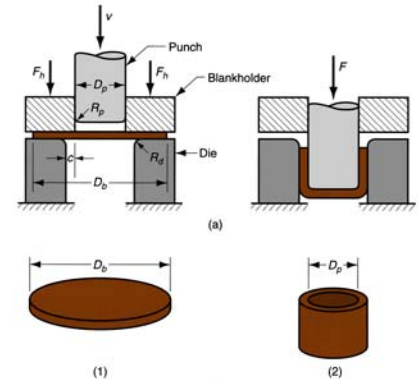
Outline

- Deep Drawing
- Deep drawing analysis
- Other Sheet metalworking operations
- Formability of Sheet Metal
  - *cupping test*
  - *bulge test*
  - *forming-limit diagram*
  - *tension tests*
    - ➢ *normal anisotropy*
    - ➢ *planar anisotropy*

Deep Drawing

- Sheet metal forming to make cup-shaped, box-shaped, or other complex-curved, hollow-shaped parts
- Sheet metal blank is positioned over die cavity and then punch pushes metal into opening

Steps:
- ✓ Initial contact
- ✓ Bending
- ✓ Straightening
- ✓ Friction and compression
- ✓ Final shape



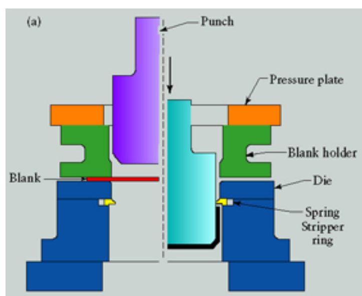
Products:

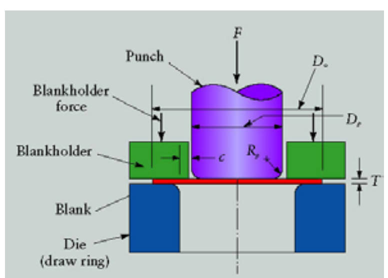
beverage cans, ammunition shells, automobile body panels

• *Deep drawing was patented in 1857.*

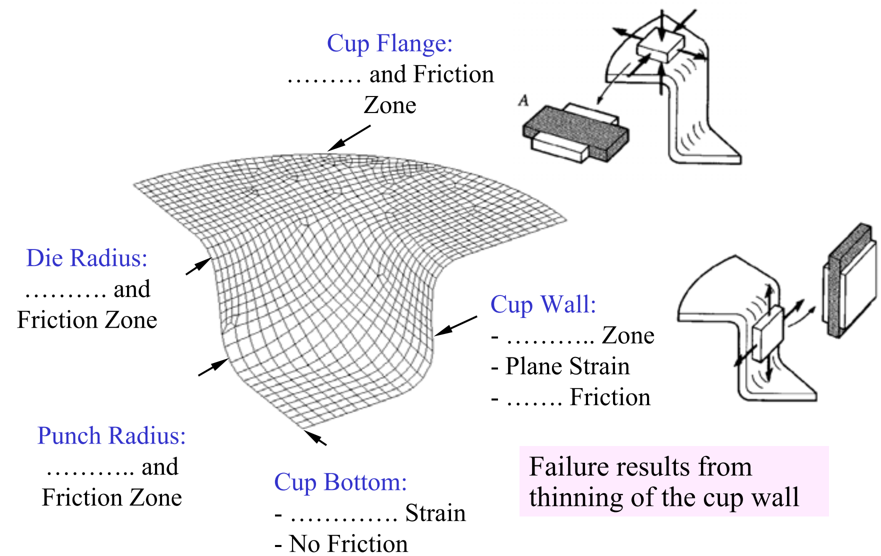
Deep Drawing

Significant Variables
- Properties of sheet metal
- Ratio of blank diameter to punch diameter
- Sheet thickness
- Clearance between the punch and the die
- Punch and die and corner radii
- Blankholder force
- Friction and lubrication at the tool/workpiece interface
- Speed of the punch





Deep Drawing: - *Variables and Defects*



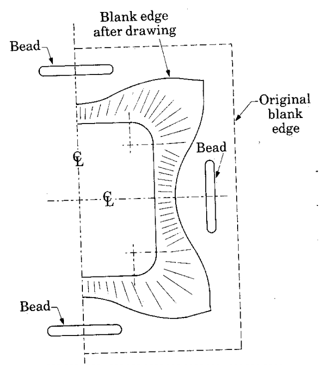
Failure results from thinning of the cup wall

