Definition and measurement

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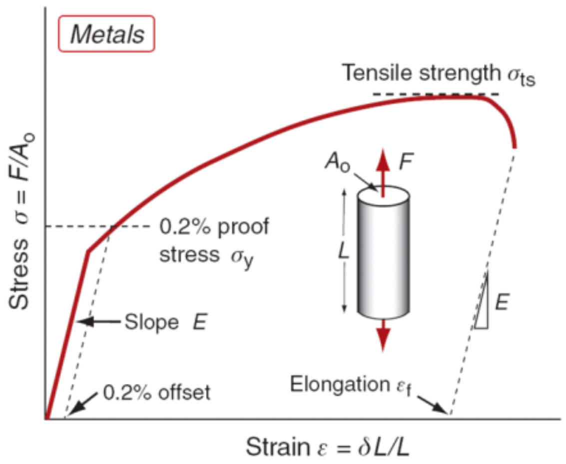
Definition

- Elasticity
  - Reversible
- Plasticity
  - Irreversible

Metals



- After yield point : metals work harden
- After tensile strength : necking (= deformation)

Polymers

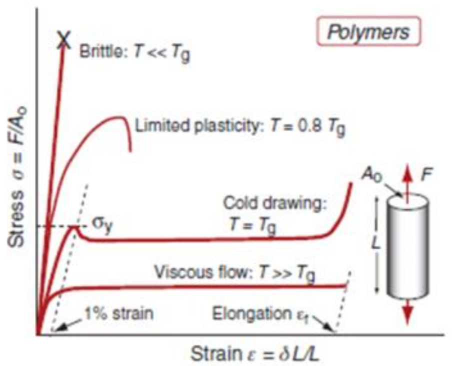


Figure 6.2 Stress–strain curve for a polymer.

- Dependent of T in comparison to T_g

- T << T_g
  - Polymers are brittle
- T < T_g
  - Plasticity becomes possible
- T = T_g
  - Cold drawing : large plastic extension , the molecules are pulled into alignment with the direction of straining , followed by hardening and fracture

- T >> T_g
    - Thermoplastics become viscous and can be moulded, become rubbery and decompose

Ceramics

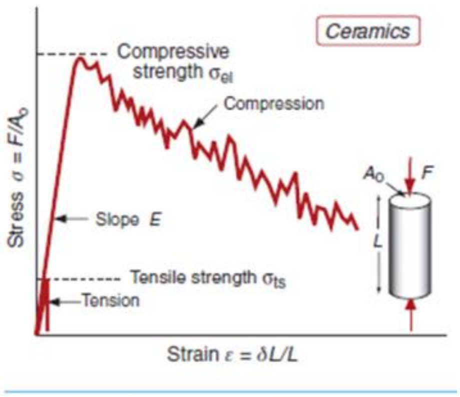


Figure 6.3 Stress–strain curve for a ceramic.

- Brittle at room temperature
- They have a yield strength, but they are so high that they are never reached in tension
    - They fracture first
- They measure it with the term compressive crushing strength
    - We call it elastic limit, because it is nog the true yield
    - σ_{el}

Plastic strain

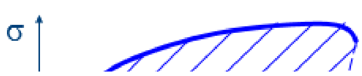
- ε_{el}
    - Permanent strain resulting from plasticity
    - Total strain (= ε_{tot}) minus the recoverable, elastic part
        - $$\varepsilon_{pl} = \varepsilon_{tot} - \frac{\sigma}{E}$$

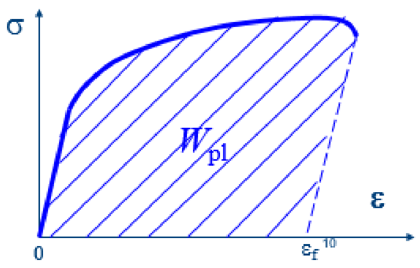
Ductility

- A measure of how much plastic strain a material can tolerate
- ε_f = elongation = tensile strain at break

Plastic work

- Deforming a material permanently by yield or crushing
- $$W_{pl} = \int_0^{\varepsilon_f} \sigma \, d\varepsilon_{pl}$$
    - Area under stress-strain curve





