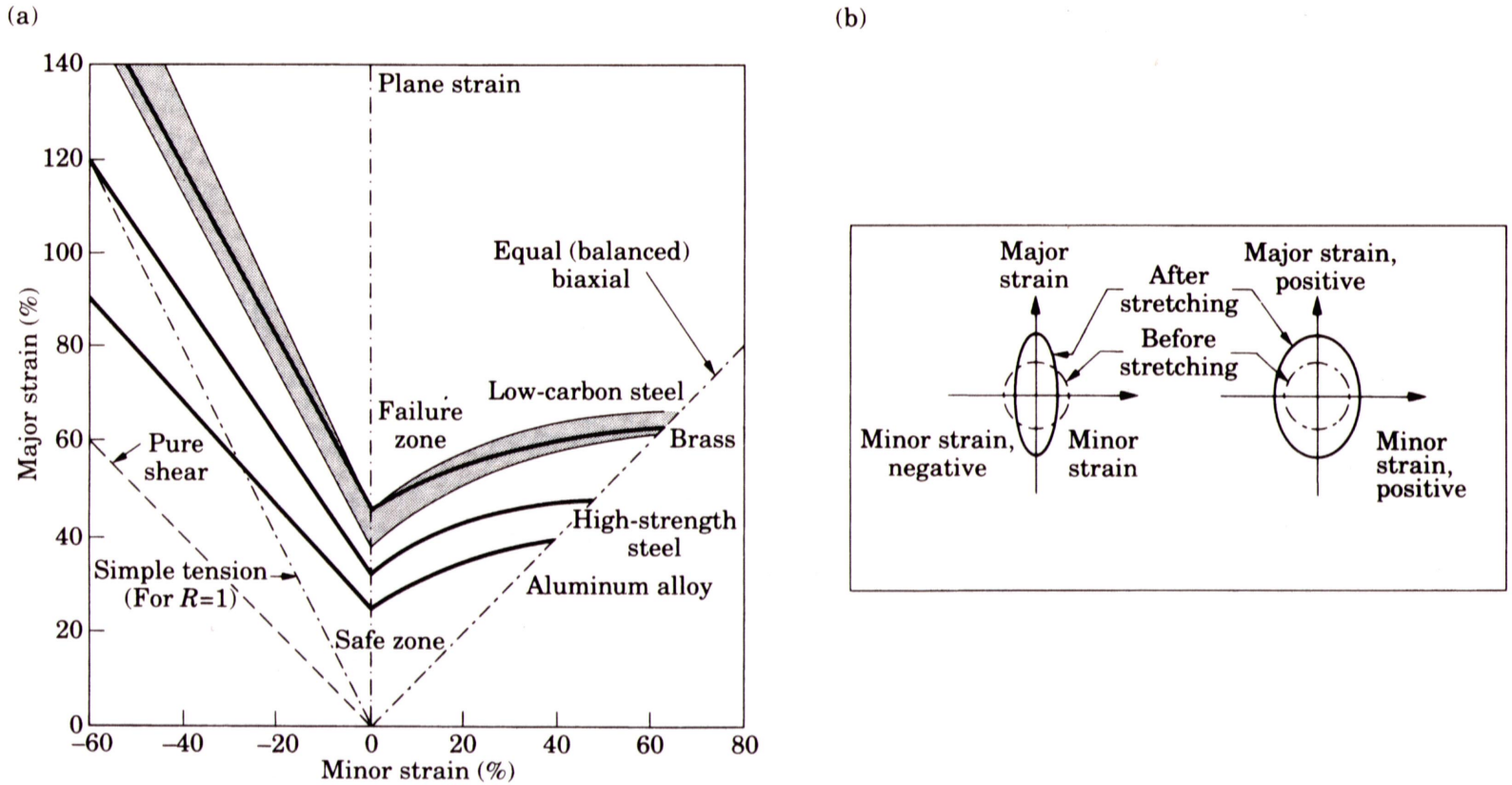


FIGURE 7.71 An example of using grid marks (circular and square) to determine the magnitude and direction of surface strains in sheet-metal forming. Note that the crack (tear) is generally perpendicular to the major (positive) strain. *Source:* After S.P. Keeler.

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

Forming Limit Diagram (FLD)

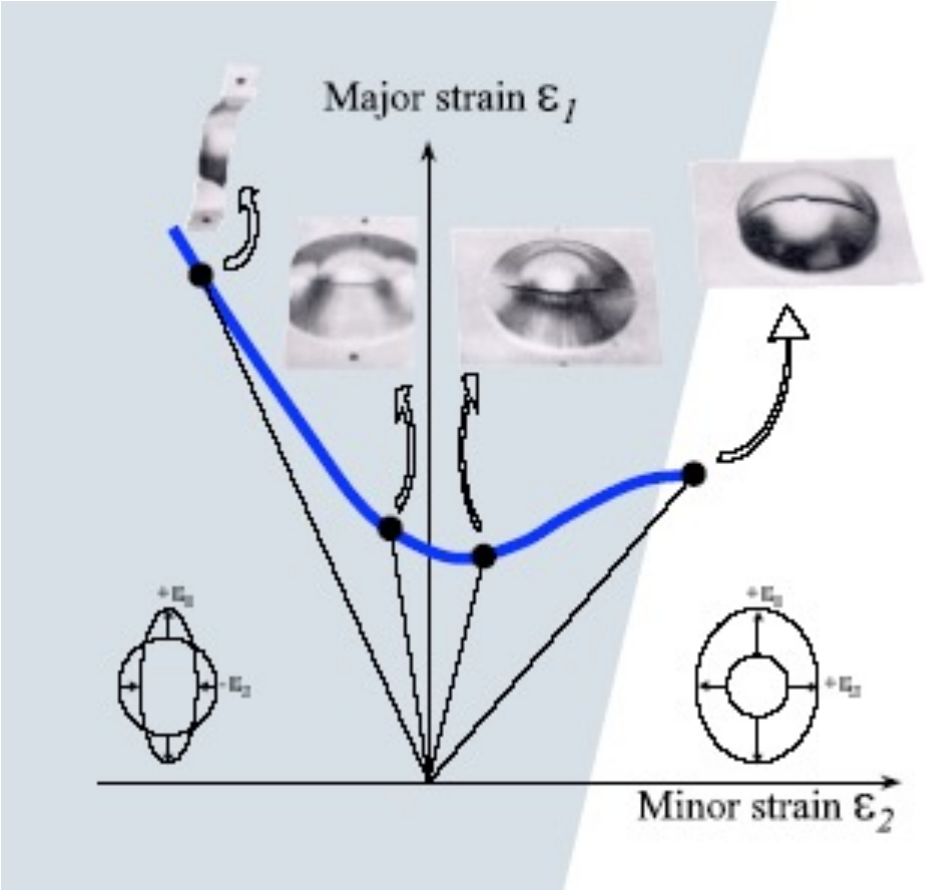
- Major and minor strains of deformed grid marks plotted



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

Forming Limit Diagram (FLD)

- Failure occurs above a forming limit line; material is safe below the line



Source: http://www.mate.tue.nl/mate/pdfs/959.pdf

Summary

- Deep Drawing Basics
- LDR
- FLD