بسم الله الرحمن الرحيم

Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1st year

06.04.2019 – Week 9

On tensile testing considerations

Dr. Mahmoud Khedr

Outline

- Quiz
- Tensile testing practice
- Poisson's ratio & True stress-strain
- Temperature effects on the mechanical properties
- Effect of Grain size change on the tensile test results
- Hydrogen Embrittlement
- Effect of cold deformation & C%

Quiz

The following data was obtained from a tensile test on a specimen of 10mm diameter and gauge length 60mm.

Load (kN)	16	32	56	72	95	110	132	142	140	135
Extension (mm)	0.2	0.4	0.7	0.9	1.5	2.5	5.0	8.5	10.0	12.0

a) Draw the load-deflection diagram

Calculate the following:

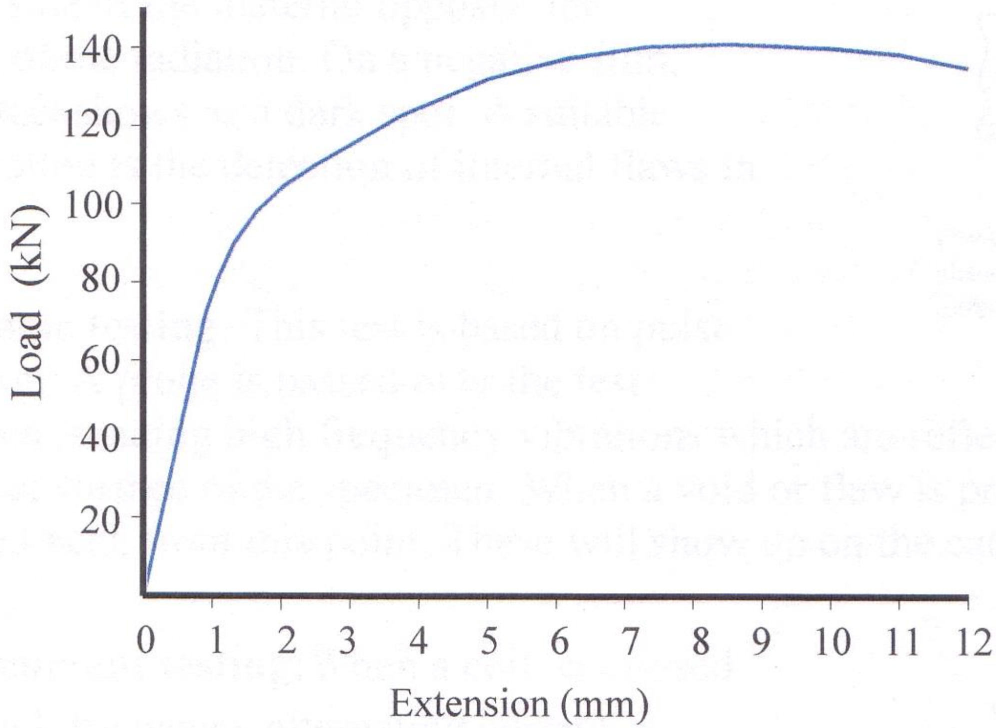
b) The modulus of Elasticity

c) The ductility %

d) The UTS

Load (kN)	16	32	56	72	95	110	132	142	140	135
Extension (mm)	0.2	0.4	0.7	0.9	1.5	2.5	5.0	8.5	10.0	12.0

a)



b) E = σ/ε = (32,000/78.55) / (0.4/60) = ______ MPa

c) The ductility % = 12 / 60 × 100% = _______ %

d) The UTS = 142,000/78.55 = ______ MPa

Youngs Modulus for Load – extension graph

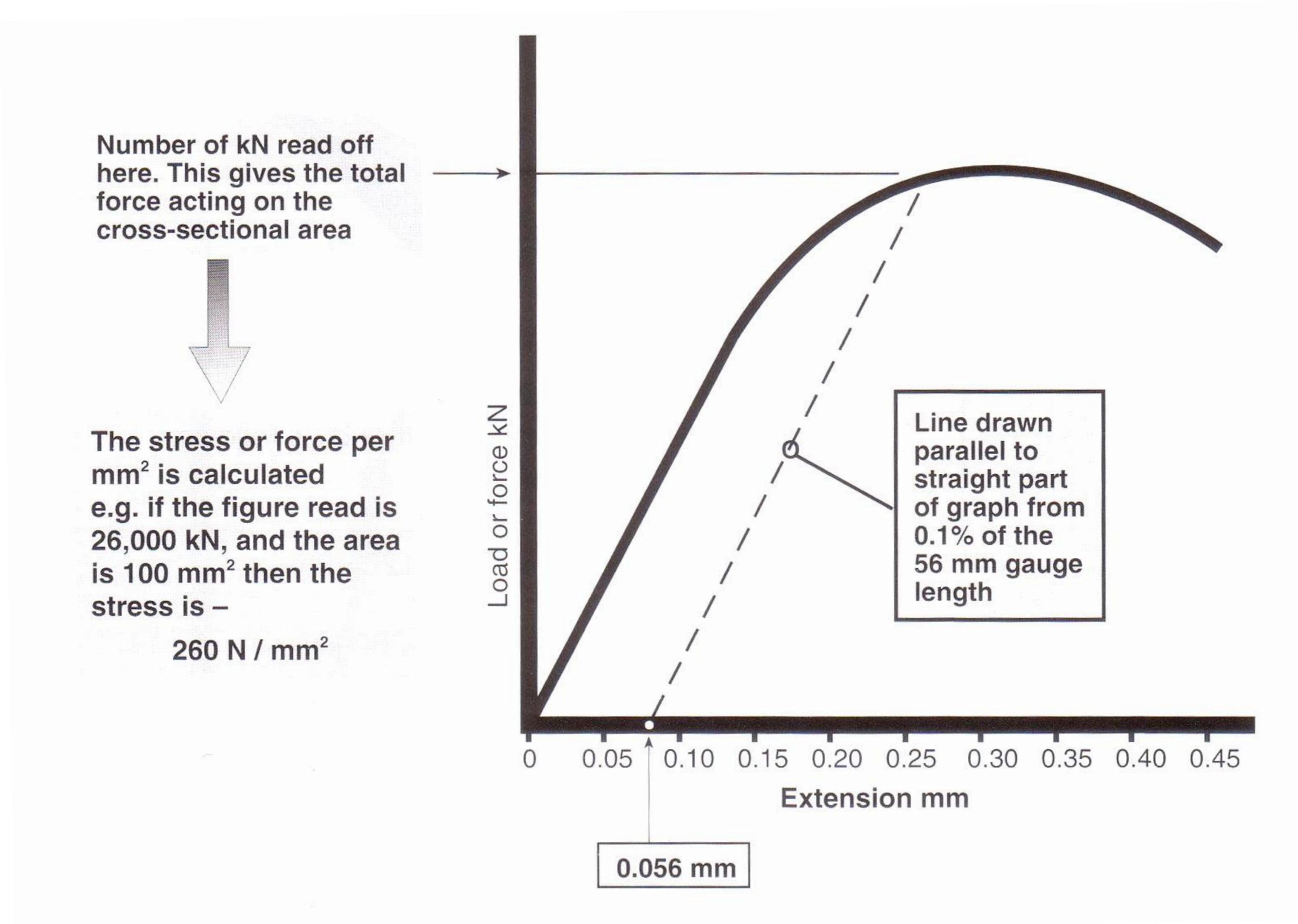
Youngs Modulus: Select point on elastic region of diagram eg. **(32,0.4)**
Diameter = 10mm, Gauge length = 60mm.

$$\text{Youngs Modulus} = \frac{Stress}{Strain} \qquad \text{Stress} = \frac{Load}{CSA} = \frac{32}{78.55} = 0.407\text{kN}/\text{mm}^2$$

$$\text{Strain} = \frac{Extension}{OrigLgth} = \frac{0.4}{60} = 0.0067$$

$$\text{Youngs Modulus} = \frac{0.407}{0.0067} = 60.7\ \text{kN}/\text{mm}^2$$

Proof stress for Load – Extension graph



Proof stress for Stress – Strain graph

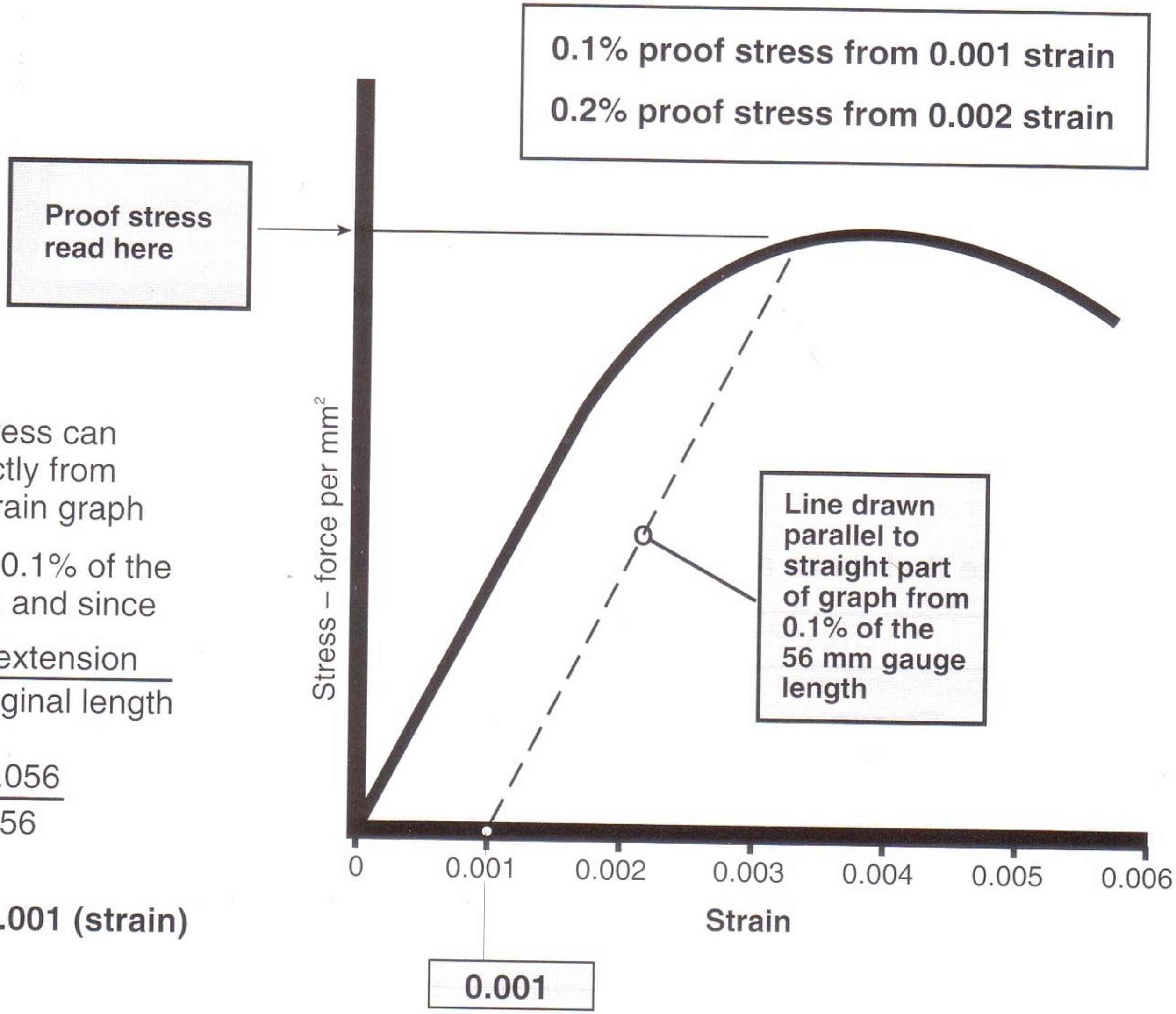
The proof stress can be read directly from the stress-strain graph