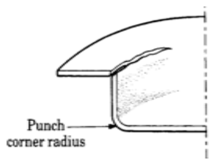
Deep Drawing: - *Variables and Defects*

During drawing, when the blank moves into the die, compressive circumferential stresses are induced in the flange

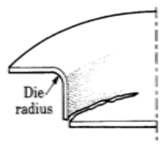
– This causes flange to **wrinkle**

– *Eg: try forcing a circular sheet of paper into a drinking glass*

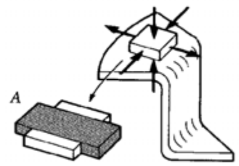




Die radius too small

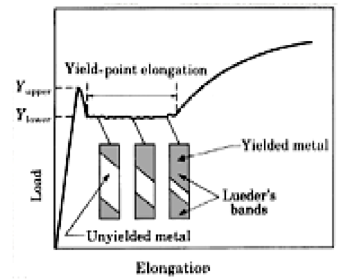


Punch radius too small

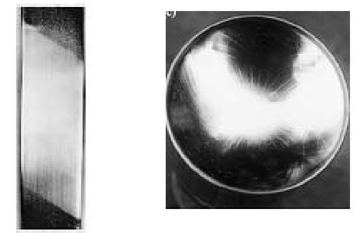


Deep Drawing: - *Variables and Defects*

- Low carbon steels exhibit this behavior
- This produces lueder's bands (stretch strain marks)
- These marks can be eliminated by reducing thickness of sheet from 0.5 % to 1.5 % by cold rolling process



Yield-point elongation in a sheet-metal specimen



Lueder's bands in a low-carbon steel sheet.

Grain size: mechanical properties and surface appearance are affected by the grain size. The coarser the grain the rougher the appearance. (Orange Peeling defect)

Analysis of Drawing

Most easily defined for cylindrical shape:

Measure of Drawing:

– **Drawing ratio:** $DR = \dfrac{D_b}{D_p}$ feasible if DR < 2

- Reduction $r = \dfrac{D_b - D_p}{D_b}$ feasible if r < 0.5

Crude measures of the severity of a deep drawing operation

Drawing Forces:

$$F = \pi D_p t (TS)\left(\frac{D_b}{D_p} - 0.7\right)$$

Max at 1/3 length

Holding Force:

$$F_h = 0.015 Y \pi \left[D_b^2 - \left(D_p + 2.2t + 2R_d\right)^2\right]$$

Analysis of Drawing

Clearance in Drawing:

$c = 1.1\ t$

where t = stock thickness

- In other words, clearance = about 10% greater than stock thickness

Thickness-to-Diameter Ratio:

Thickness-to-diameter ratio = t/D_b

Desirable for t/D_b ratio to be greater than 1%

- As ***t/D_b*** decreases, tendency for ………… 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

Shapes other than Cylindrical Cups

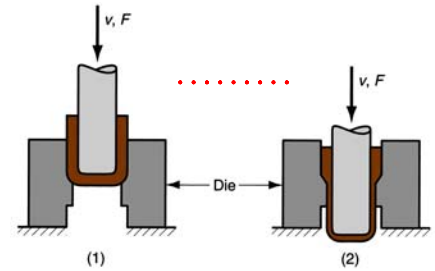
- Square or rectangular boxes (as in sinks),
- Stepped cups,
- Cones,
- Cups with spherical rather than flat bases,
- Irregular curved forms (as in automobile body panels)

• Very important commercial process.

Each of these shapes presents its own unique technical problems in drawing

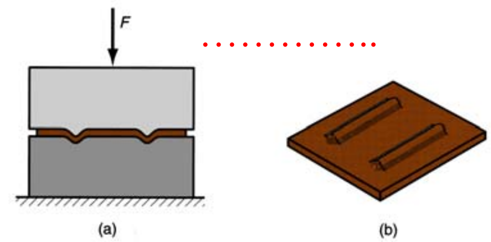
Other Sheet Metal Forming on Presses

Makes wall thickness of cylindrical cup more uniform



Examples:
beverage cans and artillery shells

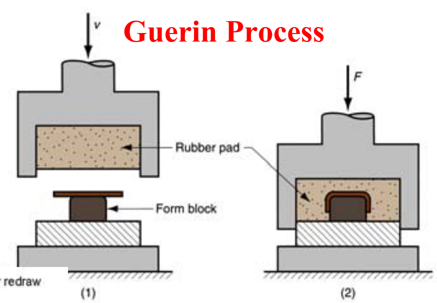
Used to create indentations in sheet, such as raised (or indented) lettering or strengthening ribs

