Lecture 3

Materials (3-1, 3-3, 3-4, 3-7, 3-12 through 3-18)

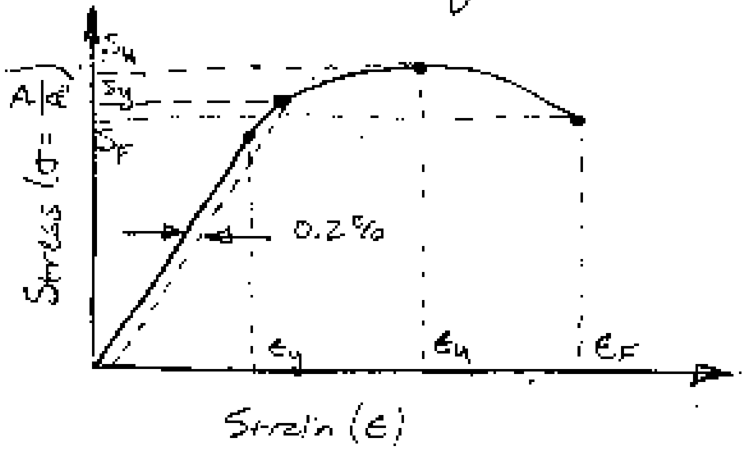
Unit strain for a test specimen,

$$\epsilon = \frac{\ell_1 - \ell_0}{\ell_0} \qquad (1)$$

where

$\epsilon \triangleq$ unit strain
$\ell_1 \triangleq$ strained length
$\ell_0 \triangleq$ initial length

Stress - strain diagrams,



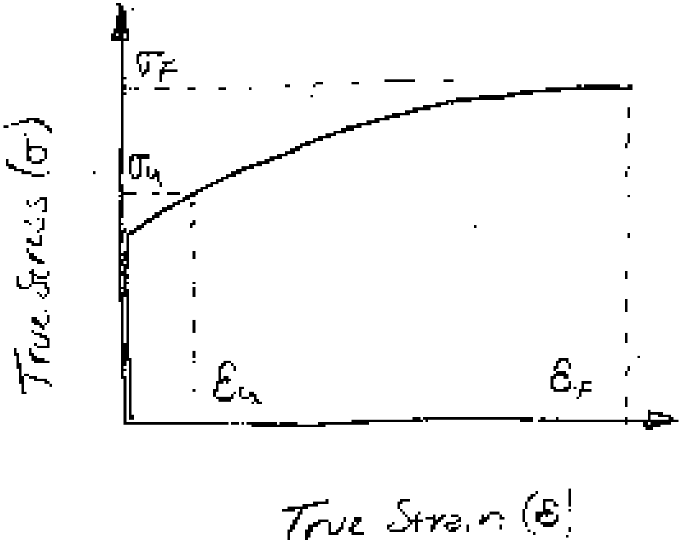
where

$A_0 \triangleq$ initial cross-sectional area
$\epsilon_u \triangleq$ ultimate strain
$\epsilon_y \triangleq$ yield strain
$\epsilon_F \triangleq$ failure strain
$S_u \triangleq$ ultimate strength
$S_y \triangleq$ yield strength
$S_F \triangleq$ failure strength

True strain (logarithmic strain),

$$\varepsilon = \int_{l_0}^{l_i} \frac{dl}{l} = \ln\frac{l_i}{l_0} \qquad (2)$$

Plotting true stress versus true strain we have,



*, When necking of the specimen occurs the true stress and engineering strain must be corrected to account for the area change at the cross-section of the specimen.

Plastic Deformation

Hooke's Law

$$\sigma = E\varepsilon \qquad * \begin{cases} \epsilon \triangleq \text{engineering strain} \\ \varepsilon \triangleq \text{true strain} \end{cases} \qquad (3$$

From Datsko true stress is computed for plastic deformation as,

$$\sigma = \sigma_0 \varepsilon^m \qquad (4)$$

where

$\sigma_0 \,\widehat{=}\,$ strength coefficient
$\varepsilon \,\widehat{=}\,$ true plastic strain
$m \,\widehat{=}\,$ strain-strengthening exponent