True versus nominal

$$\sigma_t = \frac{F}{A}$$

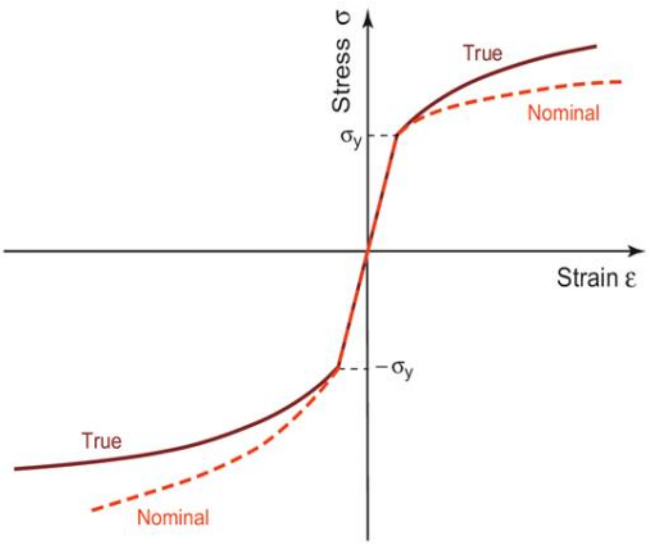
$$V = A_O L_O = A\, L$$

$$\sigma_n = \frac{F}{A_O} = \frac{F}{A}\,\frac{L_O}{L}$$

$$\varepsilon_n = \frac{\delta\, L}{L_O} = \frac{L - L_O}{L_O} = \frac{L}{L_O} - 1$$

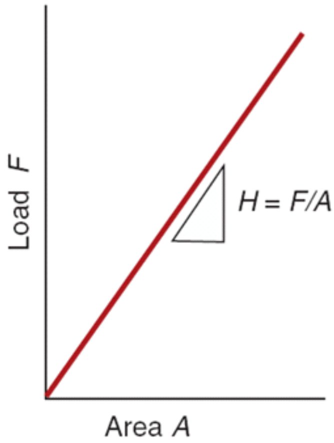
$$\sigma_t = \sigma_n(1 + \varepsilon_n)$$

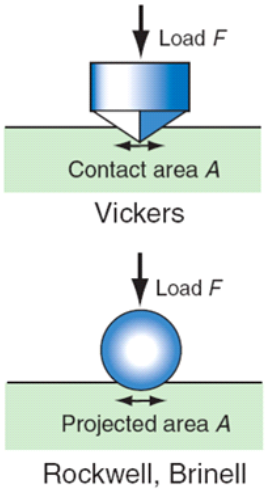
=> $\varepsilon_t = \int_{L_O}^{L} \frac{dL}{L} = \ln\left(\frac{L}{L_O}\right) = \ln(1 + \varepsilon_n)$



Hardness test

$$H = \frac{F}{A}$$





- Vickers

$$H_v \approx \frac{\sigma_y}{3}$$

Charts for yield strength

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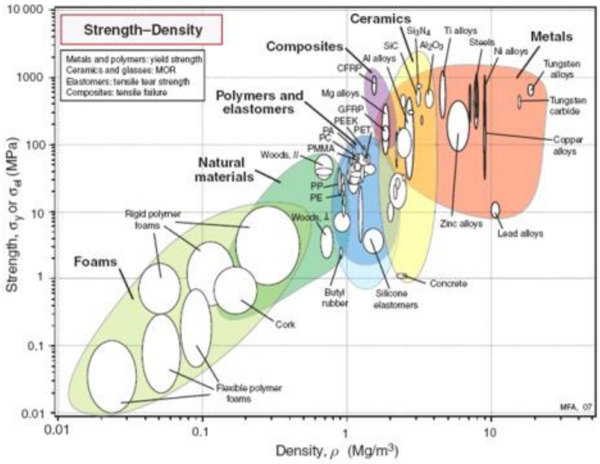
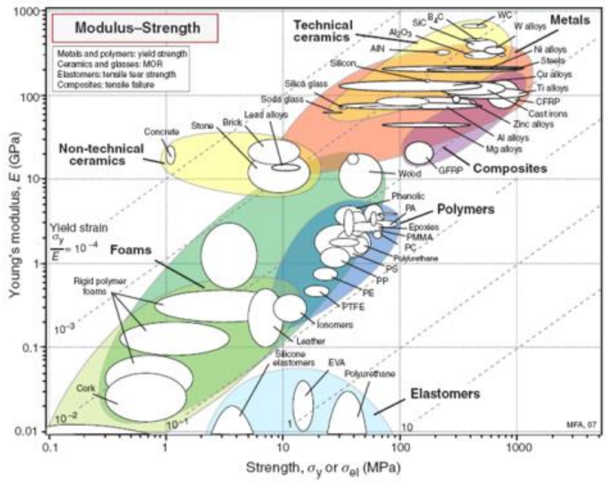
Strength-density chart



