بسم الله الرحمن الرحيم

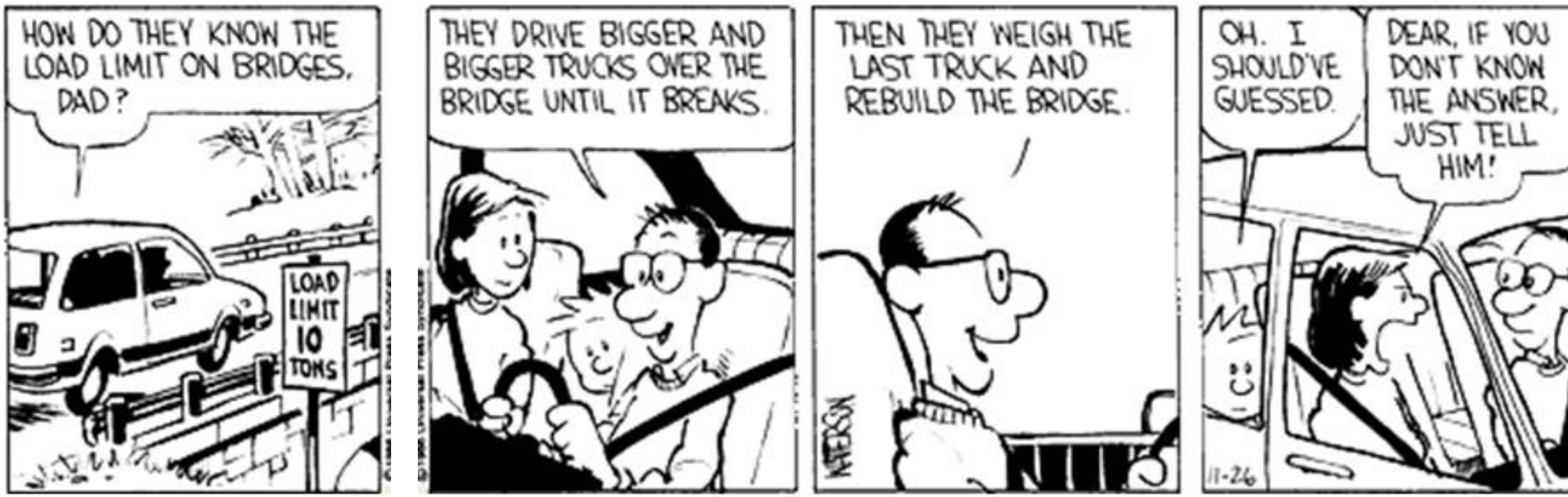
Benha University
Shoubra Faculty of Engineering

Mechanical Department
1st year Mech.

17.02.2019 – Week 2

Materials Characterization

Prof. Farida Sayed Ahmed
Dr. Mahmoud Khedr

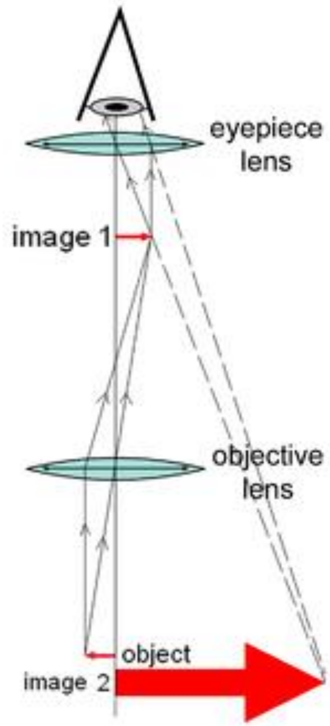

HOW DO THEY KNOW THE LOAD LIMIT ON BRIDGES, DAD?
LOAD LIMIT 10 TONS
THEY DRIVE BIGGER AND BIGGER TRUCKS OVER THE BRIDGE UNTIL IT BREAKS.
THEN THEY WEIGH THE LAST TRUCK AND REBUILD THE BRIDGE.
OH. I SHOULD'VE GUESSED.
DEAR, IF YOU DON'T KNOW THE ANSWER, JUST TELL HIM!
WATTERSON
11-26

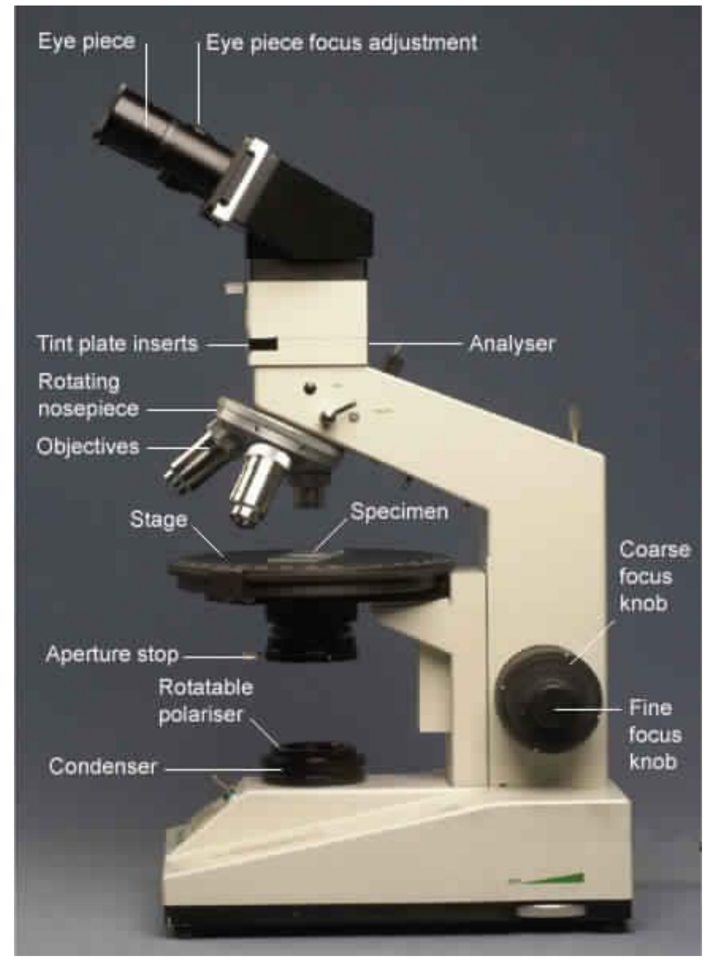
Outline

- Materials Characterization via microscopes
- Strain gauges
- Ductile & Brittle Failure
- Temperature effects on the mechanical properties

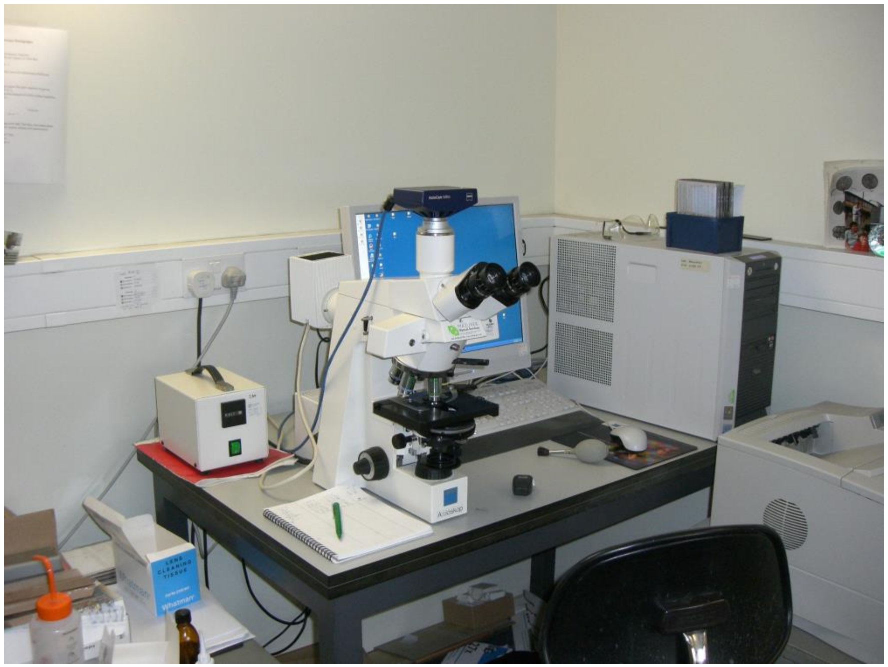
Optical microscopy (OM)

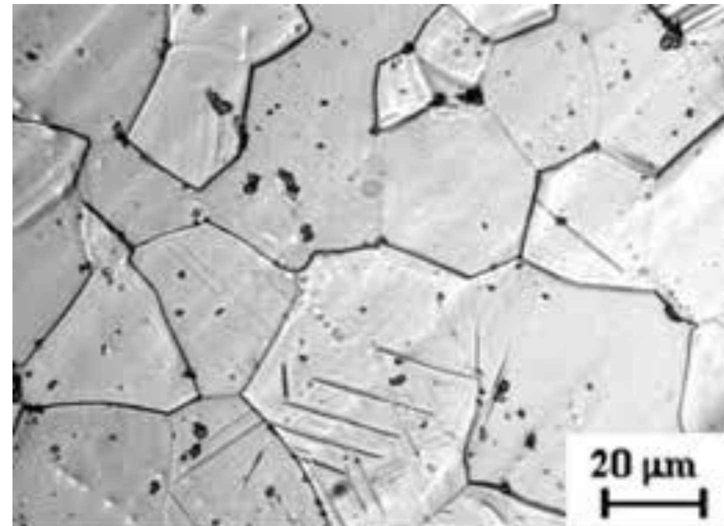
- Logical Max. zoom is 1000x.
- Characterizes the optical microstructure
- Sample dimensions!

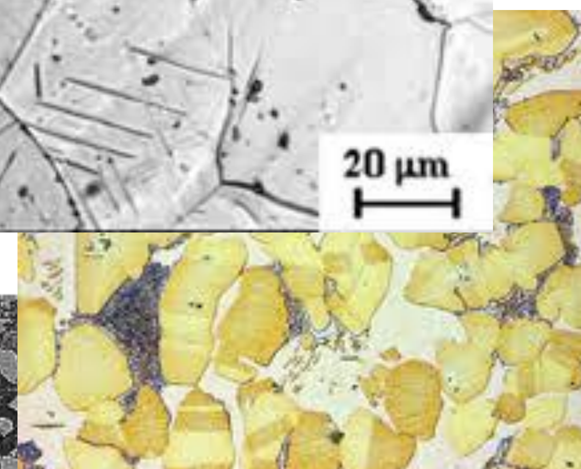


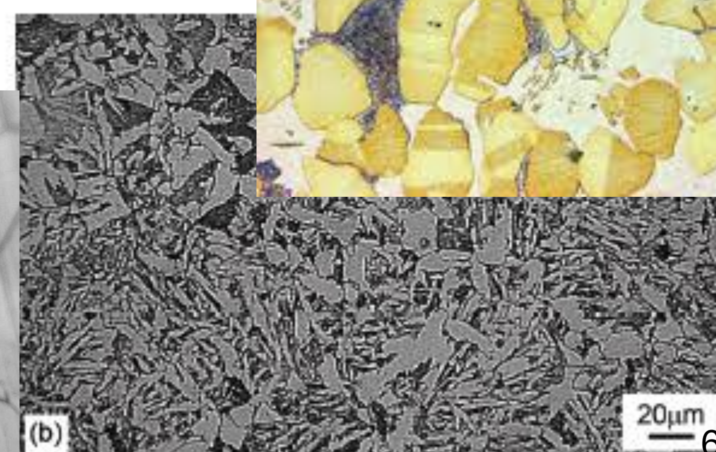


Optical microscopy (OM)

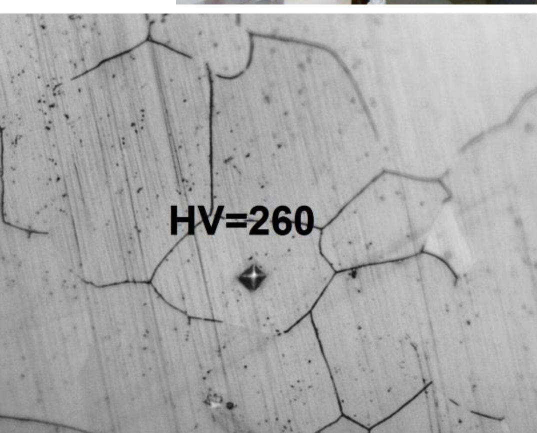


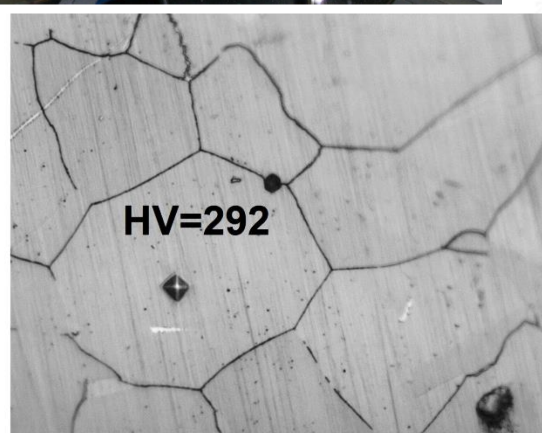






. Microstructure of samples (a) normalized and (b) air cooled (Nital 2% etching).