True stress (σ) and engineering stress (s) are calculated as,

$$\sigma = \frac{F}{A_i} \qquad (5)$$

$$S = \frac{F}{A_0} \qquad (6)$$

The relationship between logarithmic strain and unit strain is developed as follows,

$$\epsilon = \frac{l_1 - l_0}{l_0} \qquad (7)$$

$$\epsilon = \frac{l_i}{l_0} - 1 \qquad (8)$$

$$\frac{l_i}{l_0} = \epsilon + 1 \qquad (9)$$

From previous definitions we know,

$$\varepsilon = \ln \frac{l_i}{l_0} \qquad (10)$$

and therefore we can write,

$$\varepsilon = \ln (\epsilon + 1) \qquad (11)$$

Whenever specimens are deformed we can assume the volume is constant,

$$A_i l_i = A_0 l_0 \qquad (12)$$

or,

$$A_i = \frac{l_0}{l_i} A_0 \qquad (13)$$

From the definition for true stress (σ) we can write,

$$\sigma = \frac{F}{A_i} \qquad (14)$$

$$\sigma = \frac{F}{A_0 \frac{l_0}{l_i}} \qquad (15)$$

$$\sigma = S \frac{l_i}{l_0} \qquad (16)$$

$$\sigma = S(\epsilon + 1) \qquad (17)$$

And since

$$\ln(\epsilon+1) = \varepsilon \qquad (18)$$

or

$$\epsilon+1 = e^{\varepsilon} \qquad (19)$$

we can write,

$$\sigma = S e^{\varepsilon} \qquad (20)$$

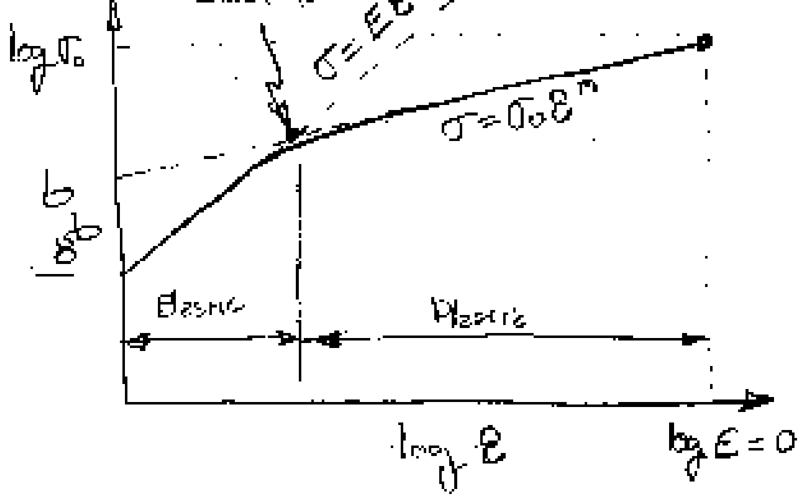
or

$$S = \sigma e^{-\varepsilon} \qquad (21)$$

In the plastic region engineering stress can be described as

$$S = \sigma_0 \varepsilon^n e^{-\varepsilon} \qquad (\text{Ramber}, \sigma = \sigma_0 \varepsilon^n)$$

True Stress - Strain Diagram



* Most materia
overyield, mov
intersection of
two lines, up,
end to the rig

Eqs. 7 and 11 are used to plot the elastic portion of the curve. Only load and extension measurements are needed from the test specimen. For the plastic region, the area of the specimen must be measured. The slope m can be determined by plotting the "plastic line."

An alternative method of determining m is as follows

$$P_i = \sigma A_i = \sigma_0 A_i \epsilon^m \qquad (23)$$

Combining eqs. 7 and 12 we have

$$\epsilon = \frac{A_0 - A_i}{A_i} \qquad (24)$$

Or

$$\frac{A_0}{A_i} = \epsilon + 1 \qquad (25)$$

From eq. 11 we can write

$$A_i = \frac{A_0}{e^{\epsilon}} \qquad (26)$$

Eq. 23 can be written as,

$$P_i = \frac{\sigma_0 A_0 (\varepsilon)^m}{e^{\varepsilon}} \qquad (27)$$

For most materials the maximum point on the load-deformation curve coincides with the point of zero slope therefor we can write