Modulus-strength chart



Origins of strength and ductility

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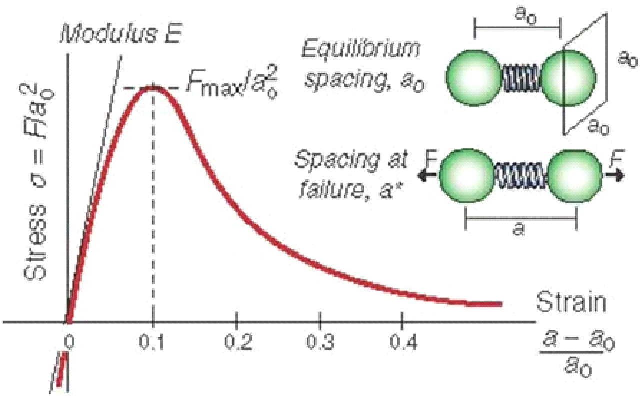
Perfection : the ideal strength

- Bonds between atoms have a breaking point
- When you pull them apart from distance a_0 to a , they will go to maximum stress, and then go apart



- Force needed to break a bond is roughly (broken when stretched to more than 10% of original length)
    - $F \approx \frac{S a_o}{10}$
- Ideal strength should be
    - $\sigma_{ideal} = F_{max}/a_0^2 = S/10a_0 = E/10$
    - $\frac{\sigma_{ideal}}{E} \approx \frac{1}{10}$

Crystalline imperfection : defects in metals and ceramics

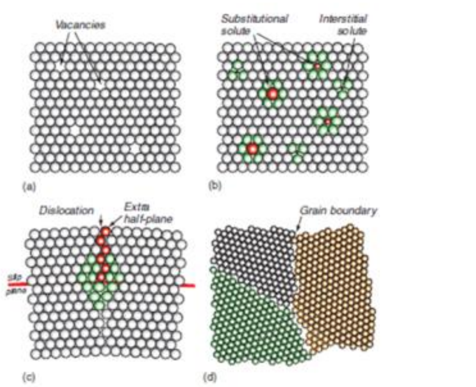


Figure 6.10 Defects in crystals. (a) Vacancies–missing atoms. (b) Foreign (solute) atom on interstitial and substitutional sites. (c) A dislocation–an extra half-plane of atoms. (d) Grain boundaries.

a) Vacancies
   - Point defects
   - An atom is missing
   - They do not influence strength, the others do
b) Solutions :
   - Substitutional solid solution
     - Dissolved atoms replace those of the host
   - Interstitiual solid solution
     - Dissolved atoms squeeze into the spaces
   - Makes them stronger
c) Dislocation
   - Upper part of the crystal has one more double-layer of atoms than the lower part
   - Makes metals soft and ductile
d) Grain boundaries
   - Perfect , but differently oriented, crystals meet
   - They are all the same atoms