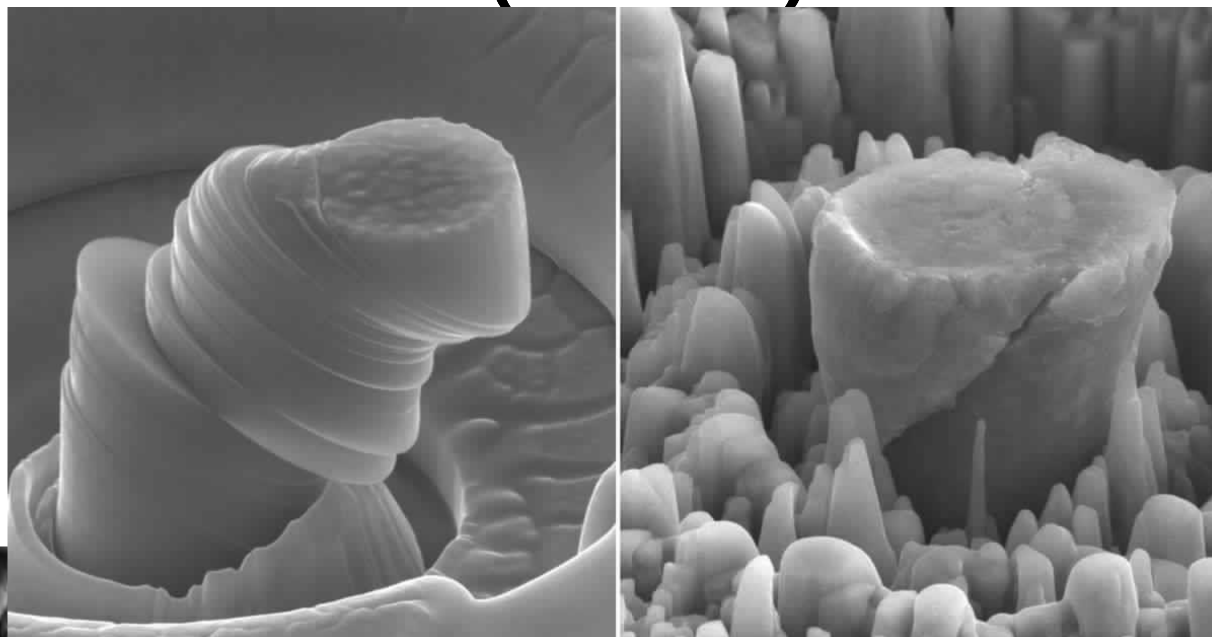


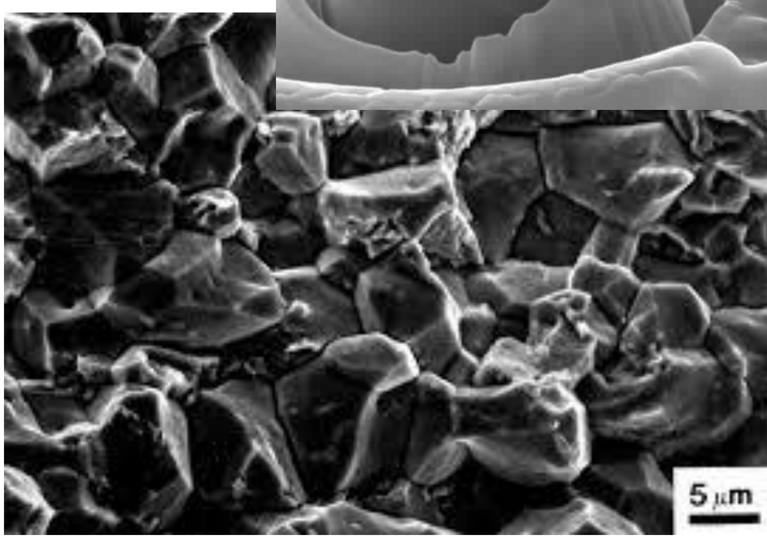
Scanning Electron microscopy (SEM)

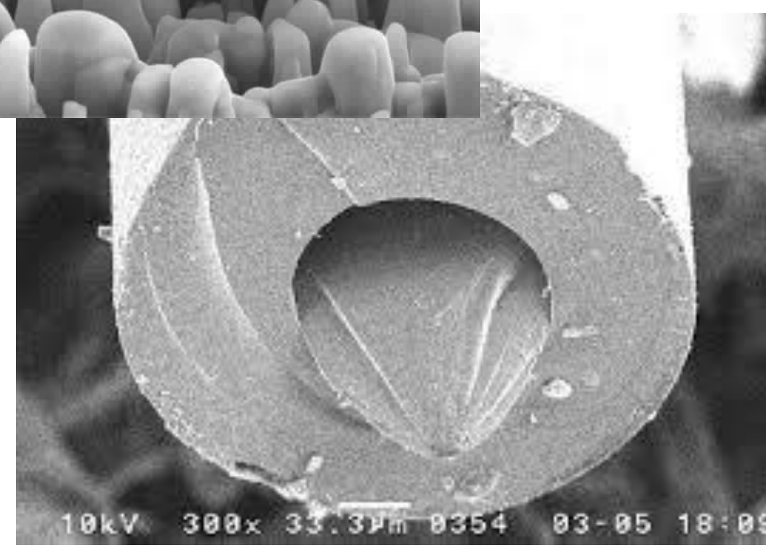
Logical max. zoom !

Sample dimensions !

Scanning Electron microscopy (SEM)