$$\frac{dP_i}{d\varepsilon} = 0 \qquad (28)$$

or

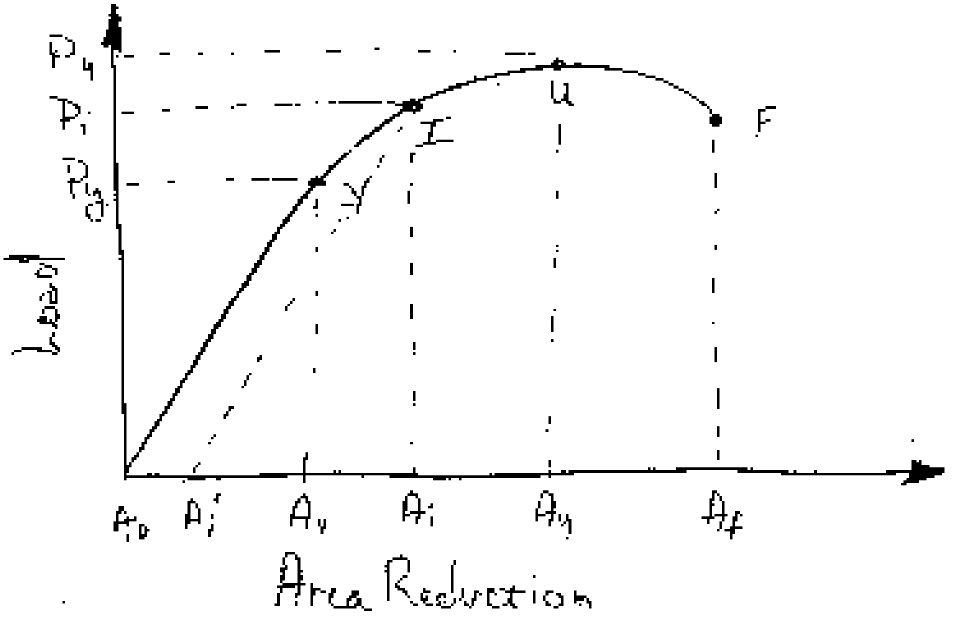
$$\sigma_0 A_0 (m\varepsilon^{m-1} e^{-\varepsilon} - \varepsilon^m e^{-\varepsilon}) = 0 \qquad (29)$$

Solving eq. 29 results in,

$$m = \varepsilon_{ult} \qquad (30)$$

Cold Working

Deliberate deformation of a material in the plastic region to change the material properties



For some material a property denoted by R is calculated to assess ductility, usually expressed as a percentage

$$R = \frac{A_0 - A_f}{A_0} = 1 - \frac{A_f}{A_0} \qquad (31)$$

This term can also be used to define a quantity of cold-working (w),

$$W = \frac{A_0 - A_i'}{A_0} \approx \frac{A_0 - A_i}{A_0} \qquad (32)$$

or,

$$A_i' = A_0(1-W) \qquad (33)$$

Cold-working produces a new set of material properties. The new yield and ultimate strengths are define as,

$$S_y' = \frac{P_i}{A_i} \tag{34}$$

$$S_u' = \frac{P_u}{A_i} \tag{35}$$

For $P_i < P_u$,

$$S_y' = \sigma_0 \varepsilon_i^m \tag{36}$$

and

$$S_u' = \frac{S_u A_0}{A_0(1-w)} = \frac{S_u}{1-w} \tag{37}$$

For points to the right of u,

$$S_u' \approx S_y' \approx \sigma_0 \varepsilon_i^m \tag{38}$$

Example

A 2024 aluminum T4 alloy is cold worked 16%. Estimate the new yield point and ultimate strengths

From Table E-22 we find the following properties:

$S_y = 296$ MPa
$S_u = 446$ MPa
$\sigma_0 = 689$ MPa
$m = 0.15$
$\varepsilon_f = 0.18$

From previous work we have,

$$\varepsilon_u = m = 0.18$$

and the area ratio for the material is,

$$\frac{A_0}{A_i} = \frac{1}{1-W} = \frac{1}{1-0.16} = 1.19$$

The true strain corresponding to 16% coldwork,

$$\varepsilon_i = \ln\frac{A_0}{A_i} = \ln(1.19) = 0.174$$

Since $\varepsilon_i < \varepsilon_u$,

$$S'_y = \sigma_0 \varepsilon_i^{\,m} = (689\ \text{MPa})(0.174)^{0.15} = 530\ \text{MPa}$$

$$S'_u = \frac{S_u}{1-W} = \frac{(446\ \text{MPa})}{(1-0.16)} = 531\ \text{MPa}$$

Hardness

The resistance of a material to penetration by a pointed tool is termed "hardness."