<u>Dislocations and plastic flow</u>

- How to make a dislocation

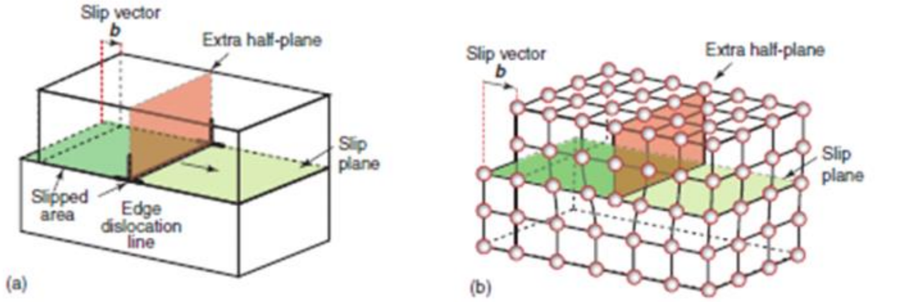
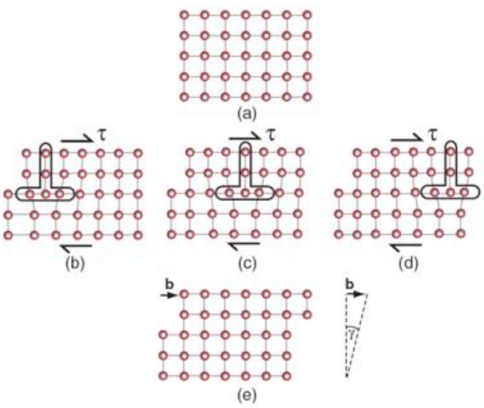


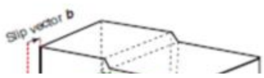
Figure 6.11 (a) Making a dislocation by cutting, slipping and rejoining bonds across a slip plane. (b) The atom configuration at an edge dislocation in a simple cubic crystal. The configurations in other crystal structures are more complex but the principle remains the same.

   - Crystal is cut along an atomic plane
   - Top part is slid across the bottom by one full atom spacing

- Beweging door aanbrenging van schuifspanning τ



- Schroefdislocatie



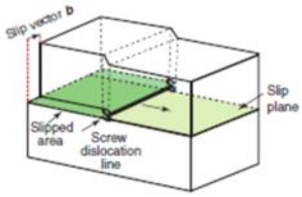
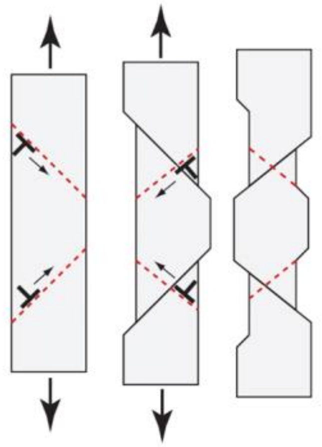


Figure 6.13 A screw dislocation. The slip vector ***b*** is parallel to the dislocation line **S—S**.

- Dislocation motion causes extension, at constant volume



Why does a shear stress make a dislocation move?

- For yielding to take place the external stress must overcome the resistance f

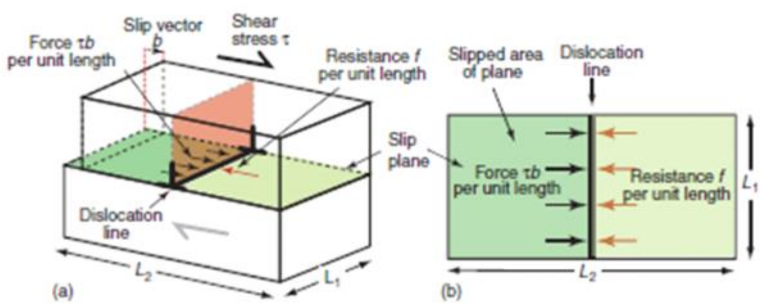


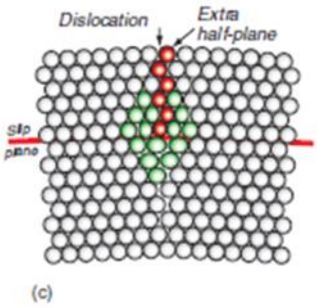
Figure 6.15 The force on a dislocation. (a) Perspective view. (b) Plan view of slip plane.