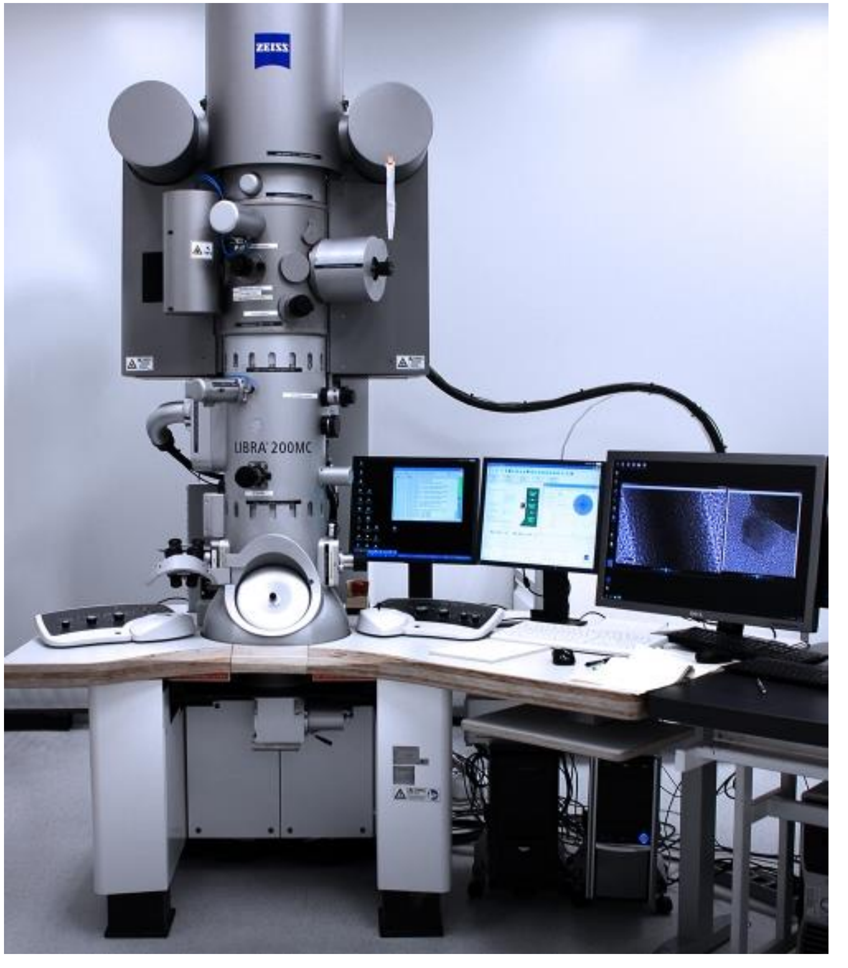




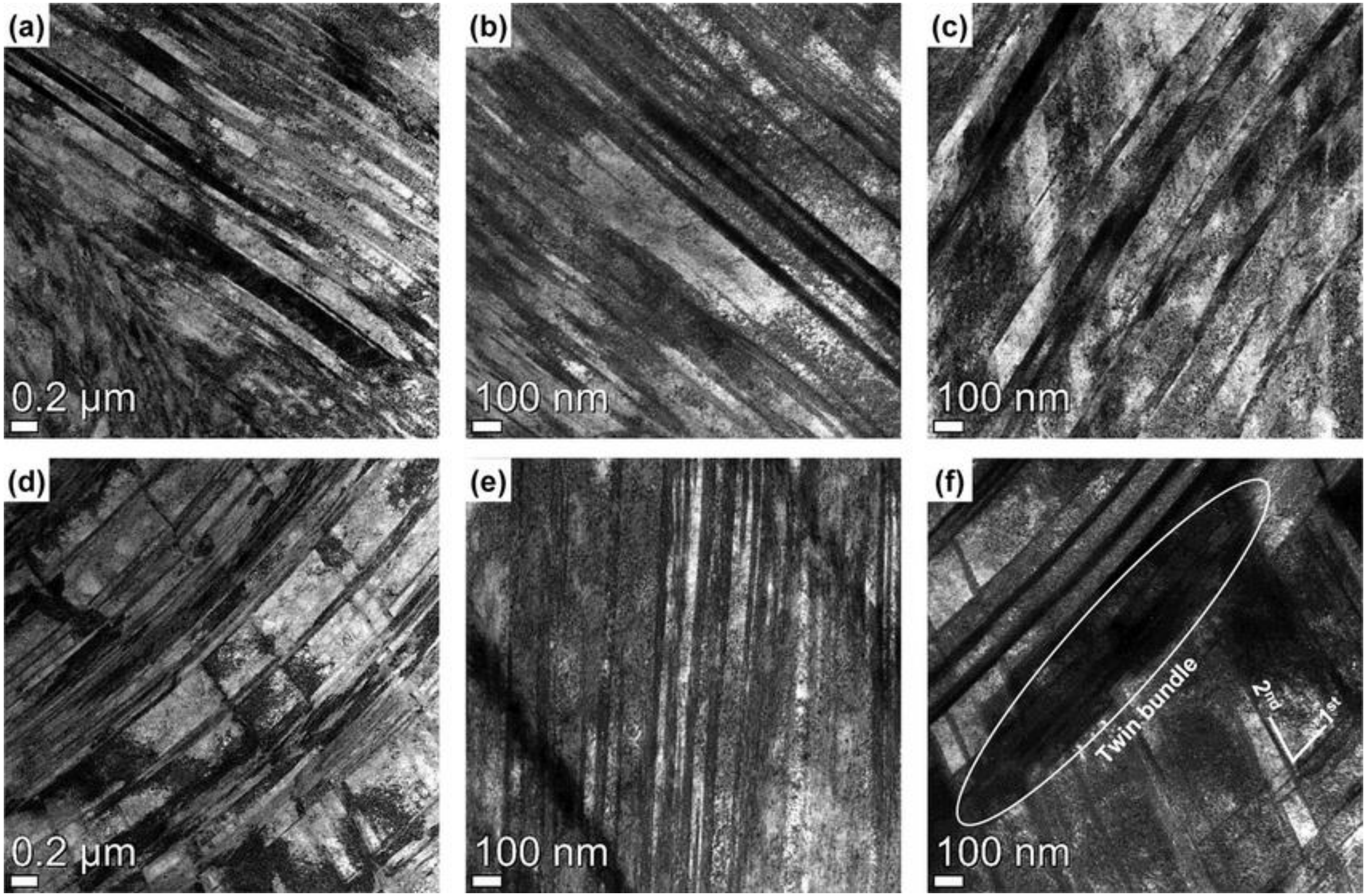
Transmission Electron microscopy (TEM)

Logical max. zoom !

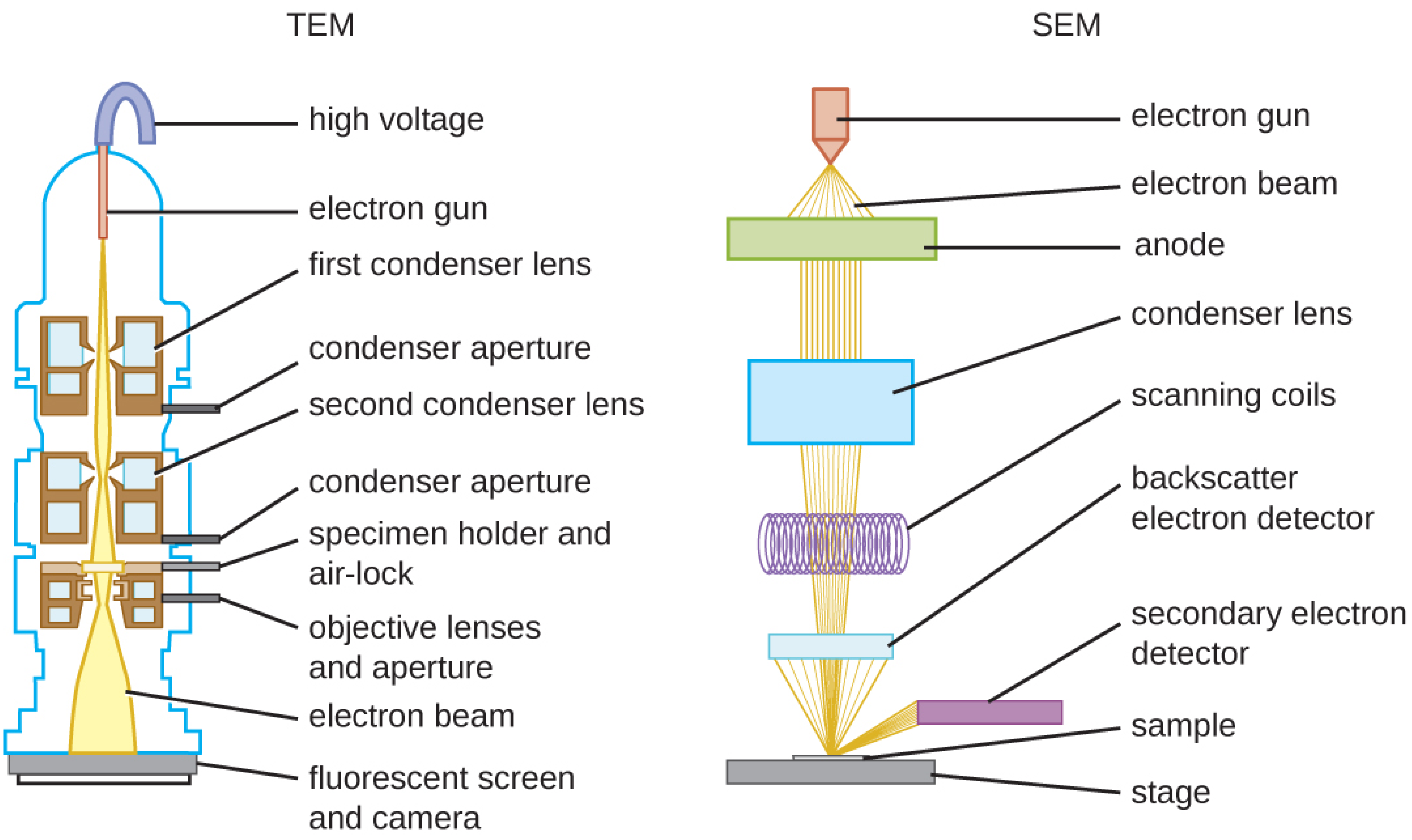
Sample dimensions !



Transmission Electron microscopy (TEM)



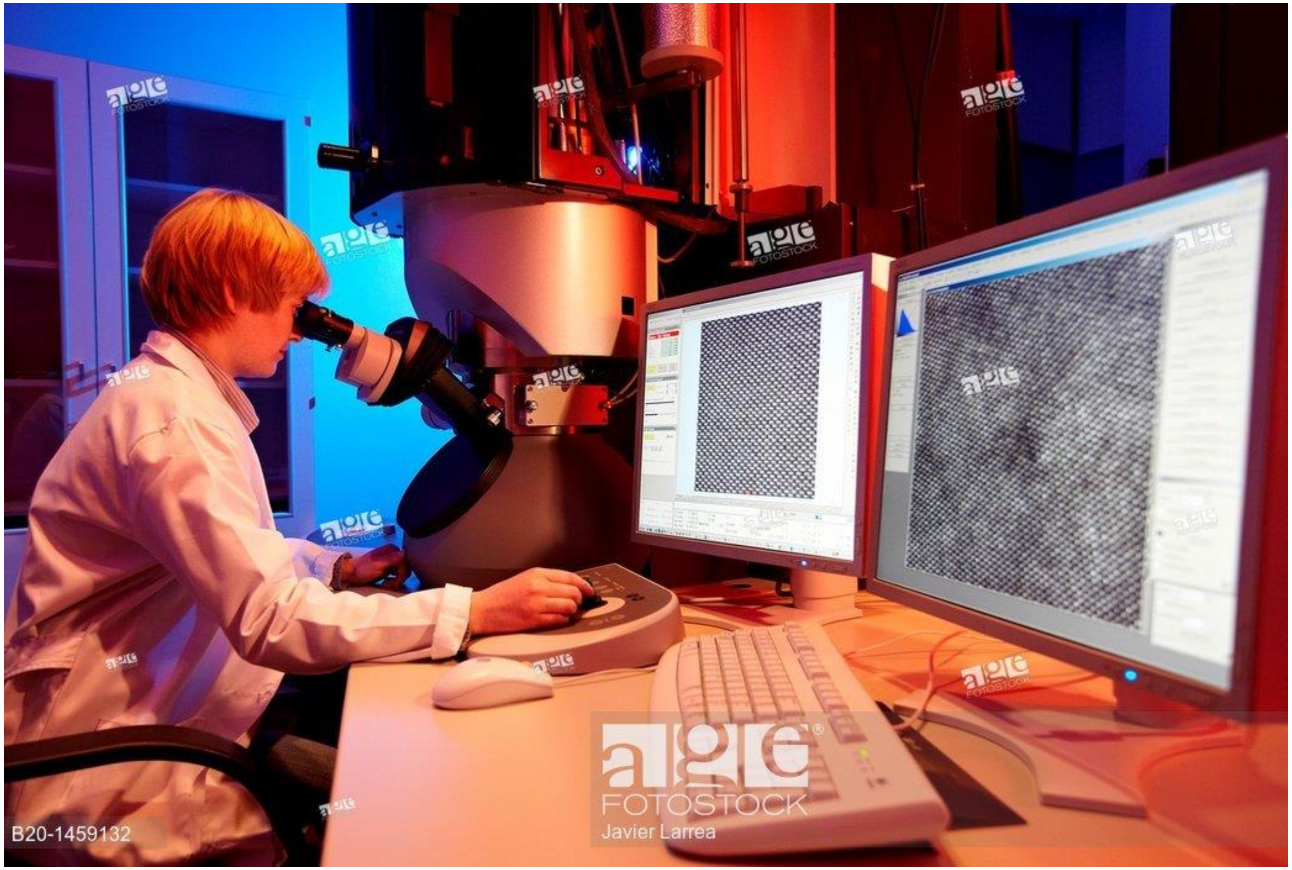
TEM vs. SEM


TEM
high voltage
electron gun
first condenser lens
condenser aperture
second condenser lens
condenser aperture
specimen holder and air-lock
objective lenses and aperture
electron beam
fluorescent screen and camera
SEM
electron gun
electron beam
anode
condenser lens
scanning coils
backscatter electron detector
secondary electron detector
sample
stage

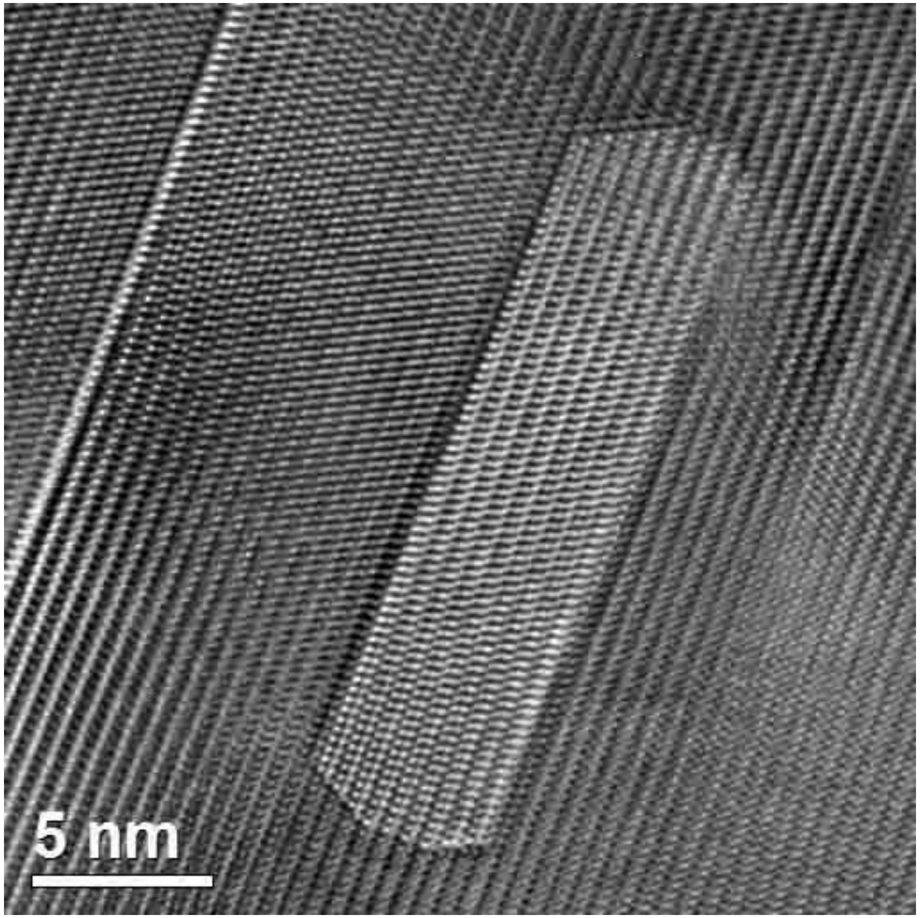
High Resolution Transmission Electron microscopy (HRTEM)

Max. zoom
!