Rockwell Hardness (A, B & C)
Brinell Hardness (H_B)

*- Relationship between the minimum ultimate strength of steels and H_B,

$$S_u = \begin{cases} 0.45\,H_B & \text{kpsi} \\ 3.10\,H_B & \text{MPa} \end{cases}$$

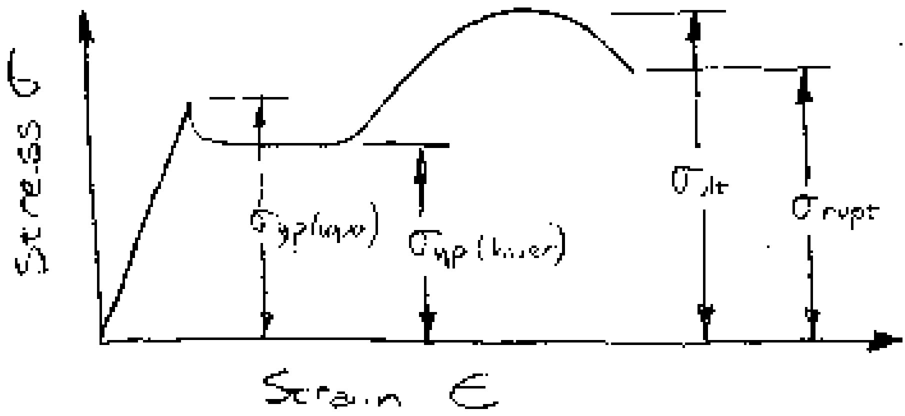
and for gray irons

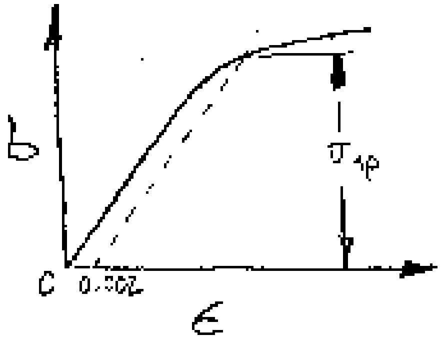
$$S_u = \begin{cases} 0.23\,H_B - 12.5 & \text{kpsi} \\ 1.58\,H_B - 86 & \text{MPa} \end{cases}$$

Material Testing

I. Tensile Tests

a.) Constant strain rate machines
b.) Constant load rate machines





for materials not having a well defined yeild point

II. Hardness Testing

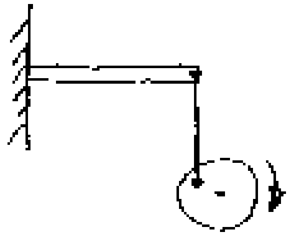
hardness – resistance to penetration

a.) Brinell (oldest and most common)
b.) Vickers (improvement on Brinell test)
c.) Knoop
d.) Rockwell A, C, D, B, F, G & E

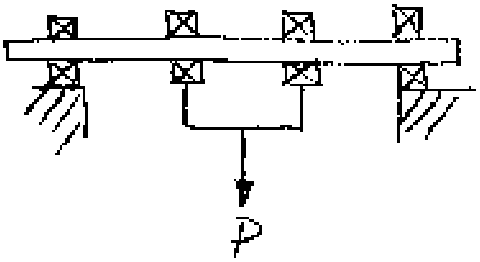
(see handout)

* For steel the ultimate strength (psi) is approximately 450 times the BHN.