0.056 mm is 0.1% of the gauge length and since

$$\text{strain} = \frac{\text{extension}}{\text{original length}}$$

$$0.1\% = \frac{0.056}{56}$$

$$= \textbf{0.001 (strain)}$$



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Watching a Tensile testing practice

1

2

3

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Poisson’s ratio & true stress-strain

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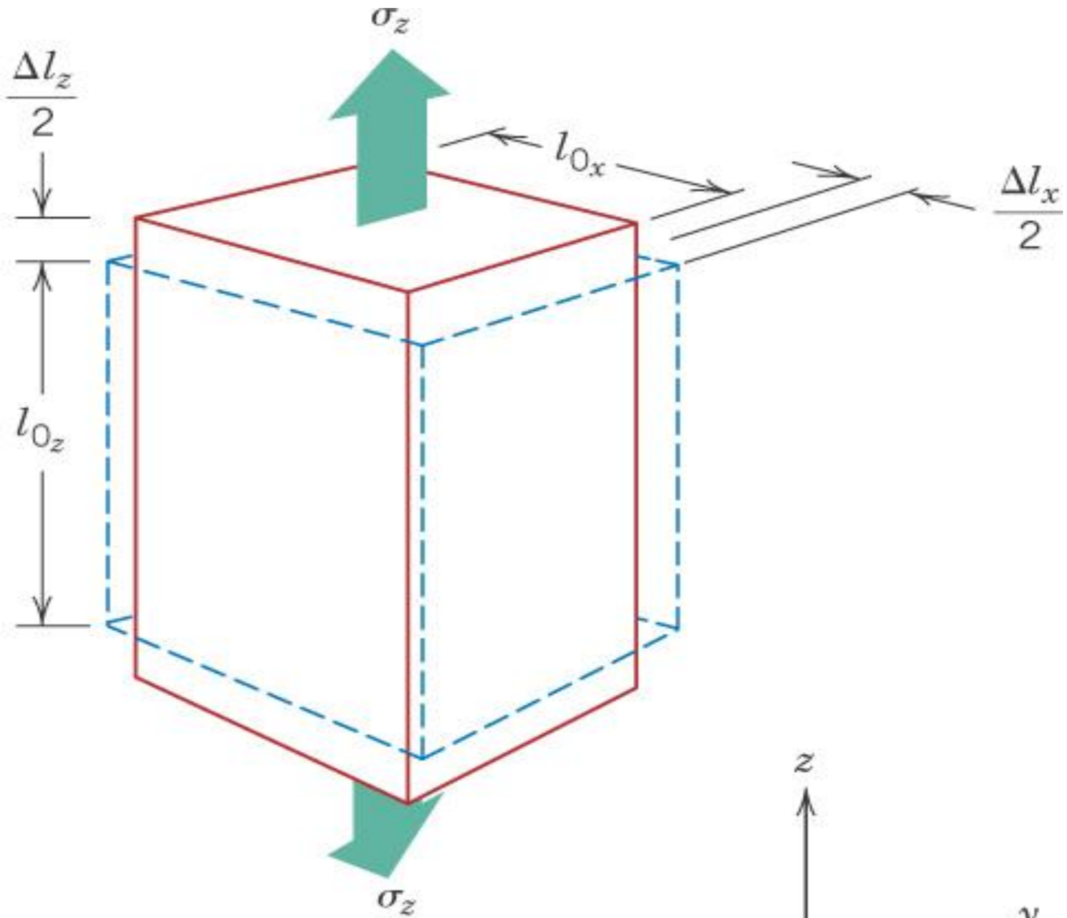
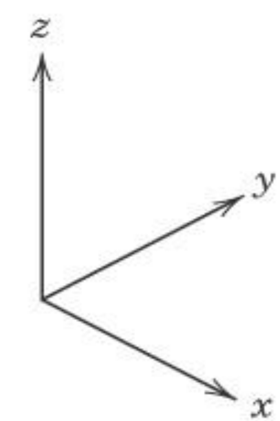
Axial (z) elongation (positive strain) and lateral (x and y) contractions (negative strains) in response to an imposed tensile stress.

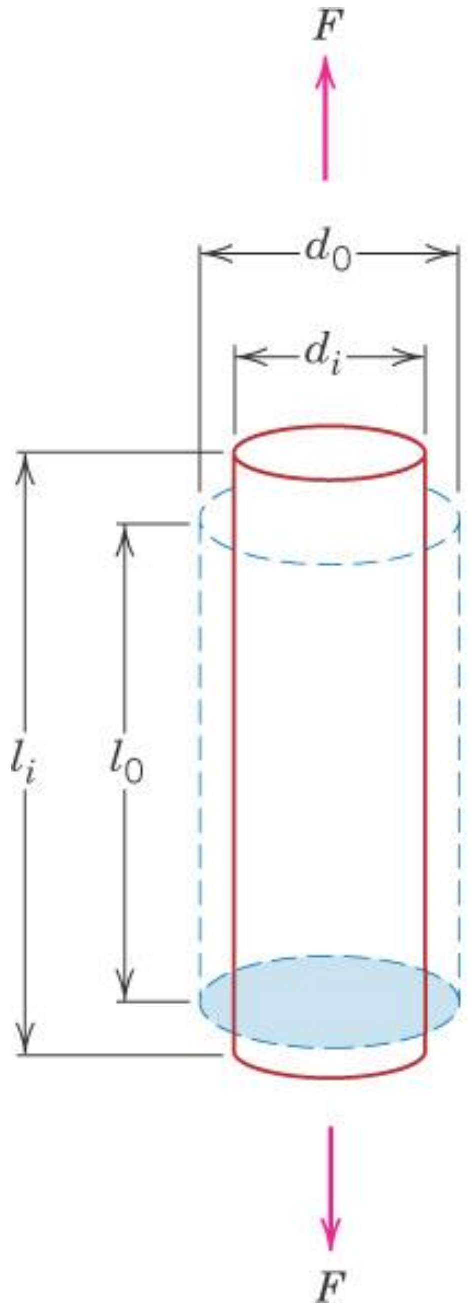


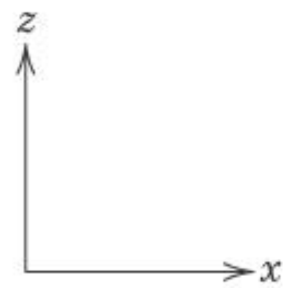


$$\frac{\epsilon_z}{2} = \frac{\Delta l_z/2}{l_{0_z}}$$

$$-\frac{\epsilon_x}{2} = \frac{\Delta l_x/2}{l_{0_x}}$$

Longitudinal strain vs. lateral strain



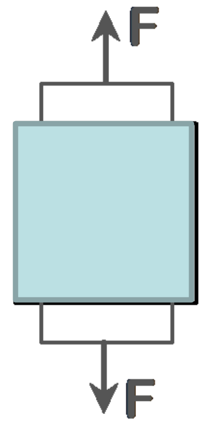


$$\epsilon_z = \frac{\Delta l}{l_0} = \frac{l_i - l_0}{l_0}$$

$$\epsilon_x = \frac{\Delta d}{d_0} = \frac{d_i - d_0}{d_0}$$

Strain is dimensionless.