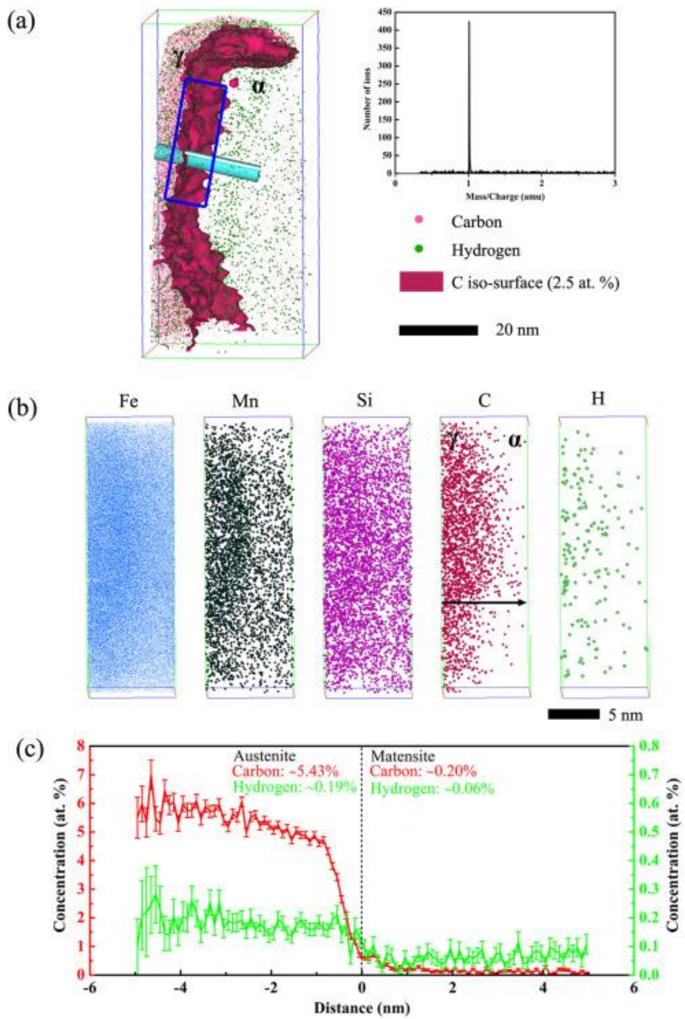
Sample dimensions
!



High Resolution Transmission Electron microscopy (HRTEM)



3D atomic probe tomography (3DAPT)



Comparison between OM, SEM & TEM

Source: Metals Handbook, vol.10, ASM

	Optical microscope	Scanning electron microscope	Transmission electron microscope
Emission	Light	Electron beam	Electron beam
Medium	Atmosphere	Vacuum $<10^{-4}$ Pa	Vacuum$<10^{-5}$Pa
Resolution	~ 200 nm	Approx. 5 nm	Approx. 0.14 nm
Contrast	Absorption reflection	Secondary electron effect	Scattering / diffraction
Lens	Optical glass lens	Electromagnetic lens	Electromagnetic lens
Depth of focus	Shallow	Very deep	Deep
Magnification change method	Lens replacement	Scanning width	Excitation of magnifying lenses
Specimen thickness	Usually 0.5 µm min.	Usually 10 mm max.	Usually 1 µm max.
Specimen preparation	Easy	Relatively easy	No easy

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Ductile & Brittle Failure

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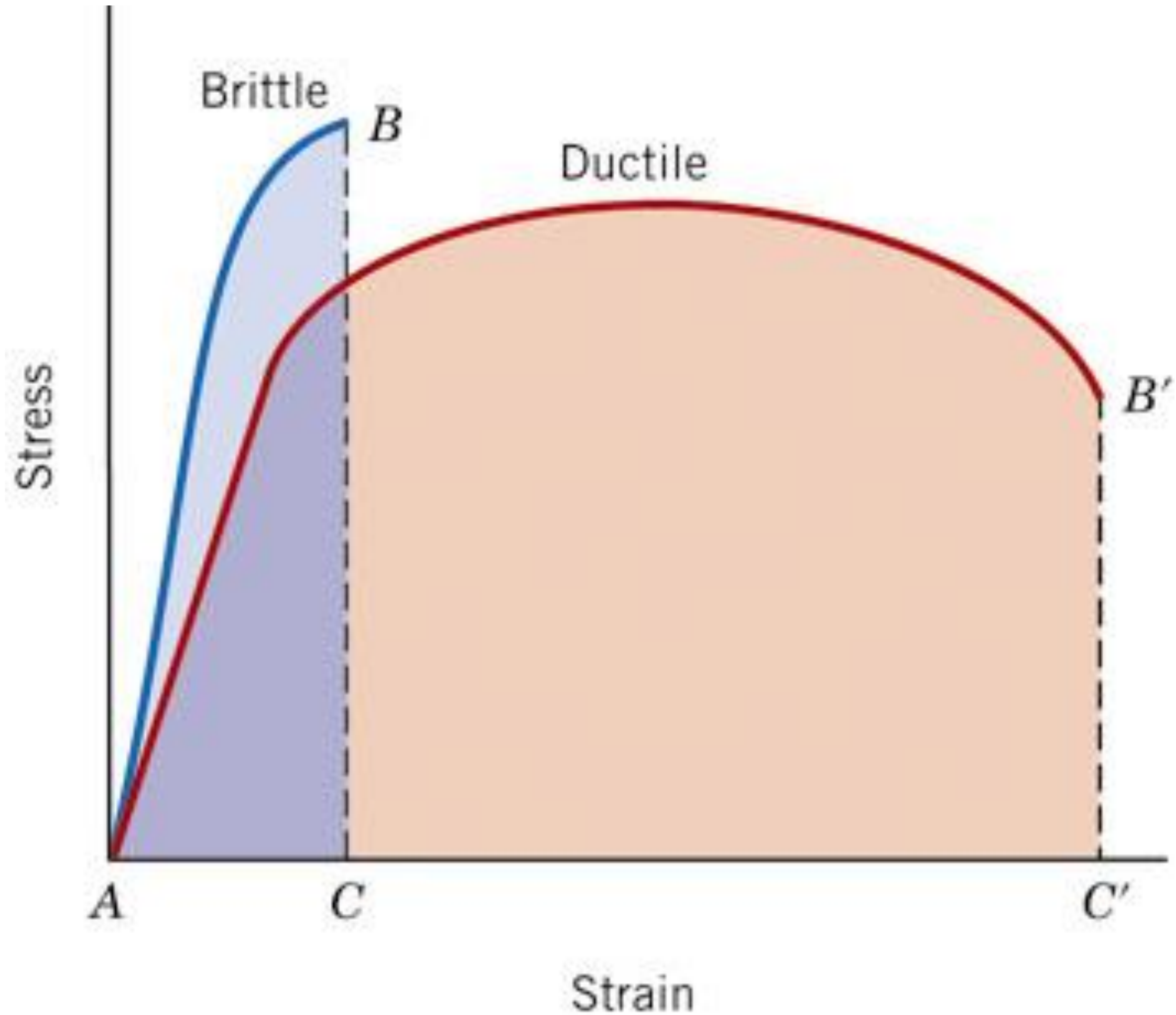
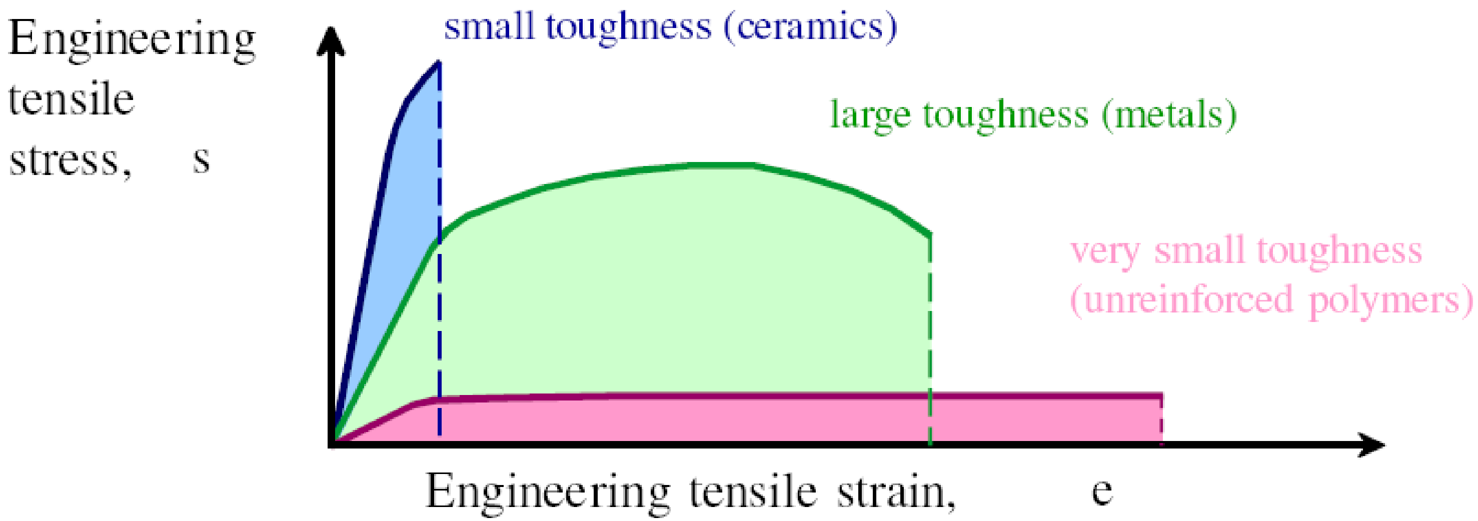
Brittle ‘vs’ Ductile