- $W = \tau L_1 L_2 b$

- $\tau b = f$

Line tension

- $T \approx \frac{1}{2} E b^2$

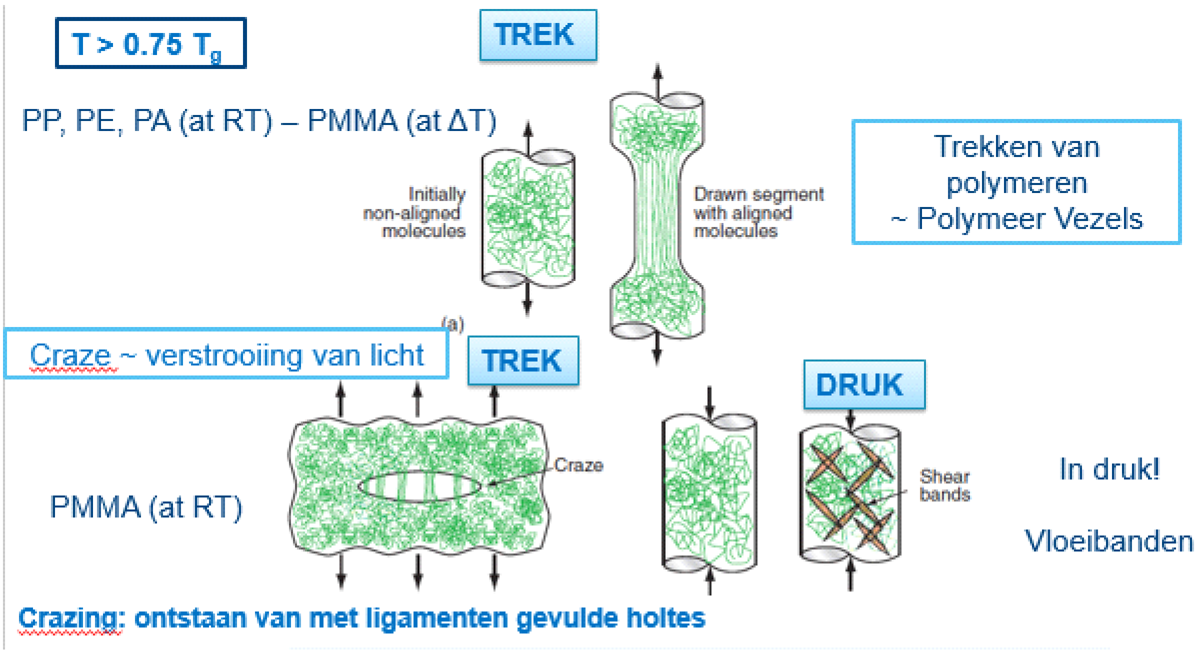


Lattice resistance (= rooster weerstand)

- f_i
    - Intrinsic resistance of the crystal structure to plastic shear

- Metalen kunnen op vershillende manieren verstevigd worden
    - $f = f_i + f_{ss} + f_{ppt} + f_{wh} + f_{gb}$
        - f_{ss} = solid solution hardening
        - f_{ppt} = precipitation hardening
        - f_{wh} = work hardening
        - f_{gb} = grain-size hardening

Plastic flow in polymers



Manipulating strength

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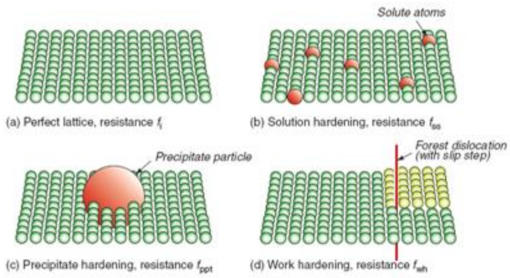
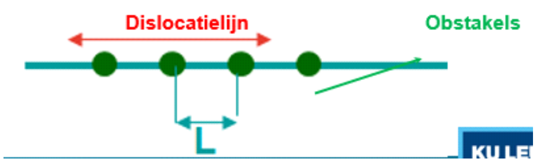
Strengthening metals