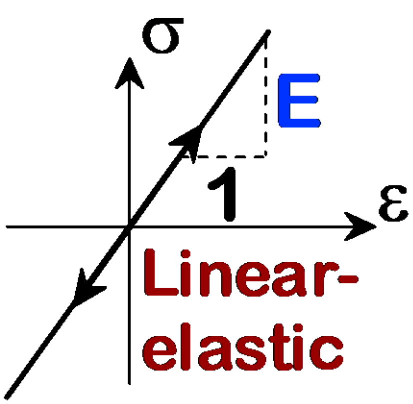
Linear Elastic Properties

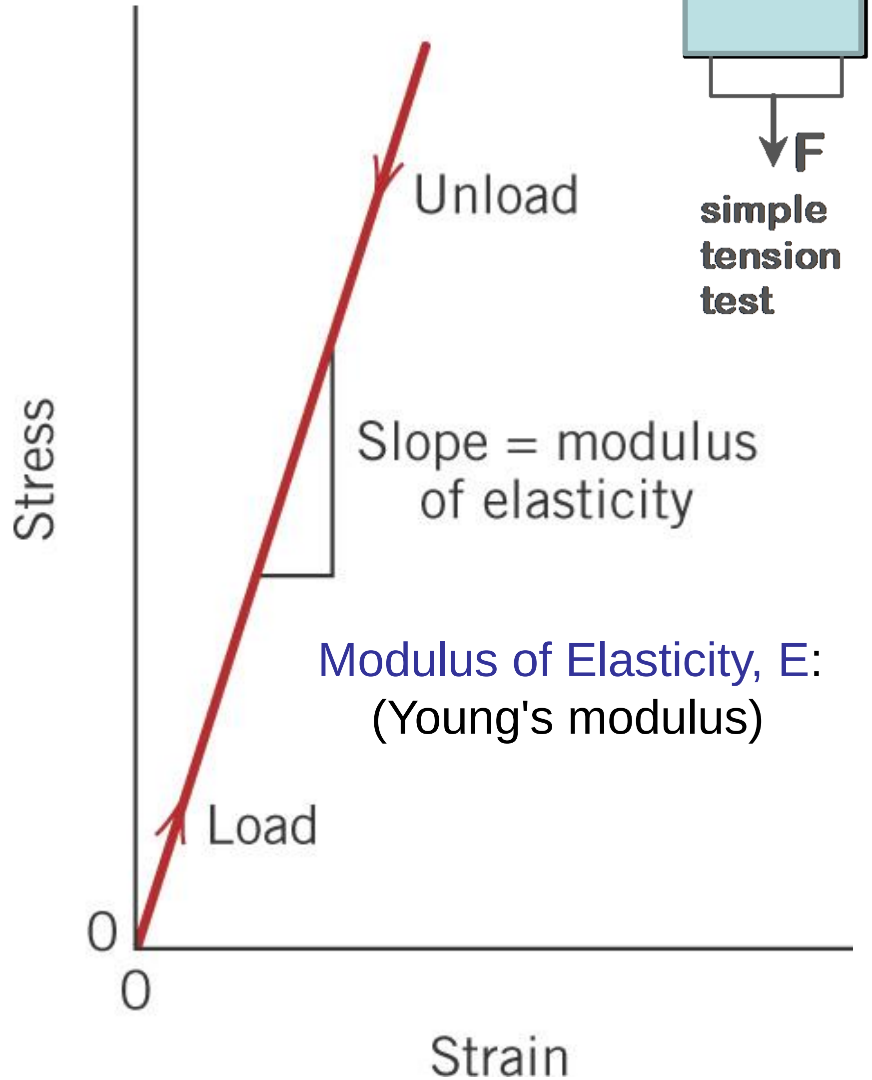


- **Hooke's Law**: $\sigma = \mathbf{E}\,\varepsilon$

- **Poisson's ratio**: $\nu = \varepsilon_x/\varepsilon_y$

  metals: ν ~ 0.33
  ceramics: ν ~0.25
  polymers: ν ~0.40





Modulus of Elasticity, E:
(Young's modulus)

Units:
E: [GPa] or [psi]
ν: dimensionless

Modified Hooke's law

Generalised Hooke's Law

Formula:

$$\varepsilon_x = \frac{1}{E}[\sigma_x - v(\sigma_y + \sigma_z)]$$

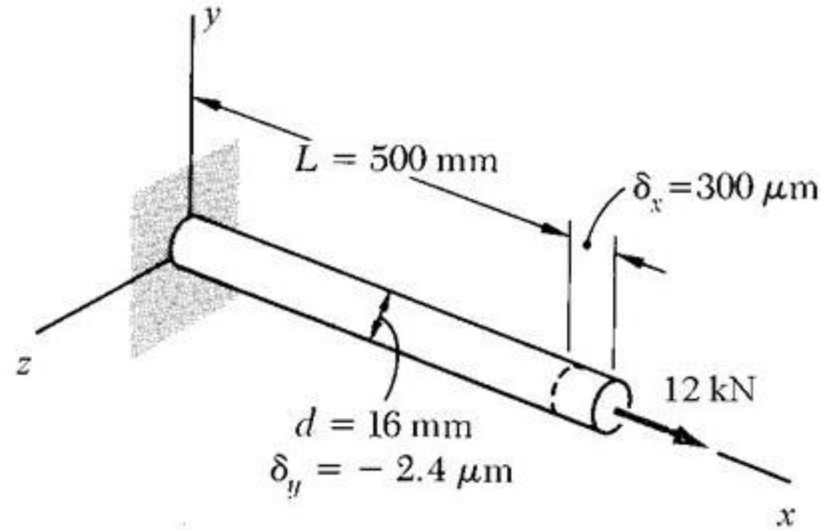
$$\varepsilon_y = \frac{1}{E}[\sigma_y - v(\sigma_x + \sigma_z)]$$

$$\varepsilon_z = \frac{1}{E}[\sigma_z - v(\sigma_x + \sigma_y)]$$

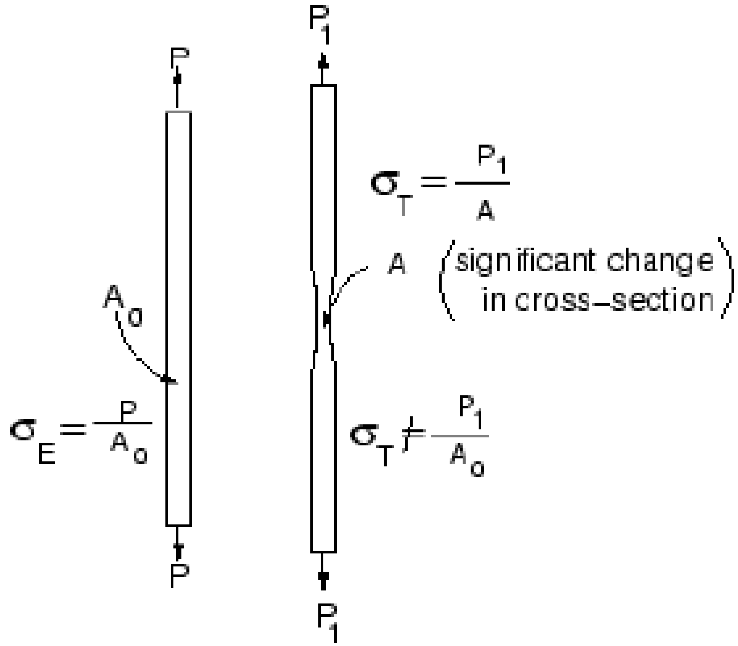
As you can see, the strain is affected by stresses in the perpendicular directions, via the Poisson's ratio (v)

Assignment

A 500 mm long, 16 mm diameter rod made of a homogenous, isotropic material is observed to increase in length by 300 μm, and to decrease in diameter by 2.4 μm when subjected to an axial 12 kN load. Determine the modulus of elasticity and Poisson's ratio of the material.



Governing rules



Volume is constant : $V_f = V_o$

$A_f L_f = A_o L_o$

$A_f = A_o L_o / L_f$ **OR** $A_o / A_f = L_f / L_o$

$\varepsilon = (L_f - L_o) / L_o = L_f / L_o - 1$

⇒ $\varepsilon = A_o / A_f - 1$ ⇒ $A_f = A_o(1+\varepsilon)$

Governing rules

True Stress and Strain:

- True stress:

$$\sigma_T = \frac{F}{A_i}$$

- True strain:

$$\epsilon_T = \ln\frac{l_i}{l_0}$$

- Conversion of engineering stress to True stress:

$$\sigma_T = \sigma(1 + \epsilon)$$

- Conversion of engineering strain to true strain:

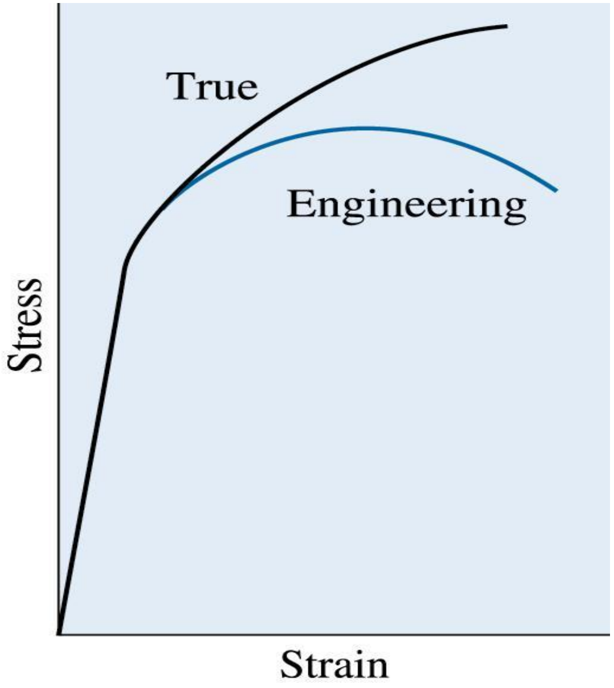
$$\epsilon_T = \ln(1 + \epsilon)$$

- True stress-strain relationship in the plastic region to the point of necking:

$$\sigma_T = K\epsilon_T^n$$

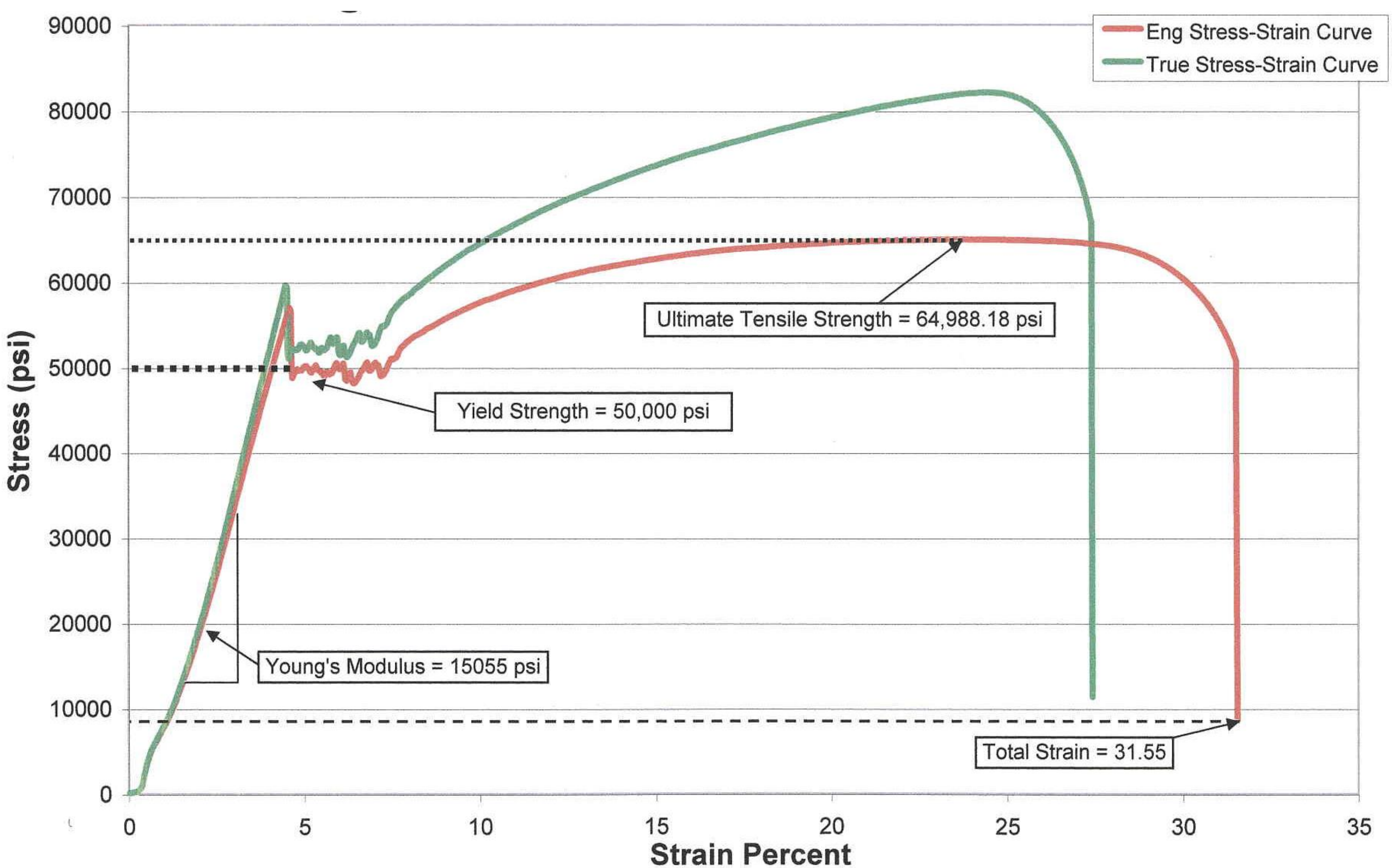
True Stress and True Strain

- True stress The load divided by the actual cross-sectional area of the specimen at that load.
- True strain The strain calculated using actual and not original dimensions, given by $\varepsilon_t \ln(l/l_0)$.



•The relation between the true stress-true strain diagram and engineering stress-engineering strain diagram.
•The curves are identical to the yield point.

Stress-Strain Results for Steel Sample



Example 3: True Stress and True Strain Calculation

Compare engineering stress and strain with true stress and strain for the aluminum alloy in Example 1 at (a) the maximum load. The diameter at maximum load is 0.497 in. and at fracture is 0.398 in.

Example 3 SOLUTION

At the tensile or maximum load:

$$\text{Engineering stress} = \frac{F}{A_0} = \frac{8000 \text{ lb}}{(\pi/4)(0.505 \text{ in.})^2} = 40{,}000 \text{ psi}$$

$$\text{True stress} = \frac{F}{A} = \frac{8000}{(\pi/4)(0.497)^2} = 41{,}237 \text{ psi}$$

$$\text{Engineering strain} = \frac{l - l_0}{l_0} = \frac{2.120 - 2.000}{2.000} = 0.060 \text{ in./in.}$$

$$\text{True strain} = \ln\left(\frac{l}{l_0}\right) = \ln\left(\frac{2.120}{2.000}\right) = 0.058 \text{ in./in.}$$

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Temperature effects on the mechanical properties

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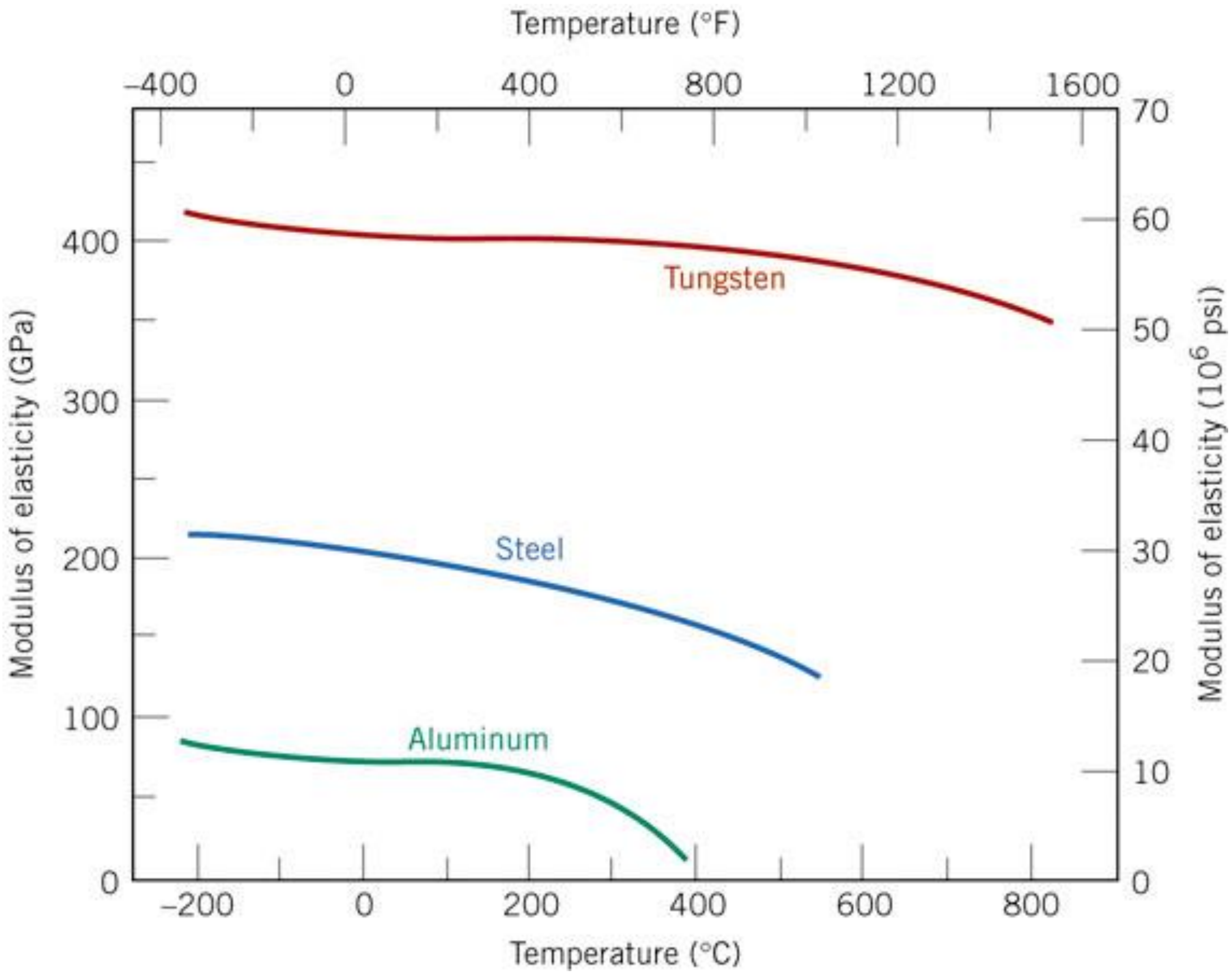
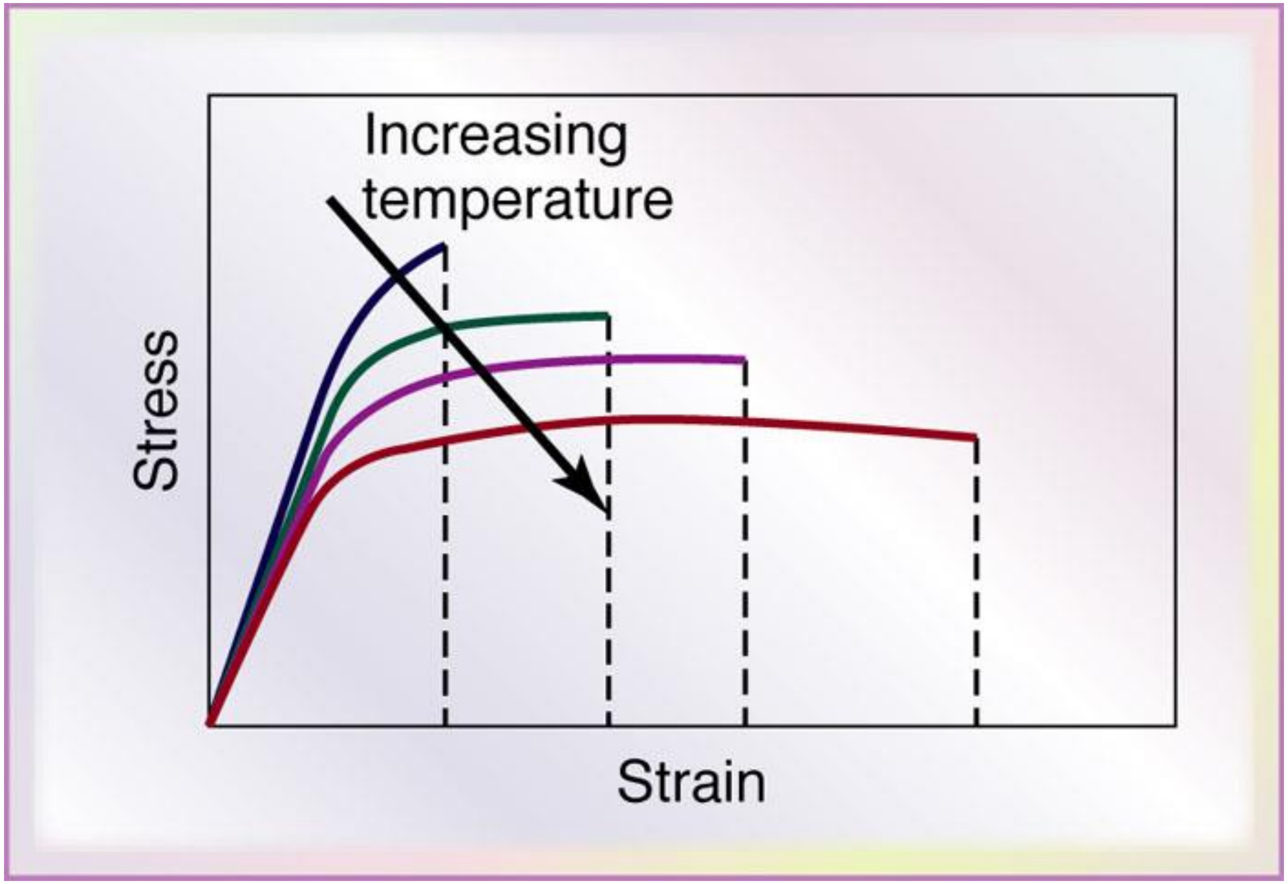
Elasticity (E) ‘v’ Temperature