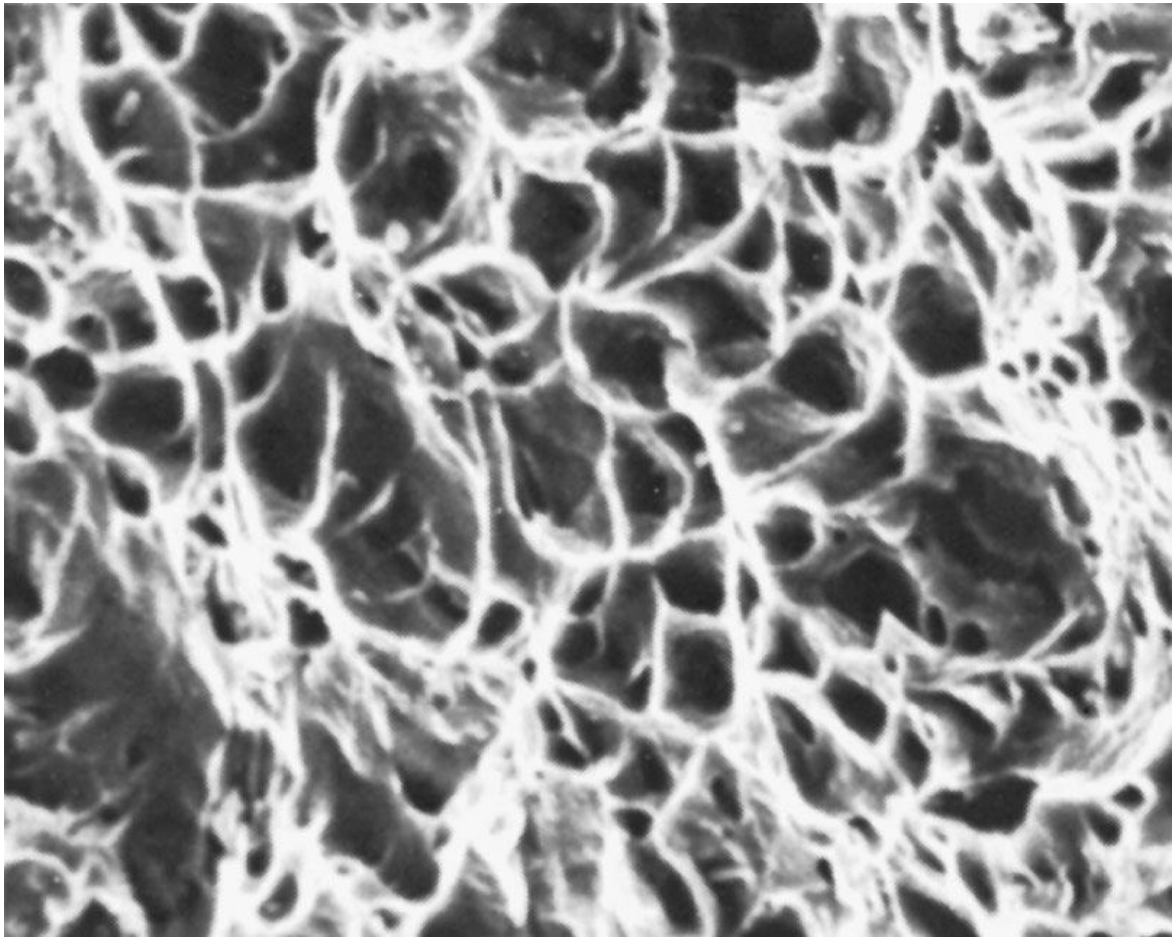
Toughness

- Energy to break a unit volume of material
- Approximate by the area under the stress-strain curve.



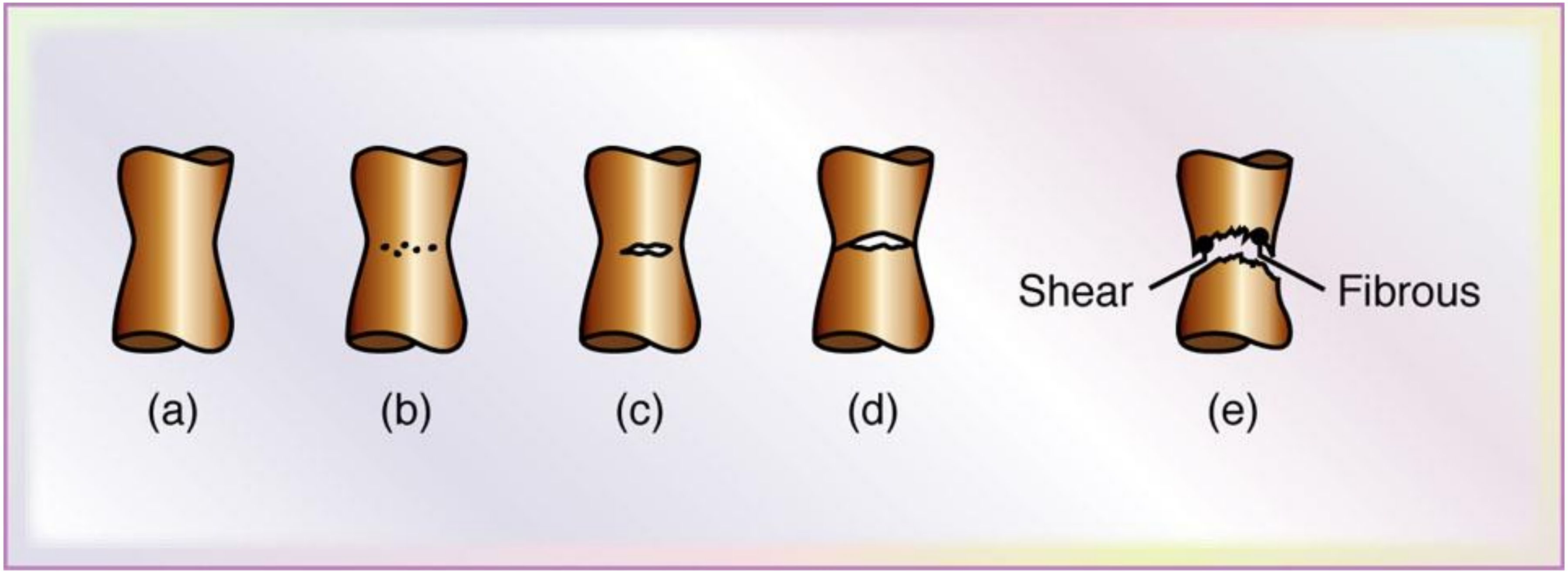
Brittle fracture: elastic energy
Ductile fracture: elastic + plastic energy

Ductile Fracture in Low-carbon Steel



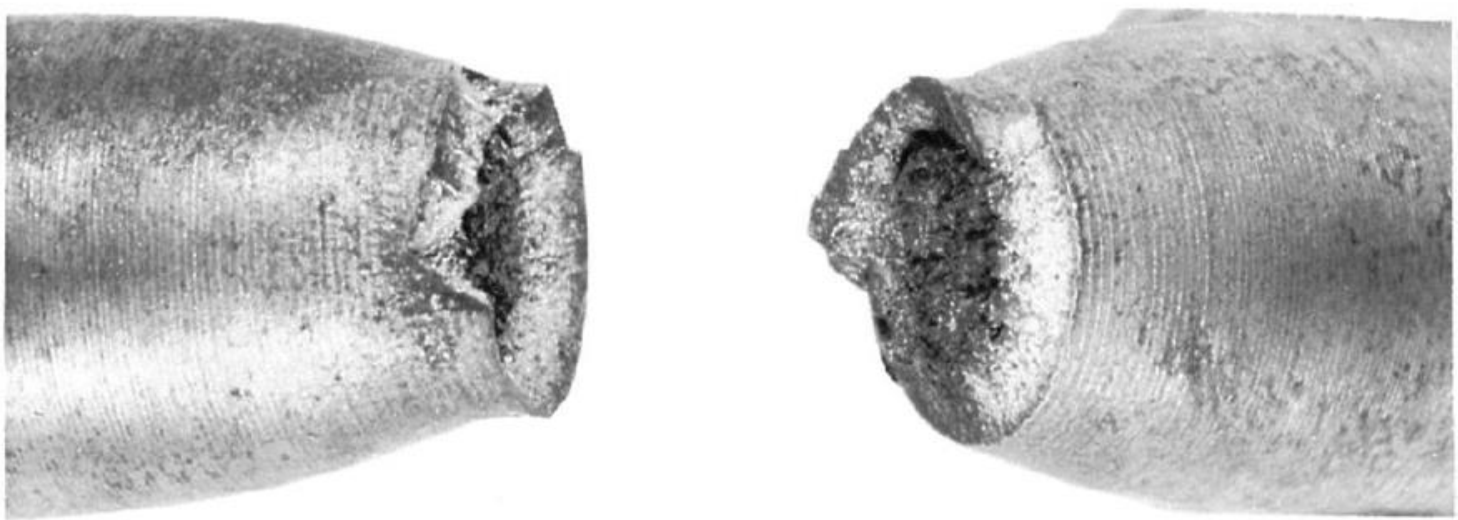
Surface of ductile fracture in low carbon steel, showing dimples. Fracture usually is initiated at impurities, inclusions, or preexisting voids (microporosity) in the metal. *Source*: Courtesy of K. H. Habig and D. Klaffke

Progression of a ductile Fracture



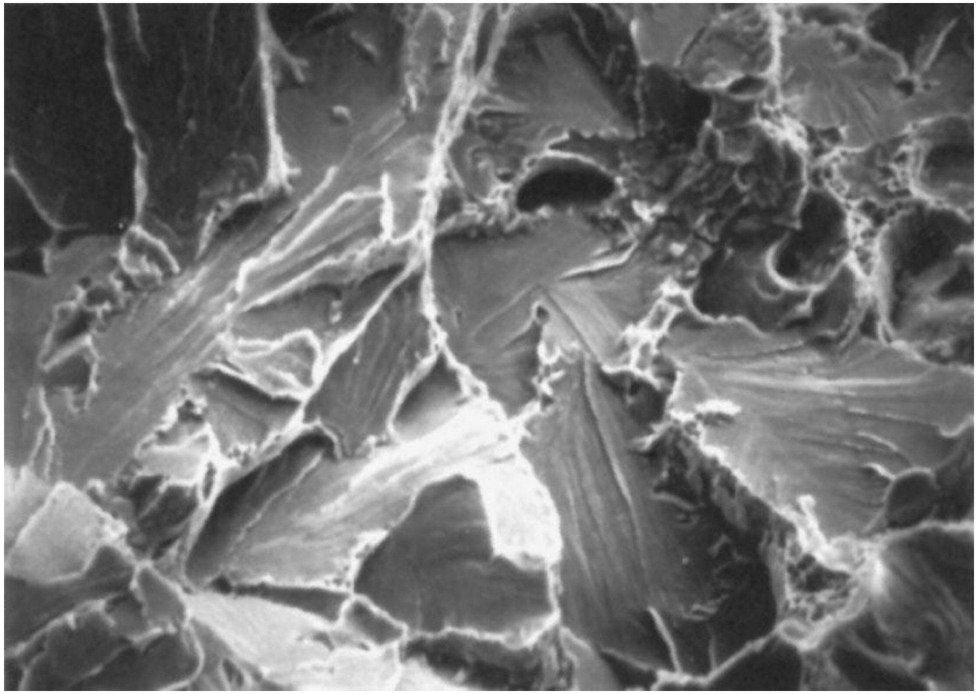
(a) early stage of necking
(b) small voids begin to form within the necked region
(c) voids coalesce, producing an internal crack
(d) the rest of the cross-section begins to fail at the periphery, by shearing
(e) the final fracture surfaces, known as cup- (top fracture surface) and cone- (bottom surface) fracture.