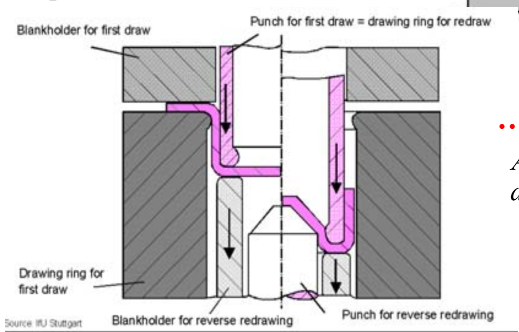


Other Sheet Metal Forming on Presses

Guerin Process

- Low tooling **cost**
- **Form block** can be made of wood, plastic, or other materials that are easy to shape
- Rubber pad can be used with different form blocks
- Process is attractive in ***small quantity production***



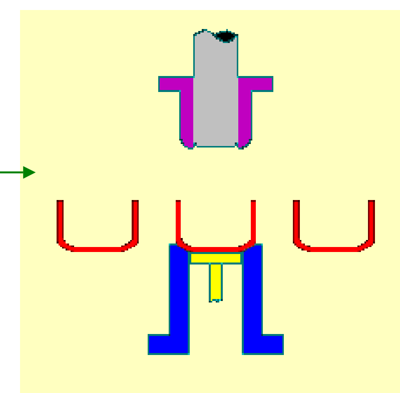


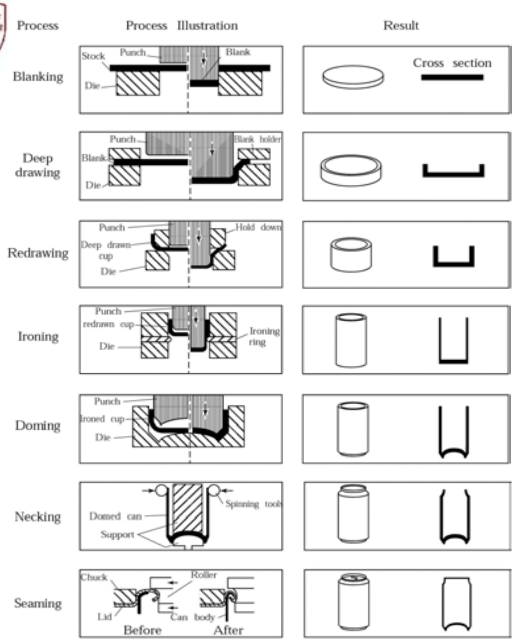
……………. Redrawing

A method to reduce the diameter of drawn cup

Methods for Reducing the Diameter of Drawn Cups

- Reverse Redrawing
- Conventional Redrawing

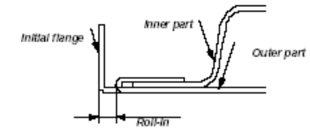




Steps in Manufacturing an Aluminum Can

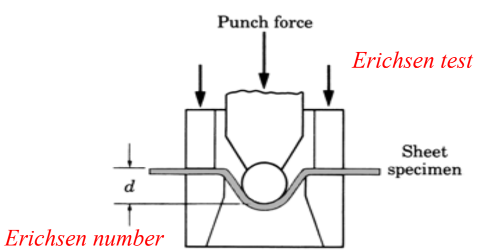
Hemming Process

- The edge of the sheet is folded over itself
- This increases stiffness of the part
- This method is now used in the automotive industry to join an outer part and an inner part.
- The metal strip is bent in stages



Defects during hemming: Springback, Fractures and Wrinkels in the flange

Formability of Sheet Metals

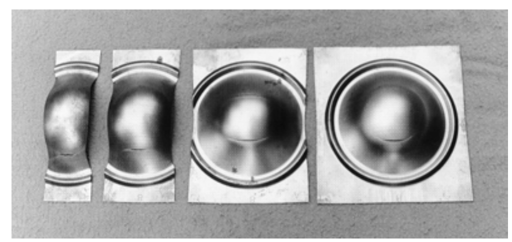


A cupping test (Erichsen and Olsen tests) to determine the formability of sheet metals

The greater the value of d the greater is the formability

- Earliest tests developed
- Simple to perform
- ……………. indicator of formability
- Do not simulate exact conditions of actual operations, WHY?