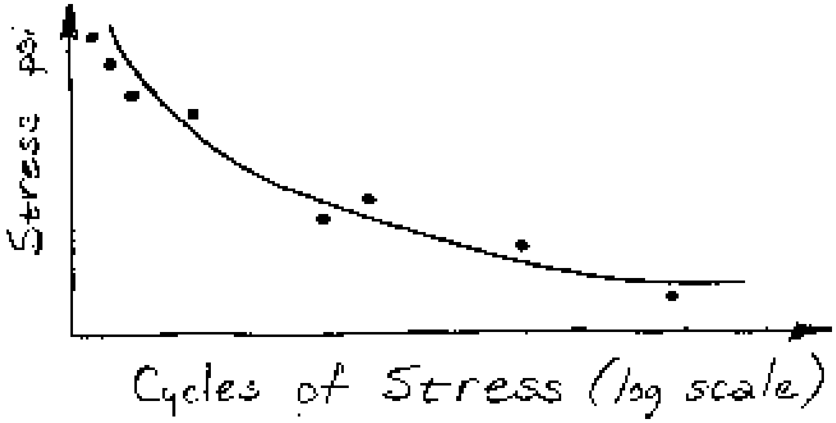
III Endurance Testing



Cantilever Beam



Rotating Beam



IV. Machinability - determination of the realive ease with which a given material may be cut with a sharp edge tool compared with B1112 (Bessemer Screw S

V. Wear

cutting wear - results when a hard rough surface is rubbed over a softer one without lubrication

abrasive wear - occurs as a result of grit being carried between rubbing surfaces

adhesion (galling) - frictional failure that manifests itself as a welding of one surface to another corrosive wear - a chemical attach that affects the wear rate

VI. Corrosion

Steel

Non-Heat Treated:
- a.) low carbon steel (hot rolled, cold drawn)
- b.) free cutting steels
- c.) low carbon sheet steel (forming, drawing etc.)
- d.) high-strength low-alloy steels, HSLA

Heat Treated:
- a.) carburized (low carbon, low alloy)
- b.) quenched and tempered (higher carbon and alloy rane

Numbering System (SAE, AISI)

carbon steels	1XXX
nickel steels	2XXX
nickel-chromium steels	3XXX
molybdenum steels	4XXX
chromium steels	5XXX
chromium-vanadium steels	6XXX
chromium-nickel-molybdenum steels	8XXX
silicon-manganese steels	9XXX

carbon steels - large changes in strength and and hardness with carbon content

alloy steels - alloys change the effects of quenching

Heat Treatment (increase strength and hardness)
- quenching (quick cooling in hot oil or molten salt)
- tempering (similar to quenching only more controlled)
- normalizing (air cooling, fairly rapid
- annealing (slow cooling results in high ductility)

* <u>Be</u> aware that residual stress often result.

Flame hardening - localized surface heating followed by rapid cooling

Strain hardening - plastic deformation using dies rollers etc. (raises σ_{yp} & σ_{ult} of ductile materials)

Stainless Steels

Steels with high chromium contents, usually betweem 11½ to 30%, and nickel contents of up to 20%. Used primarily for corrosion resistance.

Three Classes

a) Austenitic 18% Cr, 8% Ni (hardenable by cold working, nonmagnetic when fully annealed)

b) Martensitic 12% Cr (hardenable by heat treatment)

c.) Ferritic 17% Cr (nonhardenable, magnetic)

<u>Cast Irons</u>

Composition

carbon	2 - 4%
silicon	0.5 - 3%
manganese	0.2 - 1%
phosphorus	0.05 - 0.8%
sulfur	0.04 - 0.15%
iron	remainder

* gray irons primarily used as cast construction material
* good in compression, poor in tension
* difficult to weld
* excellent vibration-damping characteristics
* malleable and nodular (ductile) forms available

Aluminum Alloys

Numbering System

aluminum (99% or >)	1XXX
copper alloys	2XXX
manganese	3XXX
silicon	4XXX
mangnesium	5XXX
mangnesium and silicon	6XXX
zinc	7XXX
other	8XXX

* alloys can be heat treated and/or cold worked

Temper Designations

-F	as-cast condition
-O	annealed temper
-H	cold worked
-T	solution heat treated

Other Materials

Magnesium alloys
Copper alloys (brass, bronze, etc.)
Alloys for die casting (zinc, aluminum, magnesium)
Plastics
Composite Materials