Tension test sample after fracture

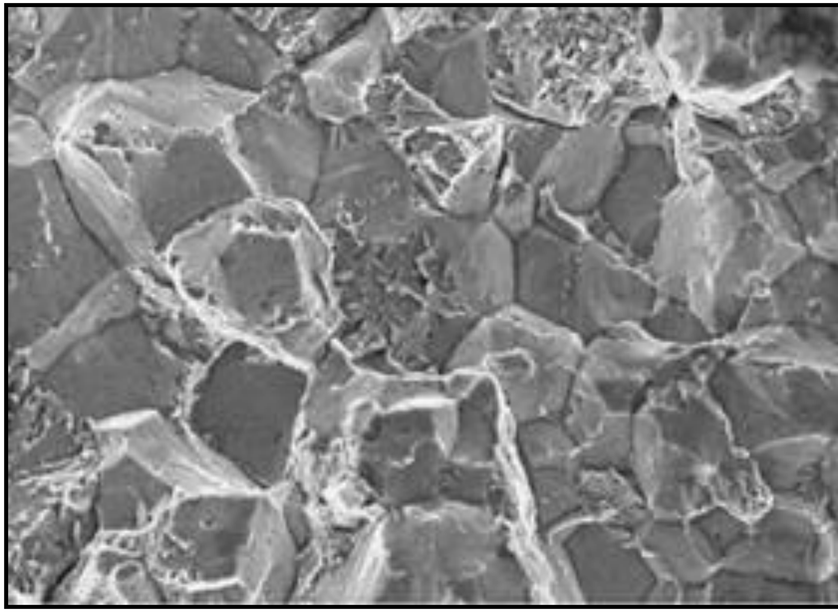


Localized deformation of a ductile material during a tensile test produces a necked region. The micrograph shows necked region in a fractured sample

Brittle Fracture Surface of Steel

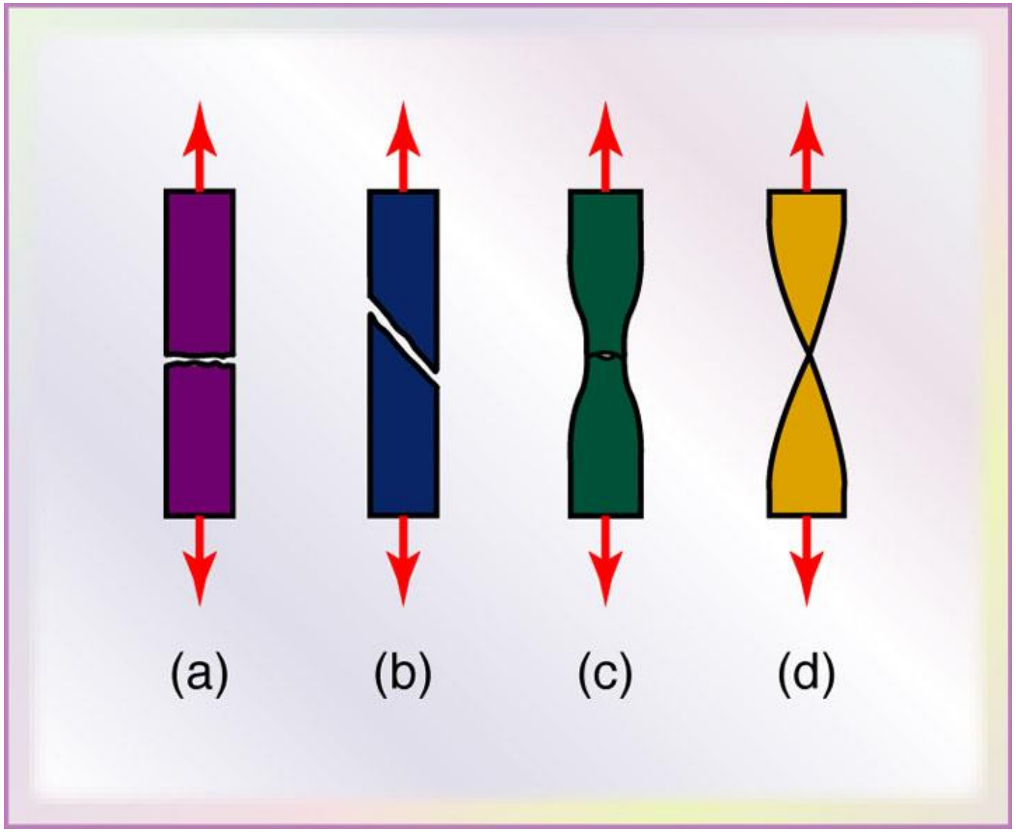


Fracture surface of steel that has failed in a brittle manner. The fracture path is transgranular (through the grains). Magnification: 200x. *Source:* Courtesy of B. J. Schulze and S.L. Meinley and Packer Engineering Associates, Inc.



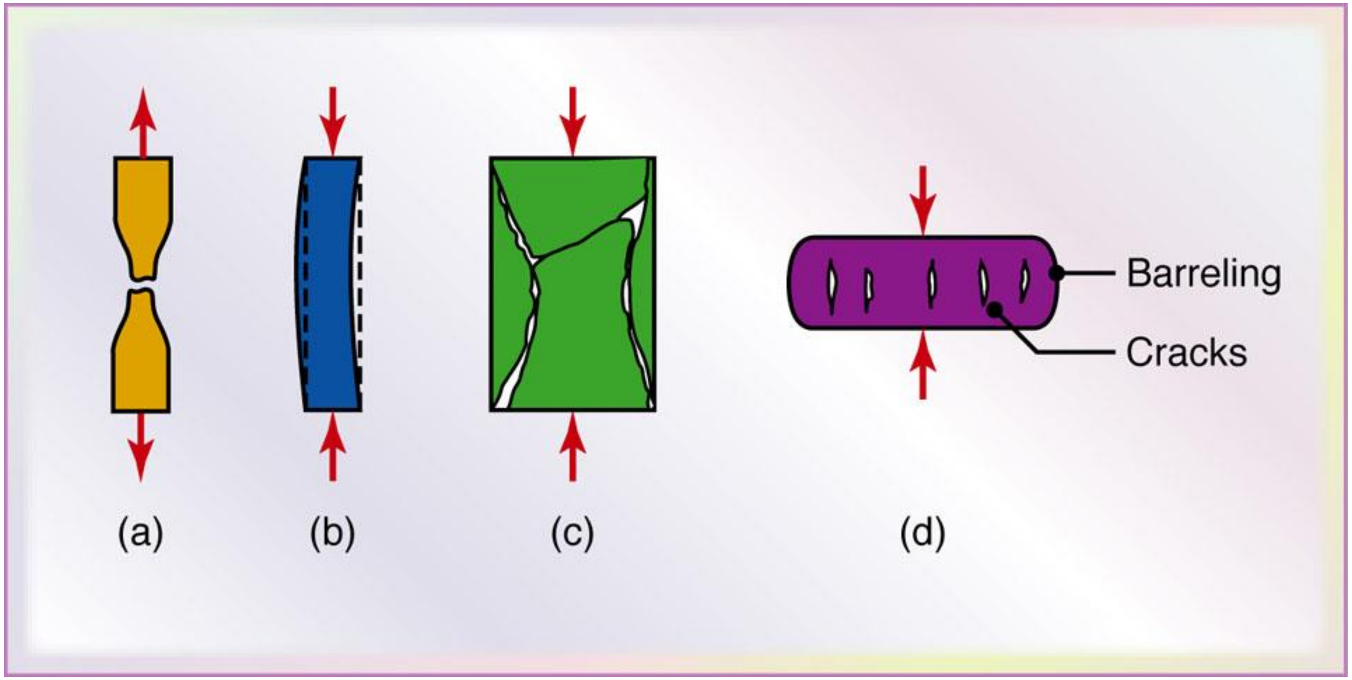
A brittle fracture surface . The fracture path is intergranular (through the grain boundaries).

Fracture Types in Tension



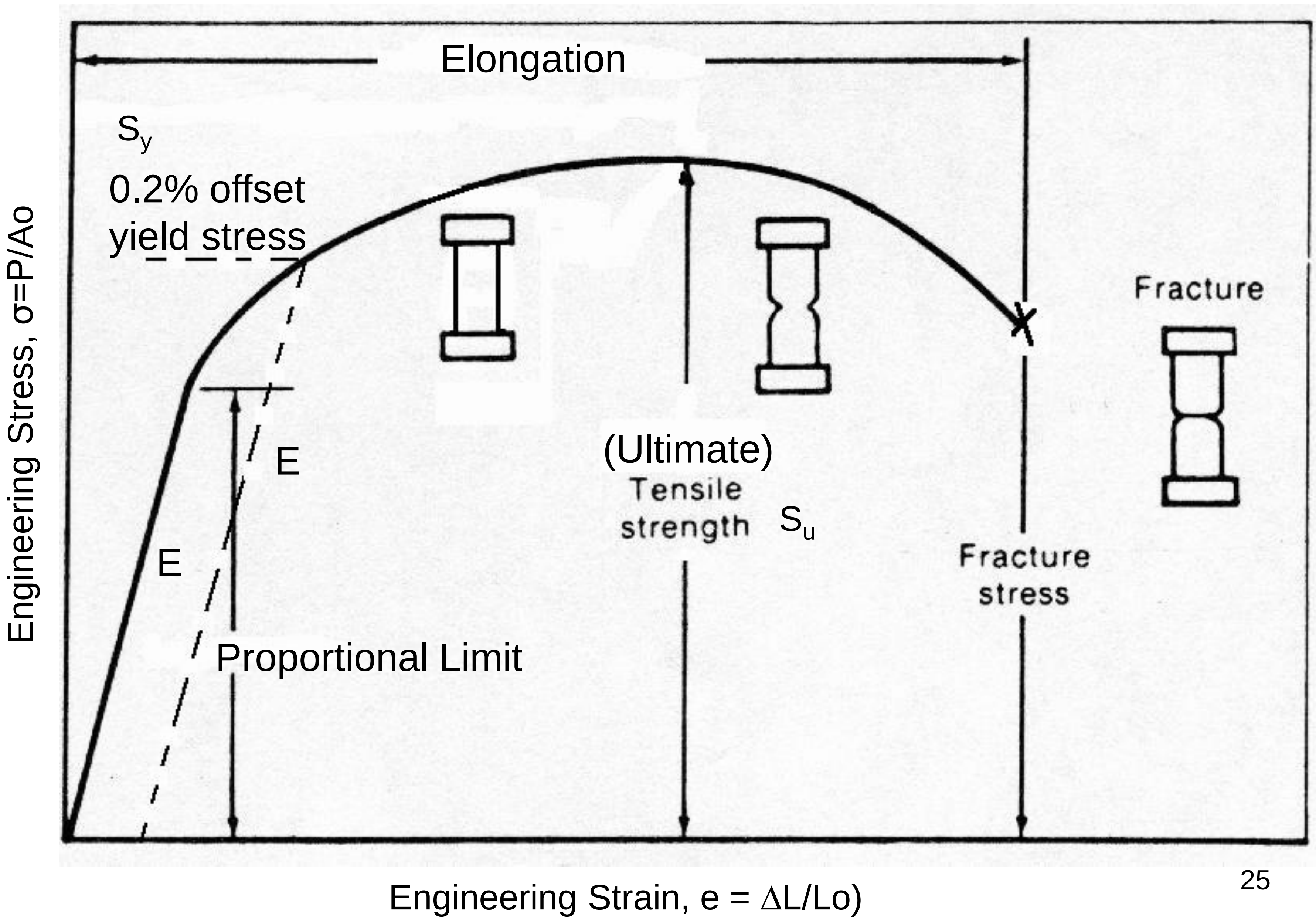
(a) brittle fracture in polycrystalline metals
(b) shear fracture in ductile single crystals
(c) ductile cup-and-cone fracture in polycrystalline metals
(d) complete ductile fracture in polycrystalline metals, with 100% reduction of area.