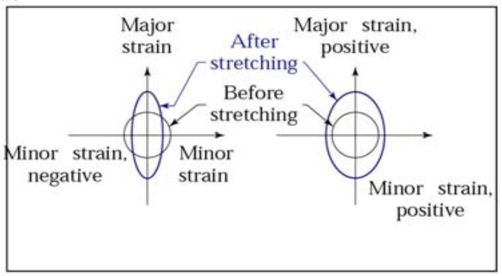
Bulge Test

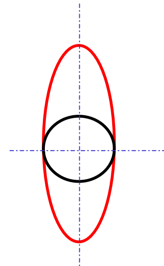


- Bulge-test results on steel sheets of various widths.
- The specimen farthest left is subjected to, basically, simple tension.
- The specimen farthest right is subjected to equal biaxial stretching

- It has been used extensively to simulate sheet forming operations
- **Hydraulic pressure** is used instead of punch ⇒ stretch forming without friction
- it is used to obtain effective-stress vs. effective-strain curves for biaxial loading under frictionless conditions

Major Strain and Minor Strain



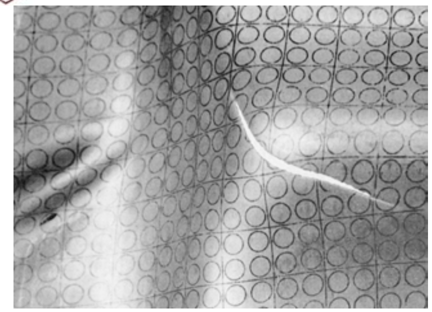


- During stretching in sheet metal, Volume constant
  $\varepsilon_l + \varepsilon_w + \varepsilon_t = 0$
- Major strain always larger than minor strain
  - Major strain ……………… than 0
  - Minor strain can be either positive, negative or zero

- Plane strain
  - Minor strain is 0

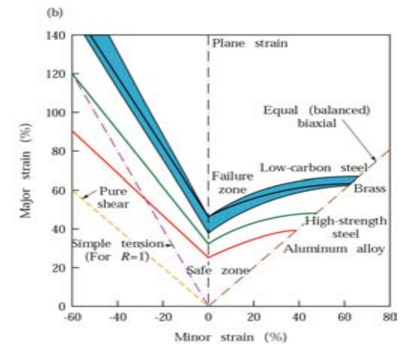
  $\varepsilon_l + \varepsilon_w + \varepsilon_t = 0$,
  thus $\varepsilon_l + \varepsilon_t = 0$

Forming Limit Diagrams



The deformation of the grid pattern and the tearing of sheet metal during forming. The major and minor axes of the circles are used to determine the coordinates on the forming-limit diagram.

Although the major strain is always positive (**stretching**), the minor strain may be either *positive or negative or zero*



Forming-limit Diagrams (FLD)

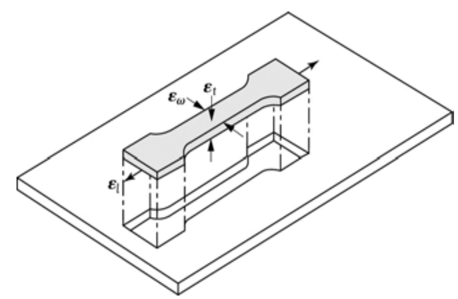
- More a research/development tool than a practical (quick) test
- Time consuming to perform
- Represents ………. forming operations reasonably well

Tension Tests

- The most basic and common test used to evaluate formability
- It determines important properties of the sheet metal such as:
  - *total elongation of the sheet specimen at fracture*
  - *strain hardening exponent*
  - *the planar anisotropy, and*
  - *the normal anisotropy*

Normal Anisotropy

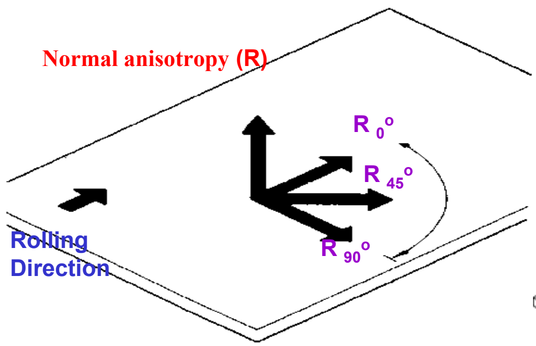
- Normal anisotropy: $R = \varepsilon_w / \varepsilon_t$
  - *Remember:* $\varepsilon_l + \varepsilon_w + \varepsilon_t = 0$
  - *Simple tension,* $R = 1.0$
- Determines thinning behavior of sheet metals during stretching; important in deep-drawing operations
- Tensile tests determine normal anisotropy