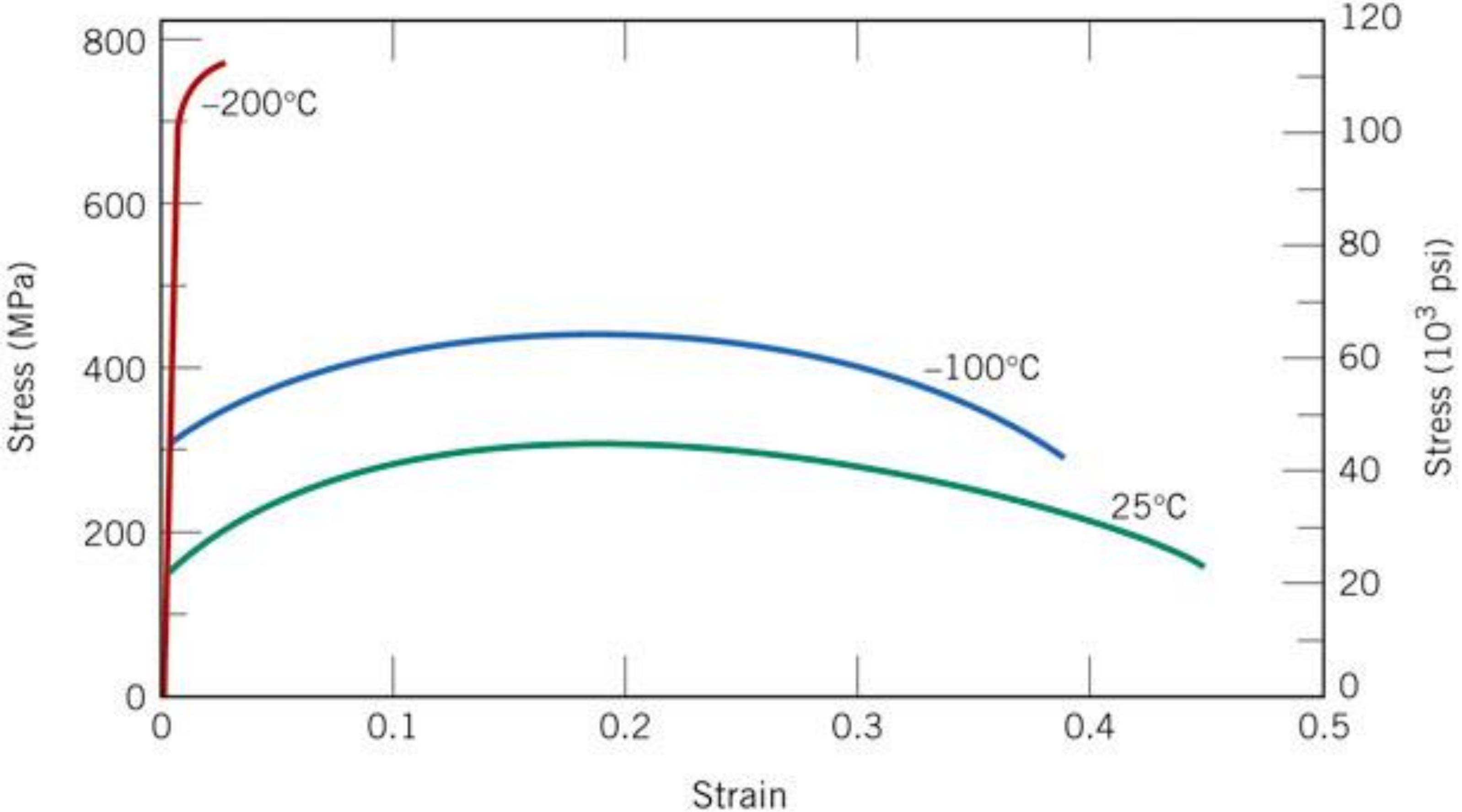


Temperature Effects on Stress-strain Curves



Typical effects of temperature on stress-strain curves. Note that temperature affects the modulus of elasticity, the yield stress, the ultimate tensile strength, and the toughness (area under the curve) of materials.

Iron at 3 temp.



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Effect of Grain size change on the tensile test results

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Strengthening of FCC structures

Traditional methods: reduction of grain sizes and dispersed precipitates, etc.

New approach:
Introduction of coherent twin boundaries (CTBs);
-Electro-deposition
-Thermo-mechanical processing

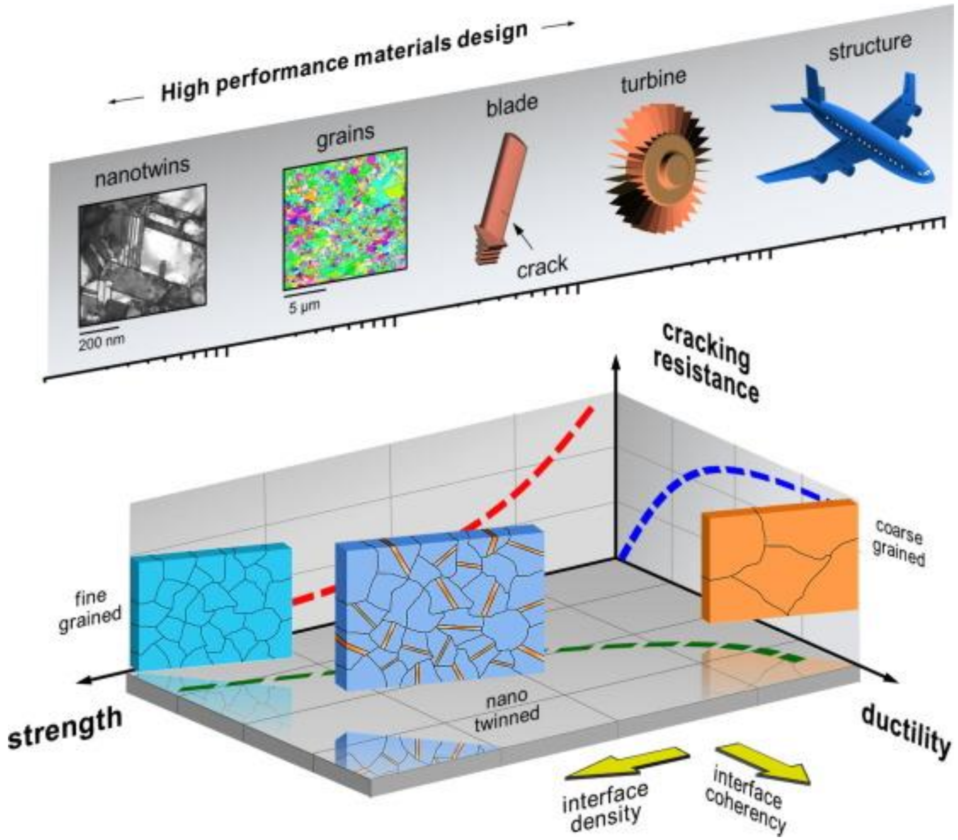


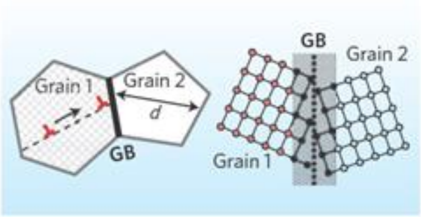
Figure 1.4. Increases of the strength, ductility and cracking resistance enhance achieving superior mechanical attributes

P. Chowdhury, H. Sehitoglu. R. Rateick, Curr. Opin. Sol. Stat. Mater. Sci. 20 (2016) 140–150.

Coherent twin boundaries (CTBs)

Twin boundaries (TBs) are planar defects which can hinder dislocations mobility.

A material containing CTBs is called a nano-twinned material.



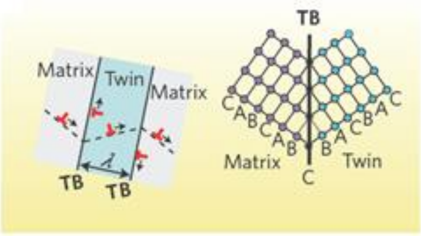


Figure 1.5 TBs hinder dislocation motion similar to GBs.

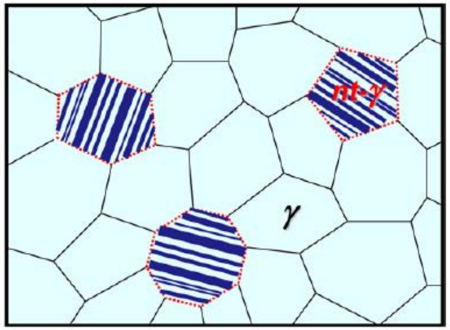


Figure 1.6 Embed TWIP steels with CTBs.