- The way to make crystalline materials stronger is to make it harder for dislocations to move
    - Dislocations move in a pure crystal when τb > f_i



a) In perfect lattice, the only resistance is intrinsic strength
b) Atom-size obstacles to motion
c) Presents larger obstacles
d) Slip plane becomes stepped and threaded with forest dislocations

- Number of obstacles touching unit length of dislocatoin line
    - $N_L = \frac{1}{L}$

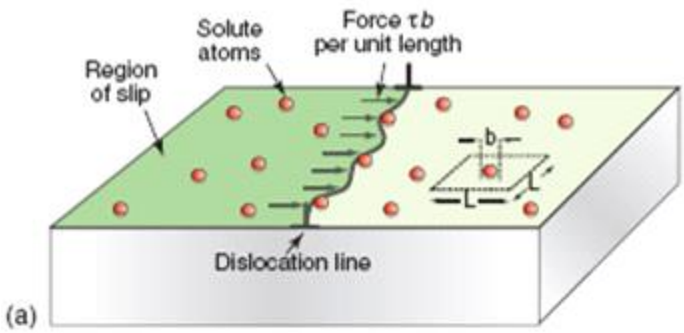


- Each individual obstacle exerts a pinning force p on the dislocation line
    - $f = \frac{p}{L}$

- The shear stress τ needed to make the dislocation move
    - $\Delta\tau = \frac{p}{b\,L}$

- Pinning is an elastic effect
    - When the dislocation moves, it produces plastic deformation
- The shear stress τ needed to force the dislocation through the field of obstacles
    - $\tau = \alpha \frac{E\,b}{L}$
        - α is dimensionless, constant = sterkte van obstakel

Solution hardening



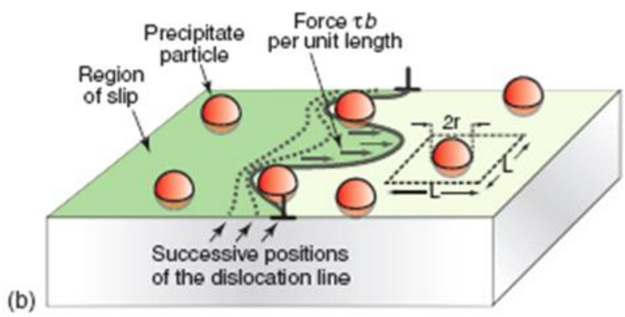
- Strenghthening by deliberate additions of imputirites, by alloying