Material Failures

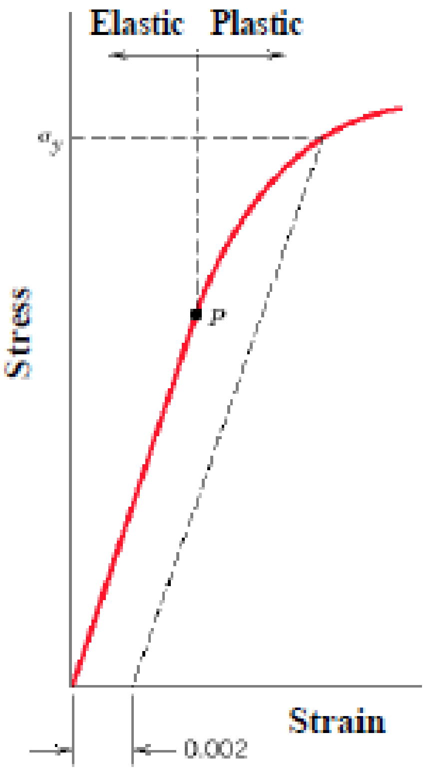


(a) necking and fracture of ductile materials;
(b) buckling of ductile materials under a compressive load;
(c) fracture of brittle materials in compression;
(d) cracking on the barreled surface of ductile materials in compression

Engineering Stress-Strain Curve



Stress-Strain Behavior



Elastic deformation

Reversible: when the stress is removed, the material returns to the dimension it had before the loading.

Usually strains are small (except for the case of plastics).

Plastic deformation

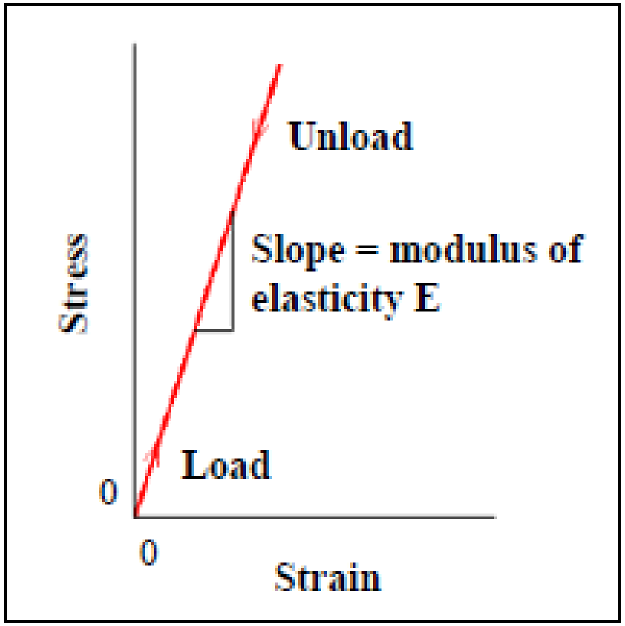
Irreversible: when the stress is removed, the material does not return to its previous dimension.

Stress-Strain Behavior: Elastic deformation

In tensile tests, if the deformation is elastic, the stress-strain relationship is called Hooke's law:

$$\sigma = E\,\varepsilon$$

E is Young's modulus or modulus of elasticity, has the same units as σ, N/m^2 or Pa



Higher E → higher "stiffness"

Engineering Stress-Strain Curve

- Express Load in Newtons (N) and Area in mm^2 to get Stress in MPa.

$$\frac{N}{mm^2} \cong MPa$$

- Mechanical properties of metals are almost always given in MPa or ksi.

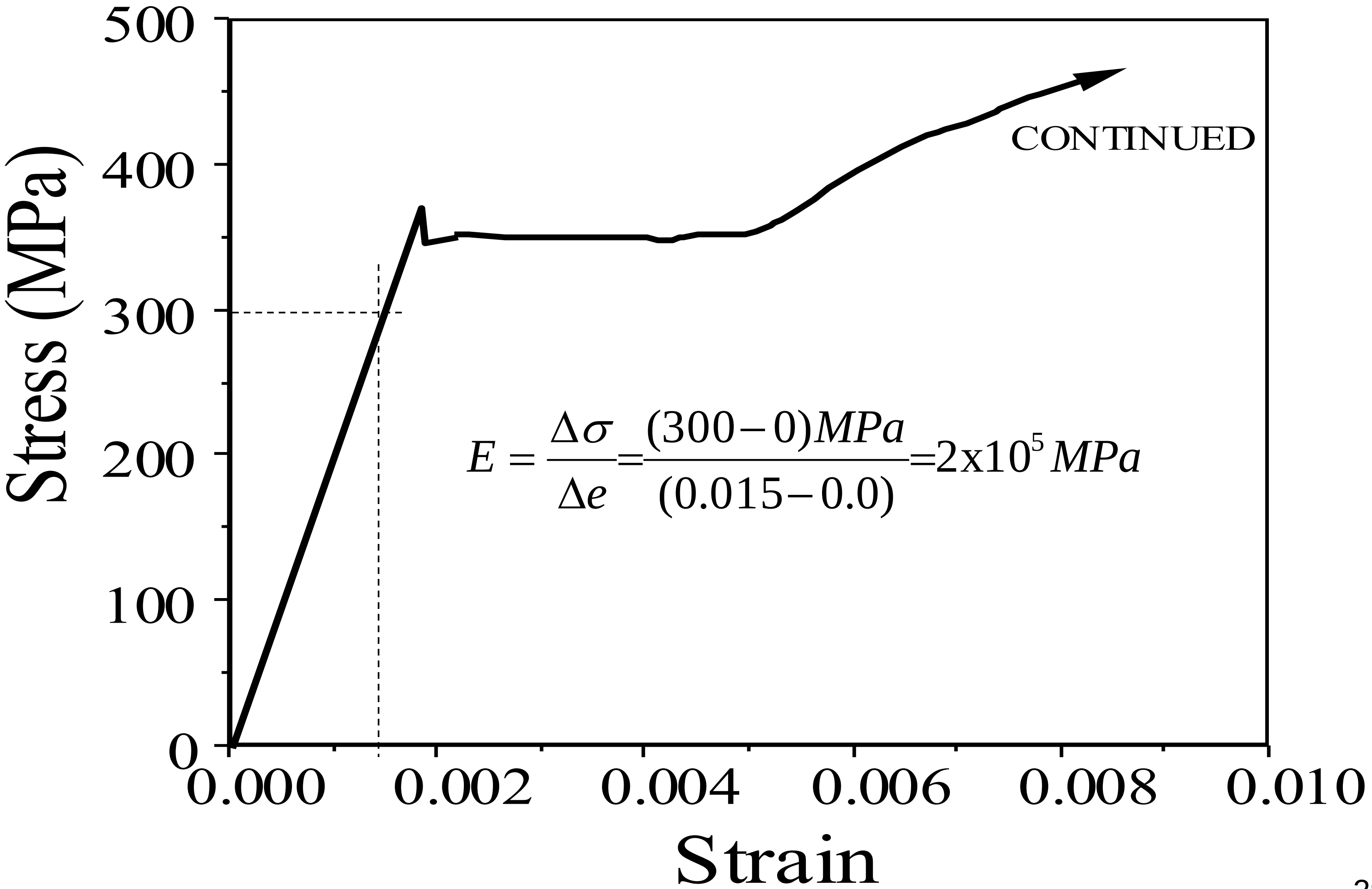
- 1000 psi = 1 ksi = 6.89 MPa

Hooke's law – Elastic deformation

- Elastic deformation is not permanent; it means that when the load is removed, the part returns to its original shape and dimensions.
- For most metals, the elastic region is linear. For some materials, including metals such as cast iron, polymers, and concrete, the elastic region is non-linear.
- If the behavior is linear elastic, or nearly linear-elastic, Hooke's Law may be applied:
- Where E is the modulus of elasticity (MPa)

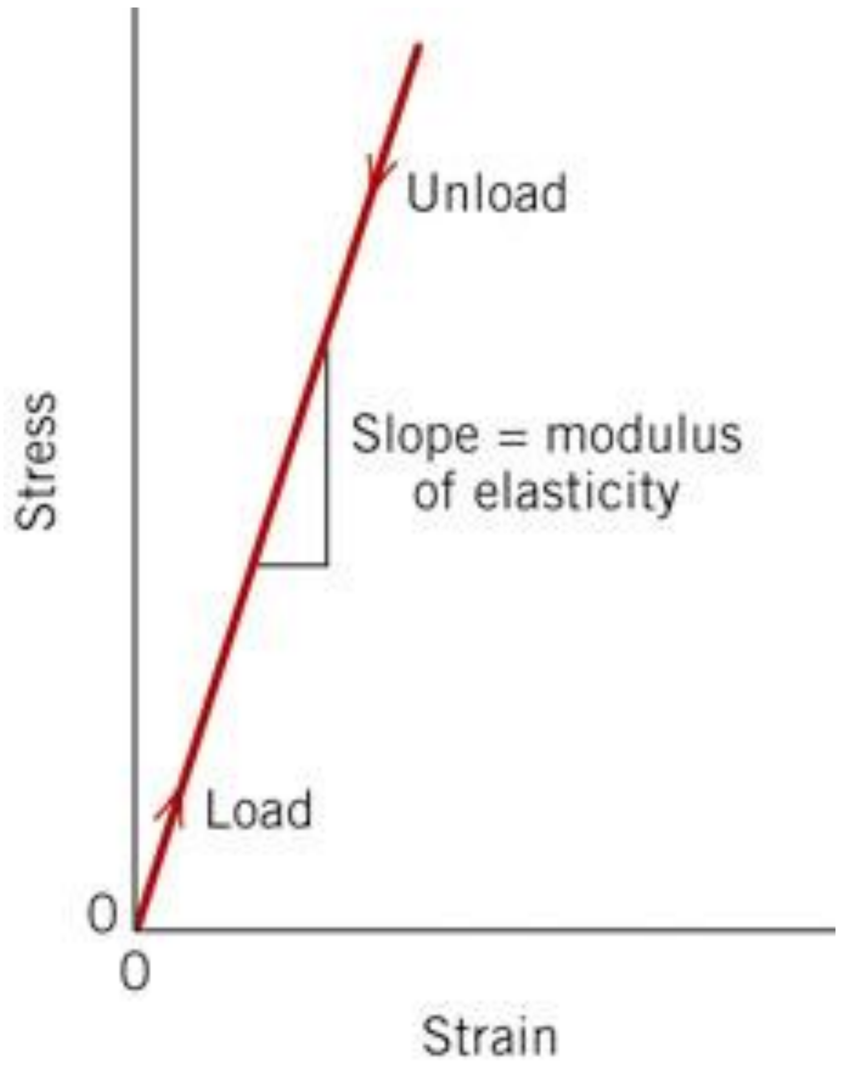
$$\sigma = Ee$$

Modulus of elasticity – Stiffness (E)

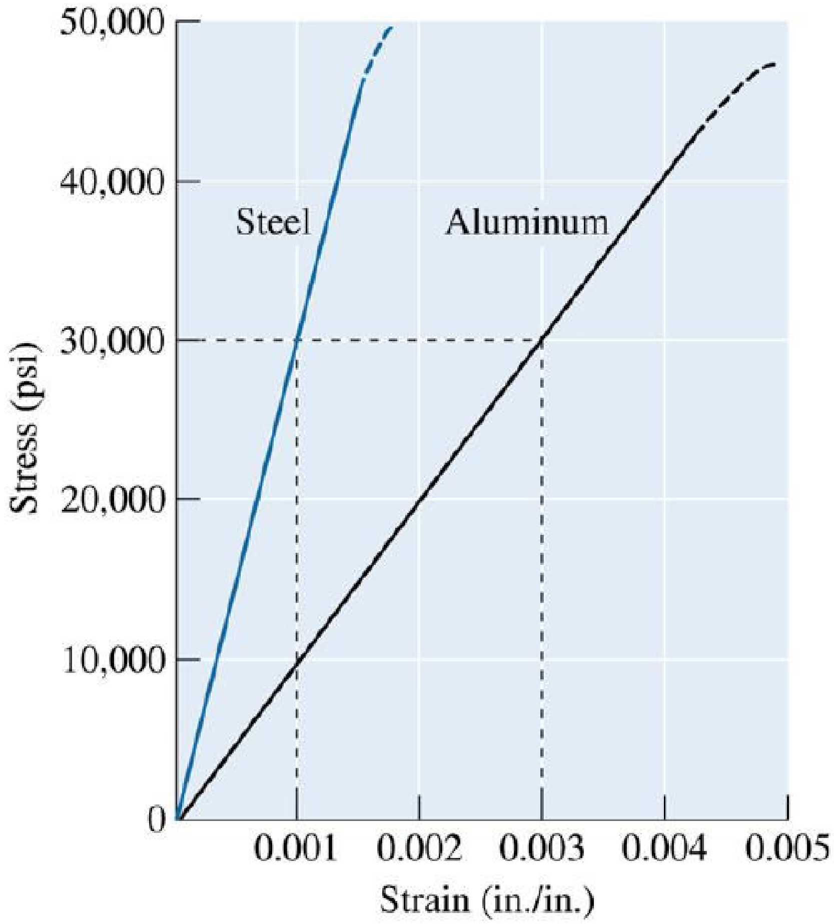


$$E = \frac{\Delta\sigma}{\Delta e} = \frac{(300-0)MPa}{(0.015-0.0)} = 2x10^5\,MPa$$