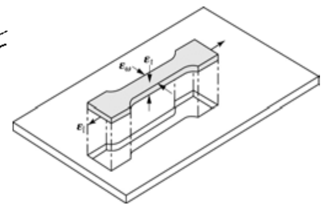


Strains on a tensile-test specimen removed from a piece of sheet metal. These strains are used in determining the ***normal*** *and* ***planar*** *anisotropy of the sheet metal.*

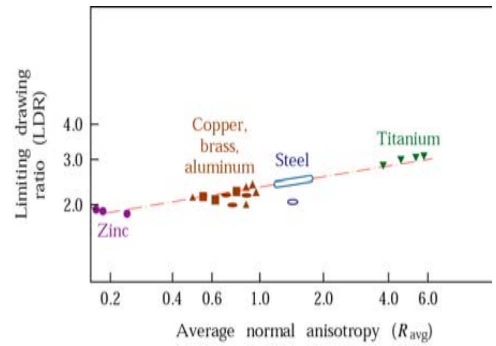
Average Normal Anisotropy

$$R_{avg} = (R_0 + 2R_{45} + R_{90})/4$$





Average Normal Anisotropy Vs Limiting Drawing Ratio



The relationship between average normal anisotropy and the limiting drawing ratio for various sheet metals

- Limiting Drawing Ratio (LDR) = D_0/D_p

Where,

D_0: Maximum Blank diameter

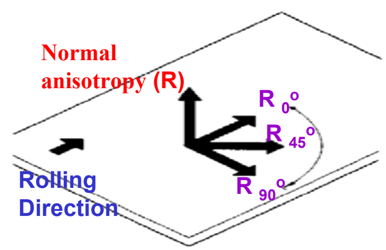
D_p: Punch Diameter

Average Normal Anisotropy, R_{avg}

Typical Range of Average Normal Anisotropy, R_{avg}, for Various Sheet Metals

	R_{avg}
Zinc alloys	0.4–0.6
Hot-rolled steel	0.8–1.0
Cold-rolled rimmed steel	1.0–1.4
Cold-rolled aluminum-killed steel	1.4–1.8
Aluminum alloys	0.6–0.8
Copper and brass	0.6–0.9
Titanium alloys (*a*)	3.0–5.0
Stainless steels	0.9–1.2
High-strength low-alloy steels	0.9–1.2

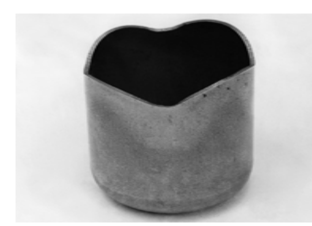
Planar Anisotropy (Earing Tendency)



Planar Anisotropy

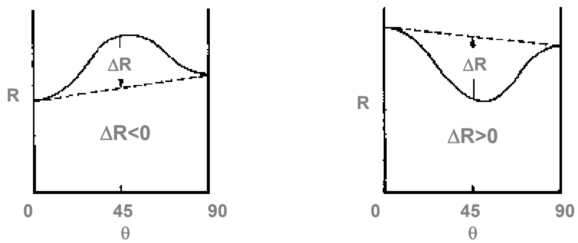
$$\Delta R = (R_0 - 2R_{45} + R_{90})/2$$

- Planar anisotropy causes ears to form in drawn cups
- When $\Delta R=0$, no ears form
- The height of the ears increases as ΔR increases
- Number of ears: 4, 6, or 8
- for better deep drawability: $R_{avg}\uparrow$ and $\Delta R\downarrow$
- ……………….. and …………………. affect these values.



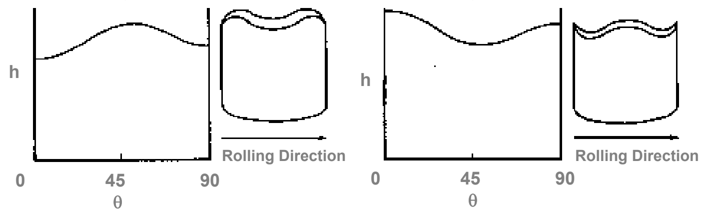
Earing and Planar Anisotropy

Effect of Planar Anisotropy on Earing



$$\Delta R = \frac{R_0 + R_{90} - 2R_{45}}{2}$$

$R = \varepsilon_w / \varepsilon_t$



Next time:

Continue Sheet Metal Forming