J. R. Greer, It's all about imperfections, Nat. mater. 12 (2013) 689–690.

K. Lu, F. K. Yan, H. T. Wang, N. R. Tao, Scr. Mater. 66 (2012) 878–883.

Strengthening of ternary Fe-C-Mn steel

Reduction of grain sizes.

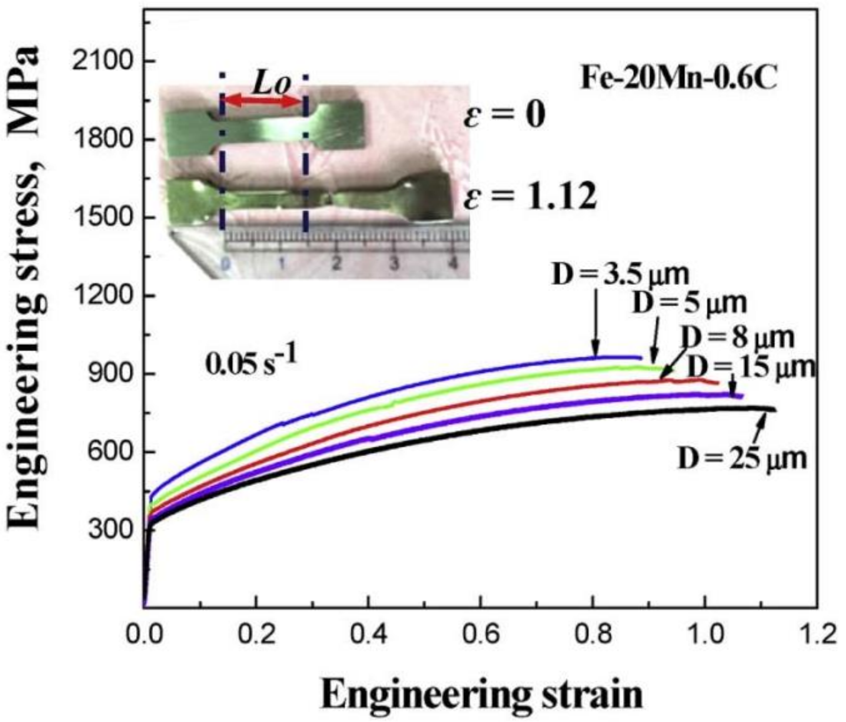


Figure 2.14. Reduction of grain sizes in ternary Fe-C-Mn steel increases its strength.

F.K. Yan, G.Z. Liu, N.R. Tao, K. Lu, Acta Mater. 60 (2012) 1059–1071.

Y. F. Shen, N. Jia, R. D. K. Misra, L. Zuo, Acta Mater. 103 (2016) 229-242.

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Strain rate sensitivity

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Strain rate sensitivity of austenitic steels

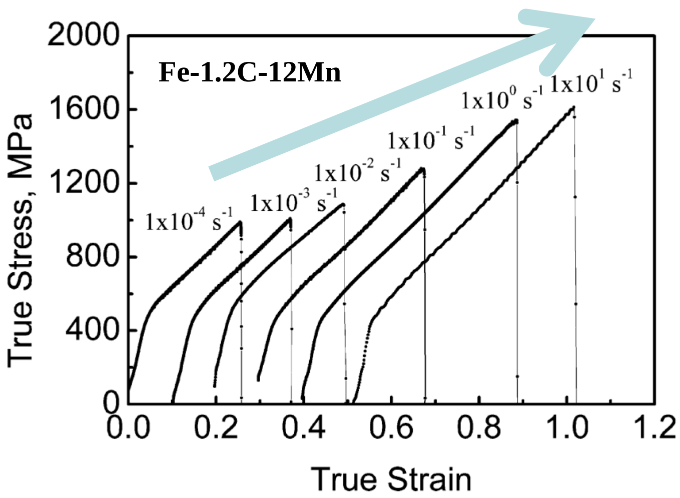

Figure 2.6 the strength and ductility of ternary Fe-1.2C-12Mn increase with a strain rate increase.

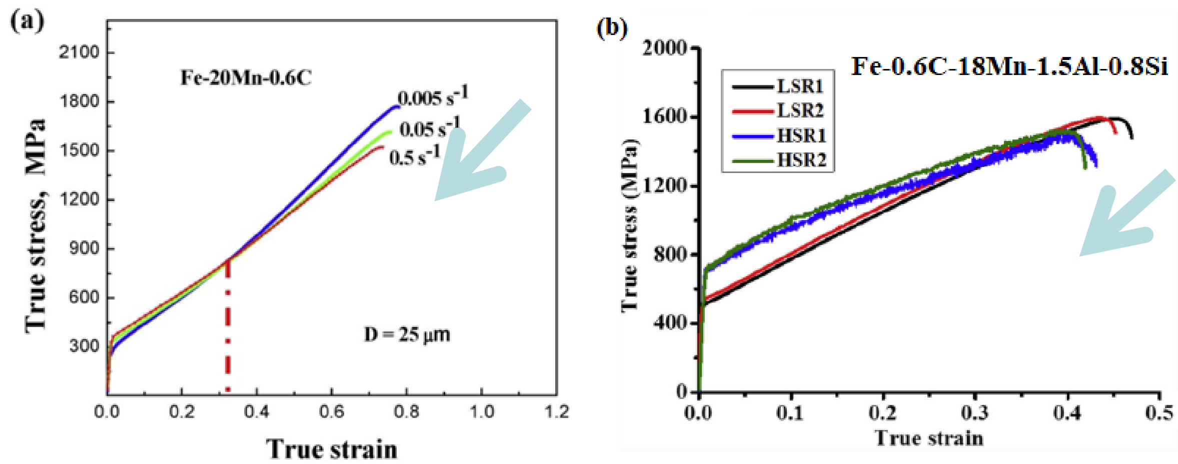

Figure 2.7 Effect of a strain rate rise on the mechanical behavior of: (a) 0.6C-20Mn-steel, (b) 0.6C-18Mn-1.5Al-0.6Si .

DSA disappears & Temperature rises !

F.C. Liu, Z.N. Yang, C. L. Zheng, F. C. Zhang, Scr. Mater. 66 (2012) 431-434.
Z. Y. Liang, X. Wang, W. Huang, M.X. Huang, Acta Mater. 88 (2015) 170-179.
Y. F. Shen, N. Jia, R. D. K. Misra, L. Zuo, Acta Mater. 103 (2016) 229-242.

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Hydrogen Embrittlement

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Hydrogen Embrittlement (HE) susceptibility

HE refers to the degradation in the mechanical properties caused by hydrogen, which leads to premature failure of the metallic materials.

Different grades of high strength steels are susceptible to HE when it services in H-environment; the diffusible hydrogen facilitates dislocations glide and planar slipping which results in a reduction of the strength and ductility of the material.

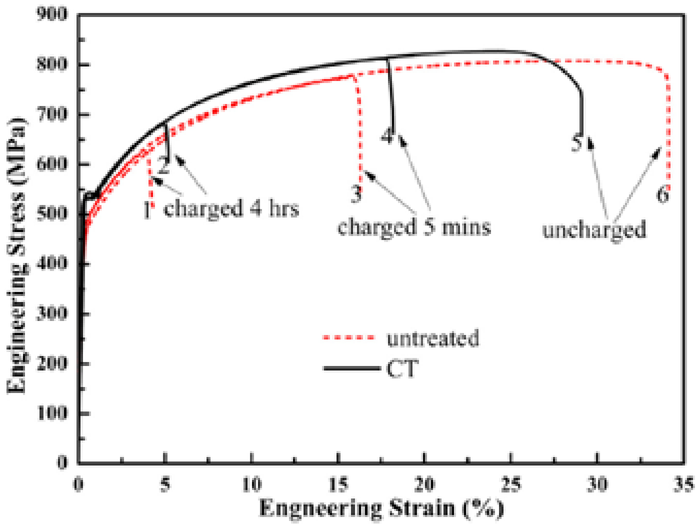

Figure 1.7. H-charging of TRIP steels severely decreases its strength and ductility.

M. Koyama, E. Akiyama, Y.-K. Lee, D. Raabe, K. Tsuzaki, Int. J. Hydrog. Energy 42 (2017) 12706-12723.

X. Zhu, W. Li, H. Zhao, L. Wang, X. Jin, Int. J. Hydrog. Energy 39 (2014) 13031–13040.

Ternary Fe-C-Mn steel severely suffers HE

The strength and ductility of Fe-0.6C-18Mn reduced by half value after in-situ charging with hydrogen.

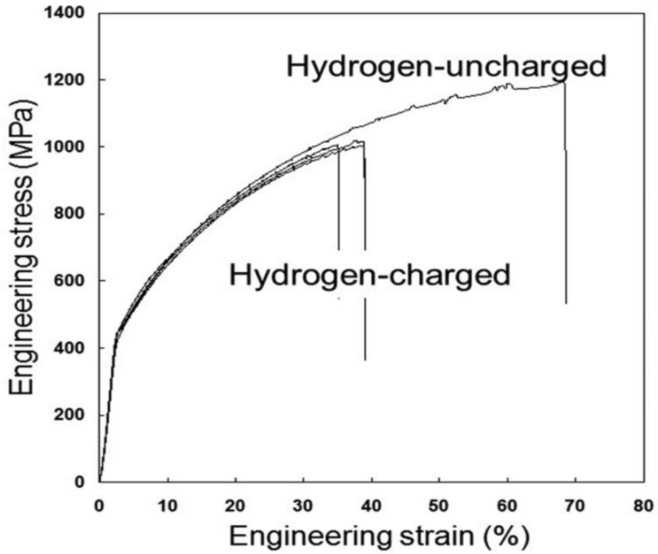

Figure 1.8. Stress-strain curves with and without hydrogen: (a) Fe-0.6C-18Mn

M. Koyama, E. Akiyama, K. Tsuzaki, Cor. Sci. 54 (2012) 1–4.
M. Koyama, E. Akiyama, Y.-K. Lee, D. Raabe, K. Tsuzaki, Int. J. Hydrog. Energy 42 (2017) 12706-12723

HE in Fe-1.2C-12Mn austenitic steels

Hydrogen enhances dislocations mobility; it locally initiates mechanical twins early; results in a premature failure due to a stress concentration on the randomly formed twin boundaries.