Stress / Strain Curve

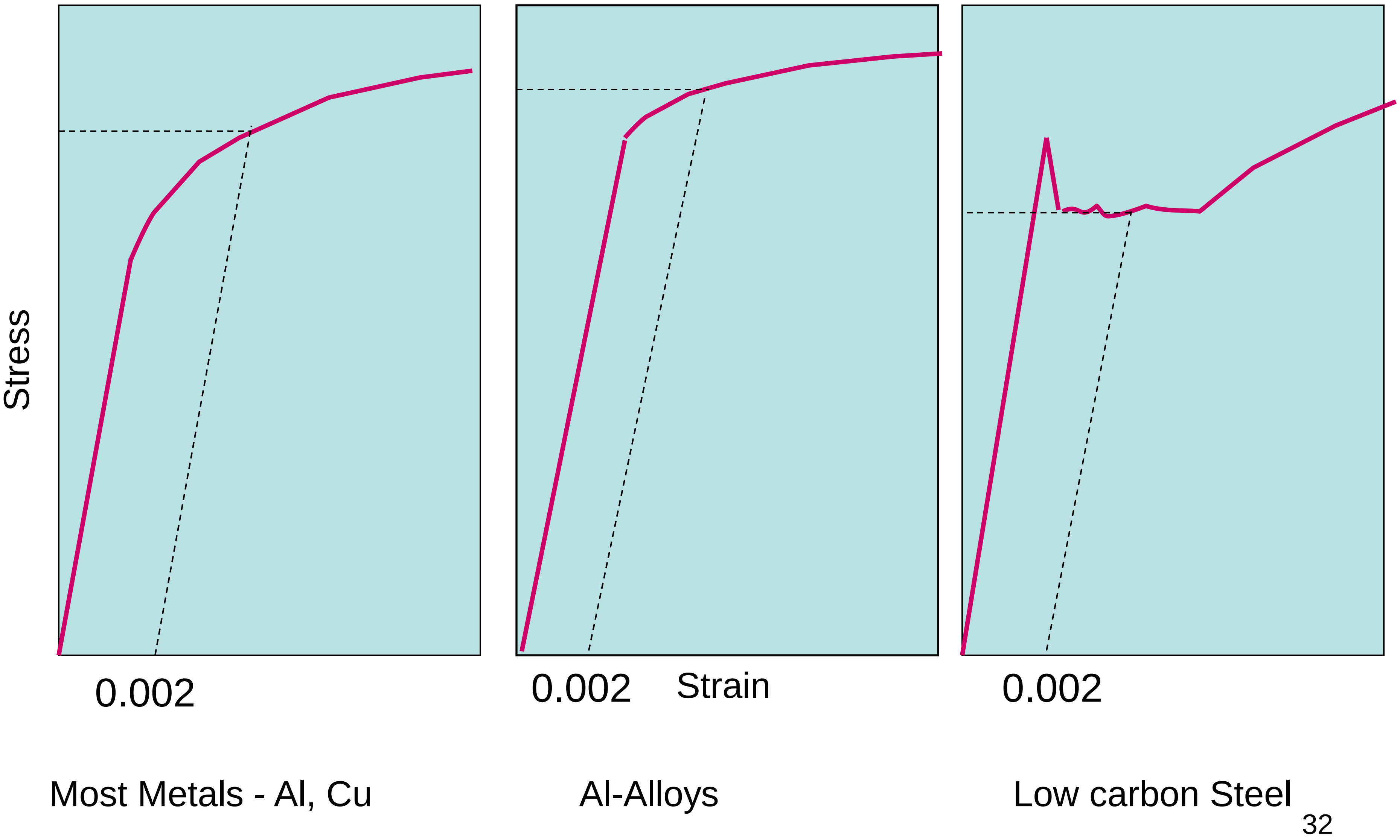


Stiffness of St vs. Al

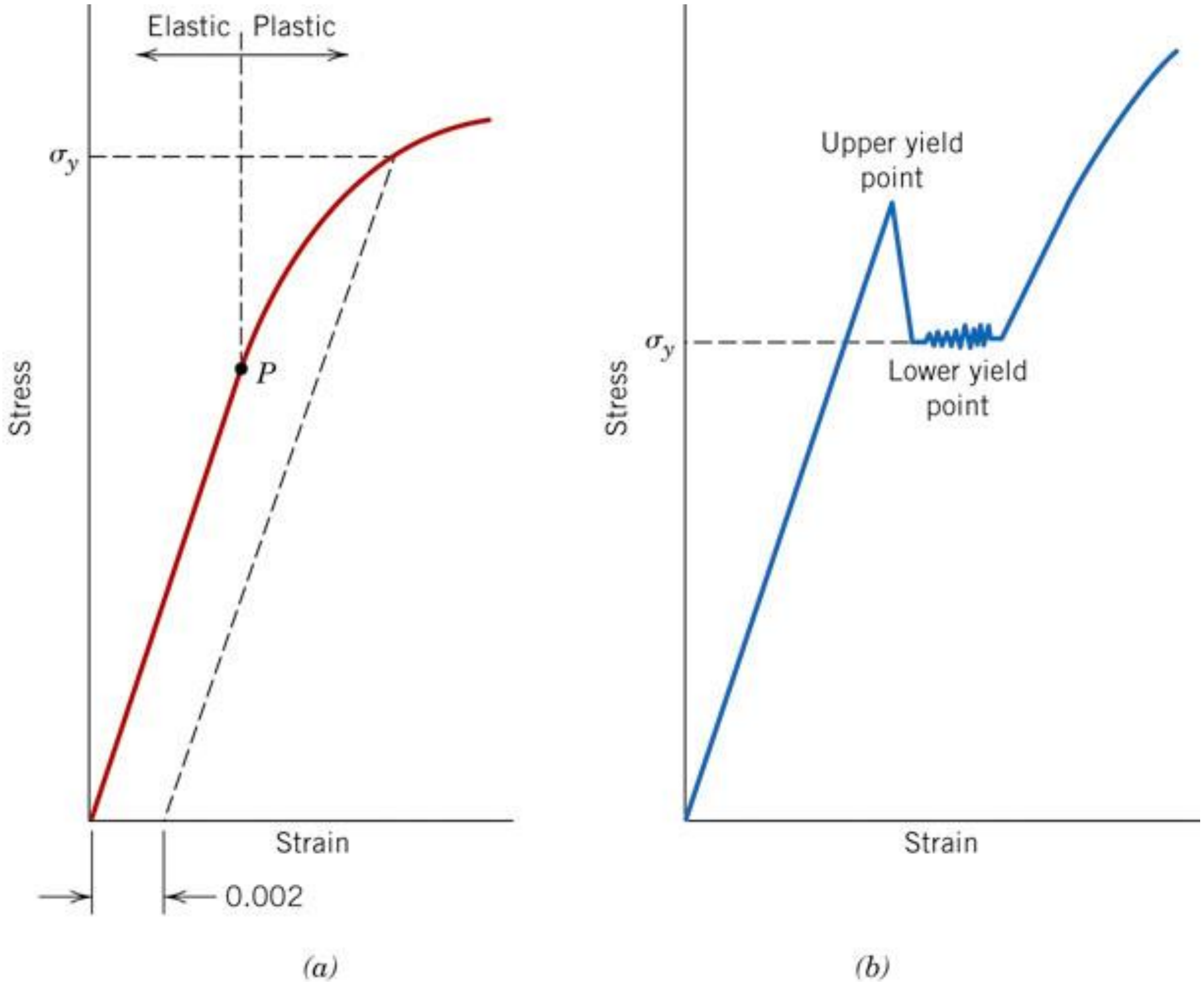


Comparison of the elastic behavior of steel and aluminum. For a given stress, aluminum deforms elastically three times as much as does steel.

Yield stress - Plastic deformation



Comparison


Elastic
Plastic
σ_y
P
Stress
Strain
0.002
(a)
Upper yield point
σ_y
Lower yield point
Stress
Strain
(b)

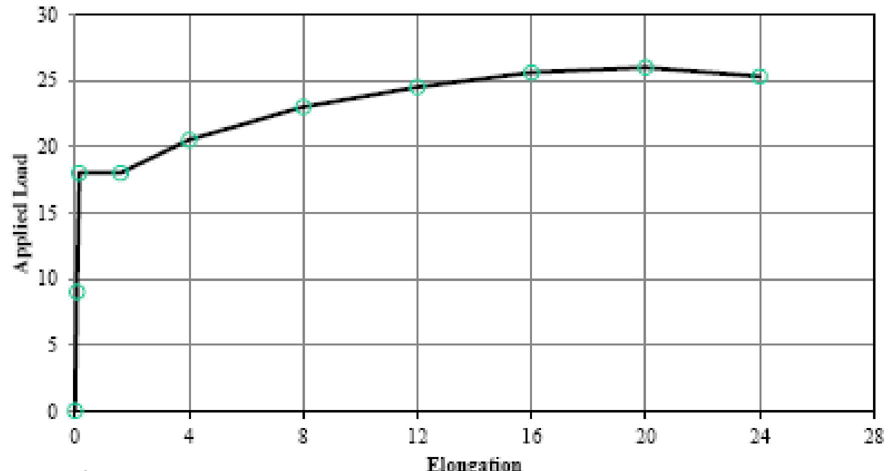
Solved Example

A static tension test was carried out on a plain steel rebar with circular cross section of diameter 8 mm. If the load-elongation readings were given the following table, then draw the load-deformation relation. Calculate the yield strength, the UTS 'ultimate tensile strength' and the percentage of elongation of the specimen.

Load (kN)	**0.0**	**9.0**	**18.0**	**18.0**	**20.5**	**23.0**	**24.5**	**25.6**	**26.0**	**25.3**
Elongation (mm)	**0.00**	**0.072**	**0.144**	**1.6**	**4.0**	**8.0**	**12.0**	**16.0**	**20.0**	**24.0**

Long Proportional Specimens:
gauge length = Lo = 10 do = 10*8 = 80 mm

Original Cross Sectional Area =
$Ao = \pi\ d^2 / 4 = \pi\ (8)^2 / 4 \quad = 50.30\ mm^2$



Yield Stress = σy = P_y / A_o = 18.0 * 1000 / 50.3 = 357 MPa

Ultimate Tensile Strength = UTS = = P_{max} / A_o = 26.0 * 1000 / 50.3 = 516= MPa

Percent age of elongation = $\frac{L_f - L_o}{L_o} \times 100 = \frac{24}{80} \times 100 = 30\%$