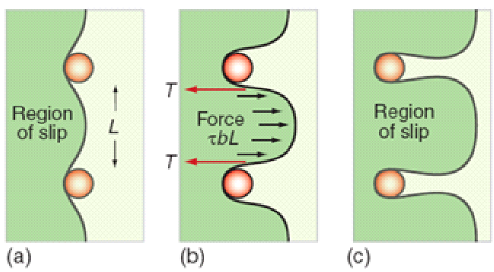
$$c = \frac{b^2}{L^2}$$

- b = atoomgrootte
- L = afstand tussen opgeloste atomen

$$\tau_{ss} = \alpha E c^{\frac{1}{2}}$$

Dispersion and precipitate strengthening

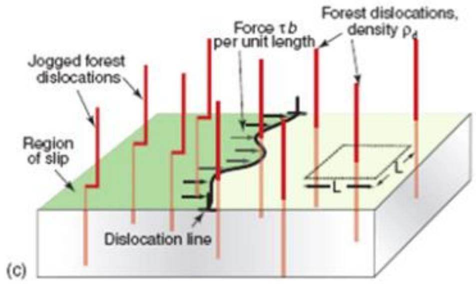




$$\tau_{\text{ppt}} = \frac{2T}{b\,L} \approx \frac{E\,b}{L}$$

$$f_{ppt} = 2\frac{T}{L}$$

Work hardening



$$L = \boldsymbol{\rho}_d^{-1/2}$$

$$p = E\frac{b^2}{2}$$

$$\boxed{\tau_{\mathrm{wh}} \approx \frac{E\,b}{2}\sqrt{\rho_{\mathrm{d}}}}$$

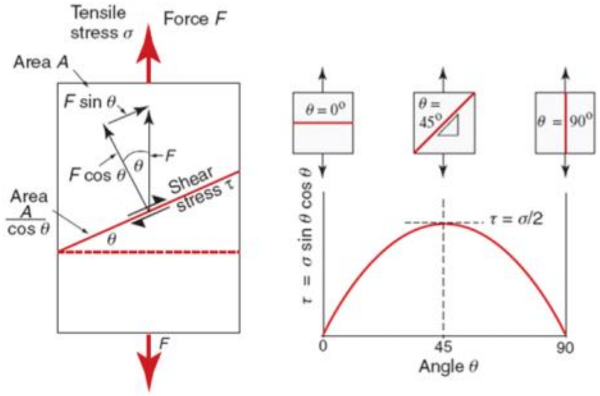
Grain boundary hardening

$$\boxed{\tau_{\mathrm{gb}} = \frac{k_{\mathrm{p}}}{\sqrt{D}}}$$

- D = korrelgrootte
- k_p = Hall-Petch constante

Relationship between dislocation strength and yield strength

$$\boxed{\tau_{\mathrm{y}} = \tau_{\mathrm{i}} + \tau_{\mathrm{ss}} + \tau_{\mathrm{ppt}} + \tau_{\mathrm{wh}} + \tau_{\mathrm{gb}}}$$

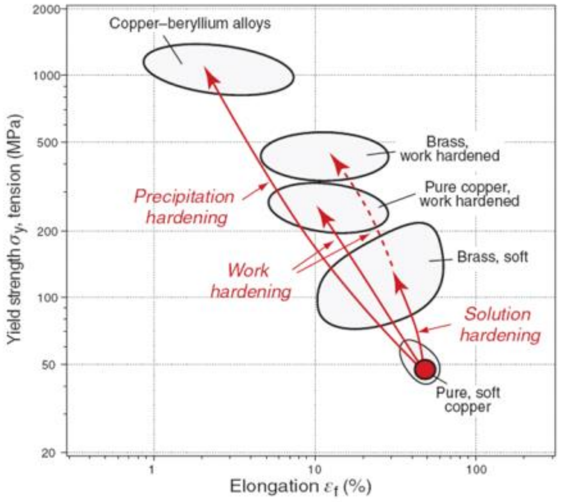


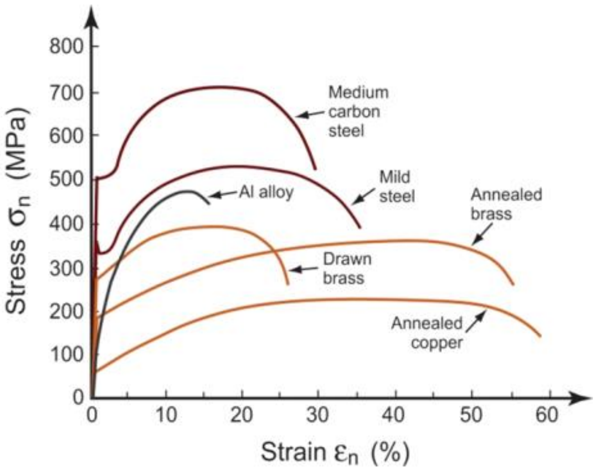
- Shear stress
    - $\tau = \dfrac{F \sin\theta}{A/cos\theta} = \ \sigma\, sin\theta\ cos\theta$

- Maximum shear stress
    - $\tau = \dfrac{\sigma}{2}$

- $\sigma_y \approx 3\tau_y$

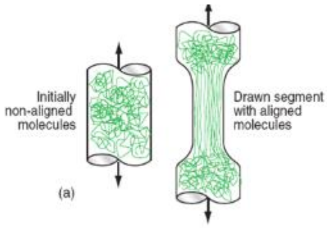
<u>Strength and ductility of alloys</u>



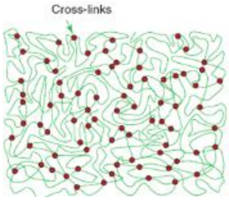


<u>Strengthening polymers</u>

- Verstevigen door
    - Mengen van meerdere polymeren
    - Trekken



- Kruisverbindingen



- Verstevigende deeltjes of vezels