Without hydrogen: fracture surface showed ductile fracture features.

With hydrogen: hydrogen enhanced crack formation due to stress concentration on the randomly formed twin boundaries.

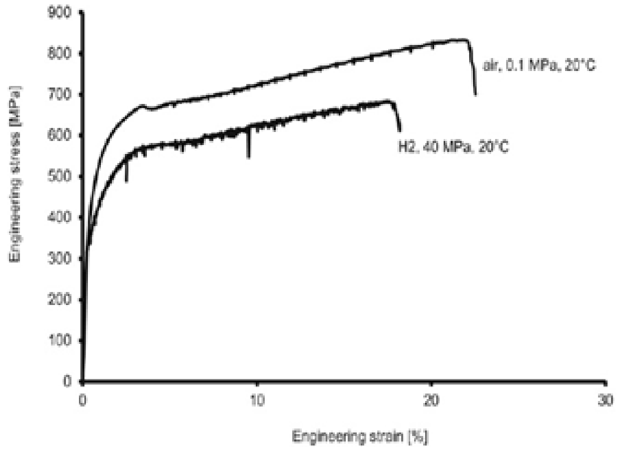

Figure 2.17 H-charging decreases the strength and ductility of Hadfield steel.

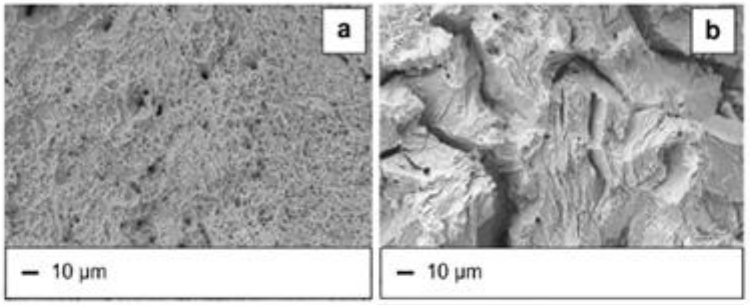

Figure 2.18 fractured surfaces of Hadfield steel (a, b) without and with H, .

T. Michler, C. S. Marchi, J. Naumann, S. Weber, M. Martin, Int. J. Hydrog. Energy 37 (2012) 16231–16246.

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Effect of cold deformation & C% on the tensile testing results

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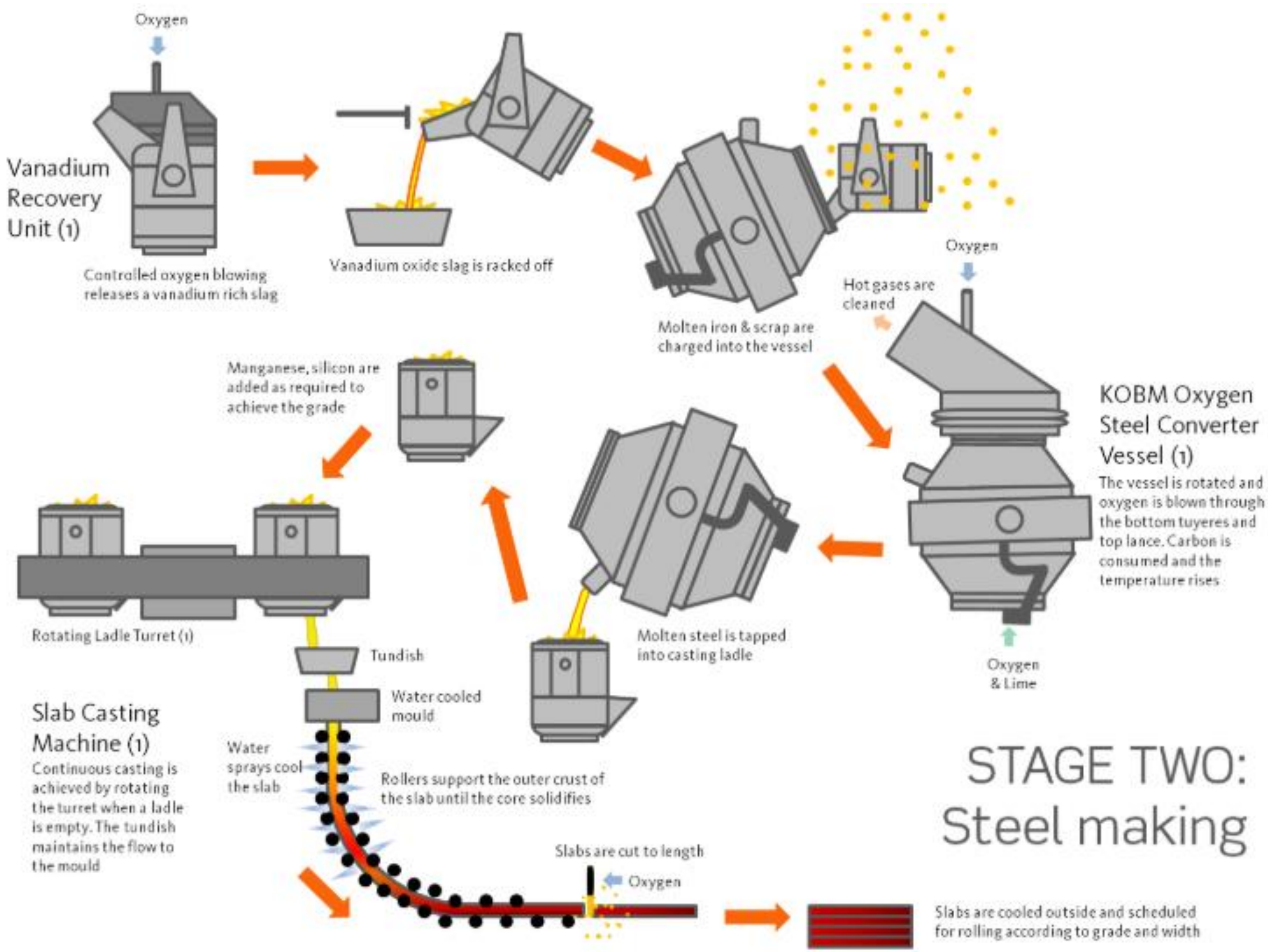
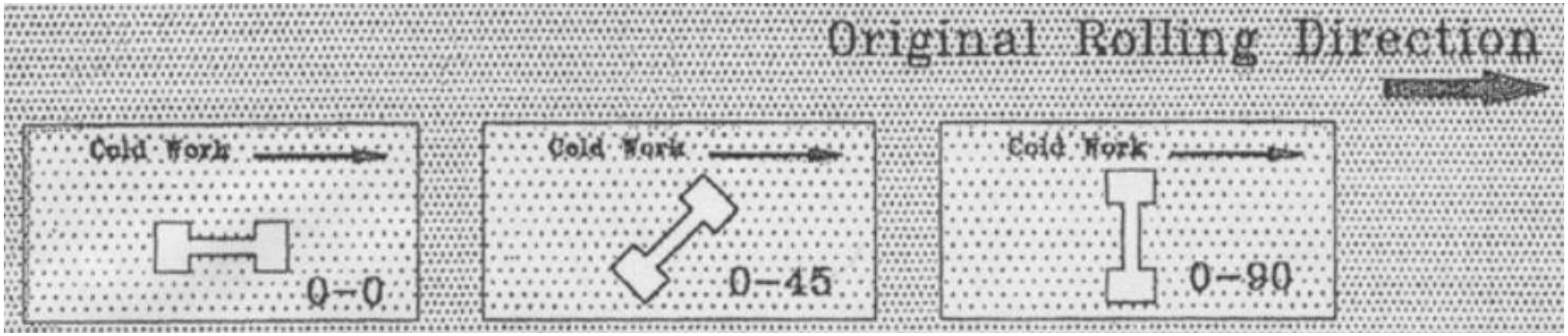
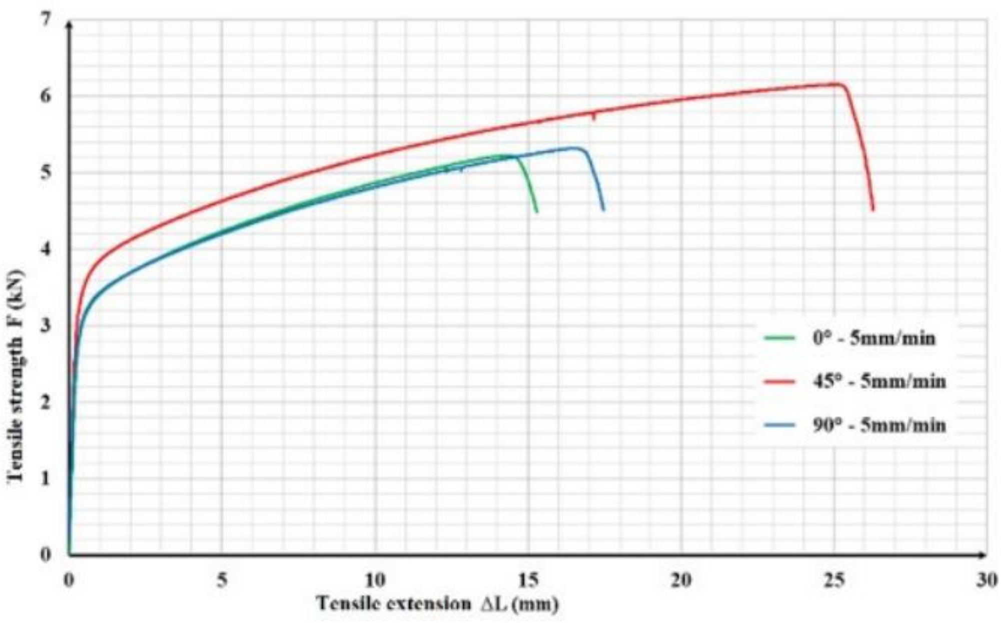
Steel making



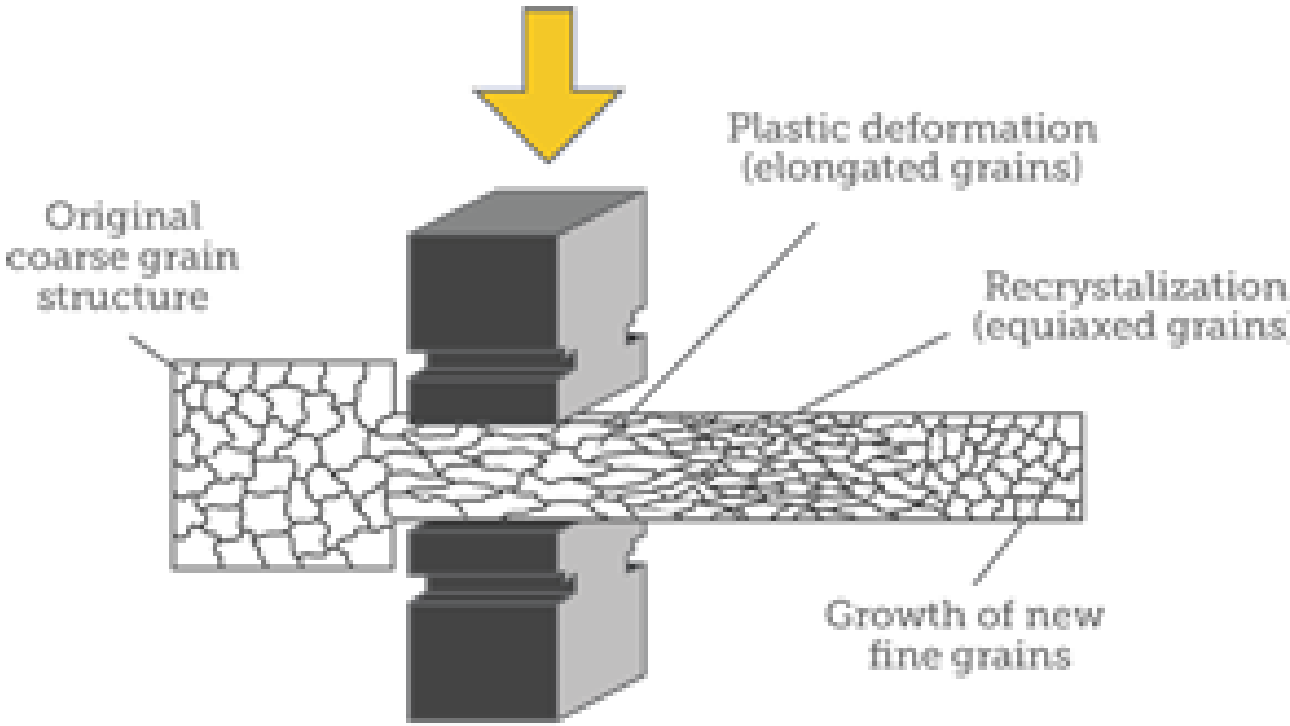
Steel making

Effect of rolling direction on tensile testing results of austenitic stainless steel (AISI304)





Cold working



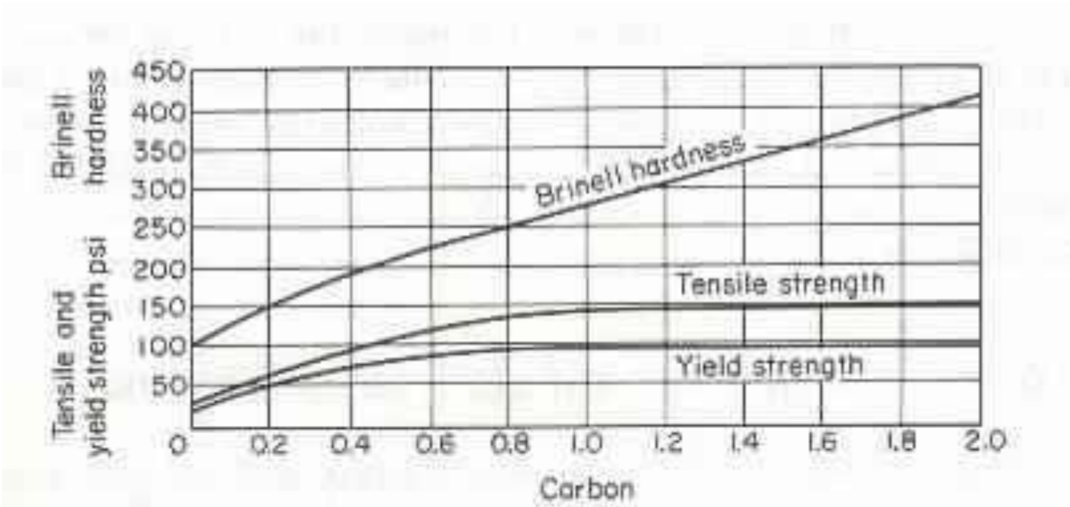
How the open die forging process affects the crystal structure.

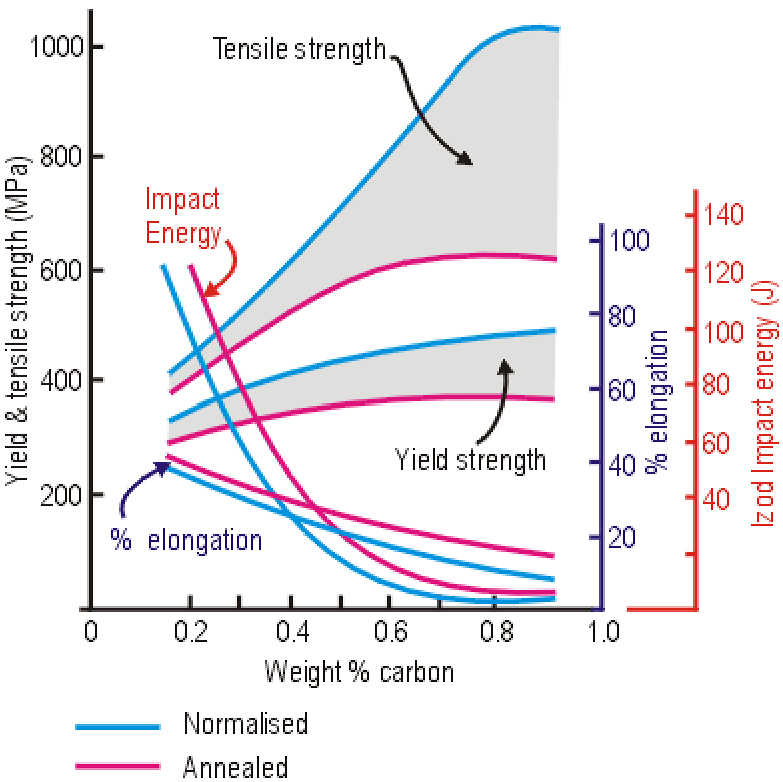
Video !

Effect of cold work on tensile testing results

Reduction of area by drawing, %	Yield strength, psi	Tensile strength, psi	Elongation, in 2 in., %	Reduction of area, %
0	40,000	66,000	34	70
10	72,000	75,000	20	65
20	82,000	84,000	17	63
40	86,000	95,000	16	60
60	88,000	102,000	14	54
80	96,000	115,000	7	26

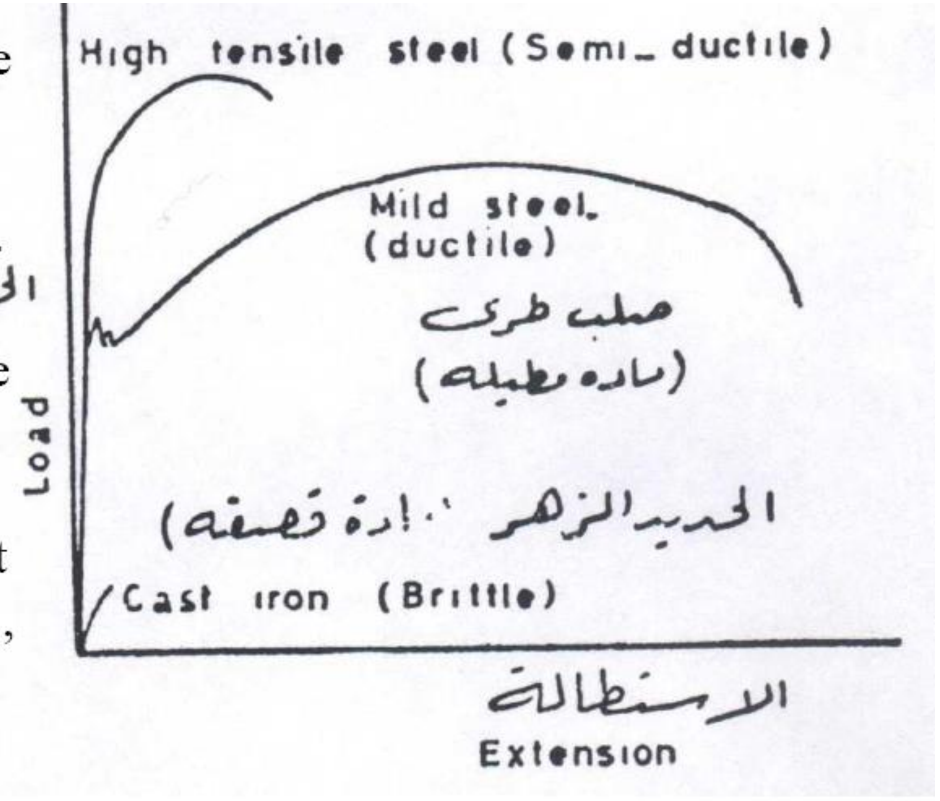
the effect of Carbon content on the tensile behavior of plain C-steel





Comparison between P-δ curves in Tension Test

1. Elastic proportional line is visible for mild steel and HTS but not Cast Iron.
2. No yielding takes place for semi-ductile and brittle materials.
3. Necking and cup and cone failure takes place for ductile and semi ductile metals.
4. Ductility is maximum for MS but lesser ductile is exhibited in HTS, while extremely low ductility is measured for CI.
5. HTS exhibit much higher UTS than MS while CI exhibits low UTS



Load-deformation curves for MS, HTS and Cast Iron

The effect of Carbon content on the tensile behavior