
بسم الله الرحمن الرحيم

***Benha University***
***Shoubra Faculty of Engineering***

***Mechanical Department***
***1st year Mech.***

**24.02.2019 – Week 3**

# On tensile testing considerations

***Prof. Farida Sayed Ahmed***
***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

# 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:

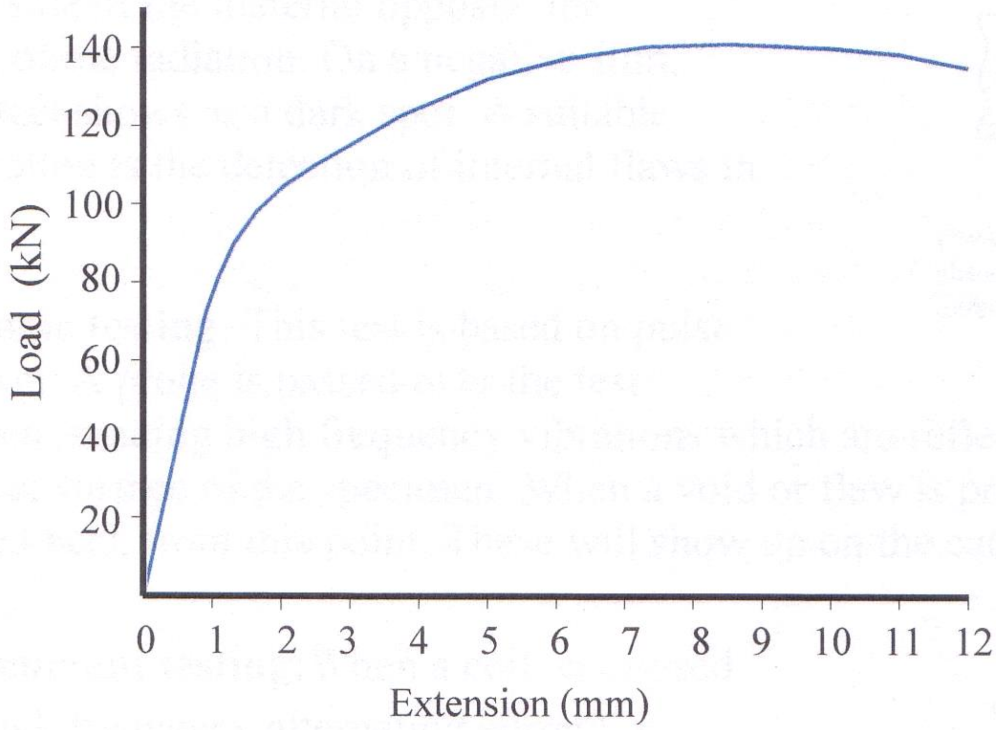
b) The modulus of Elasticity

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

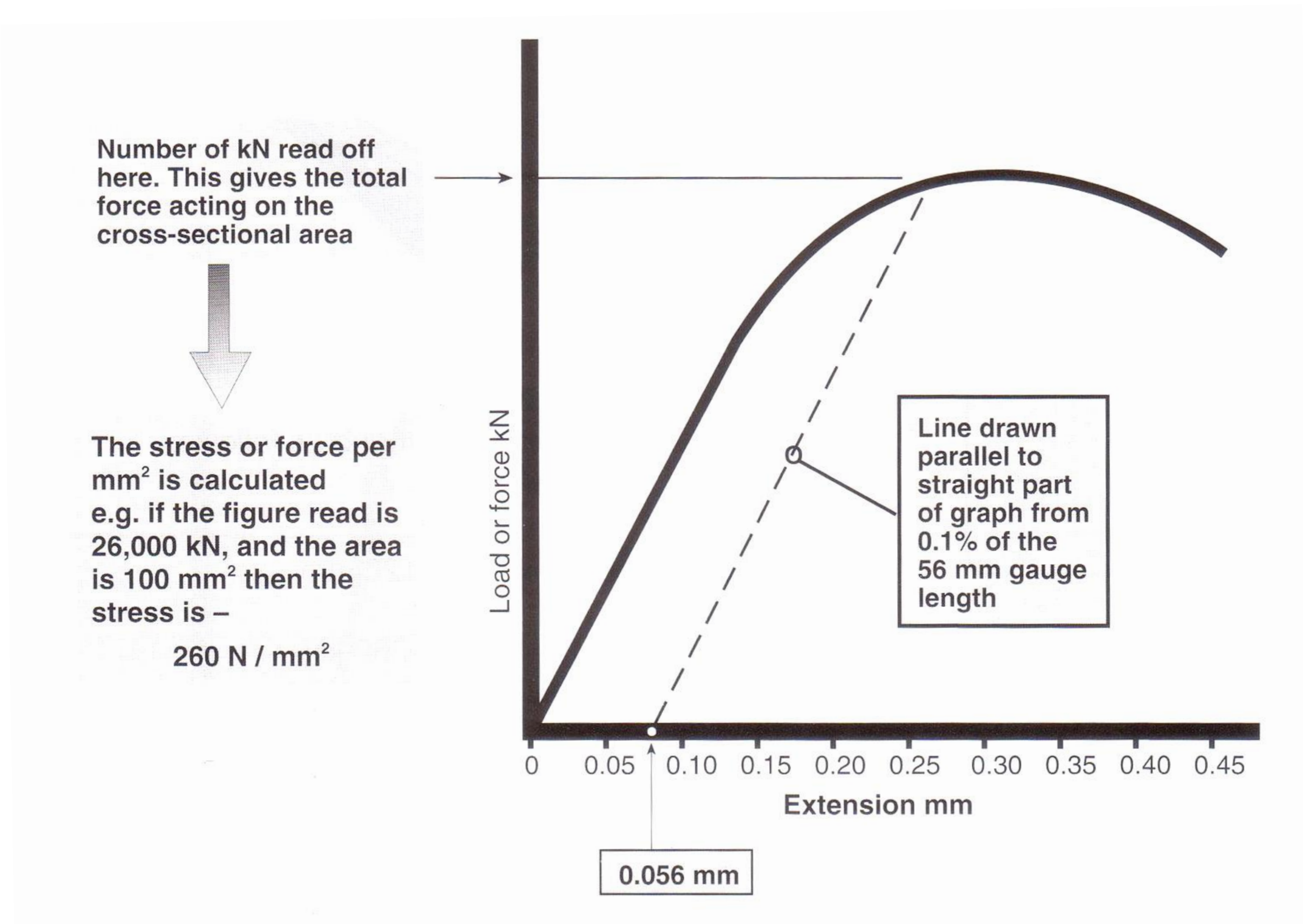
**Youngs Modulus:** Select point on elastic region of diagram eg. **(32,0.4)**
Diameter = 10mm, Gauge length = 60mm.

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

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

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

# Proof stress for Load – Extension graph



# Proof stress for Stress – Strain graph

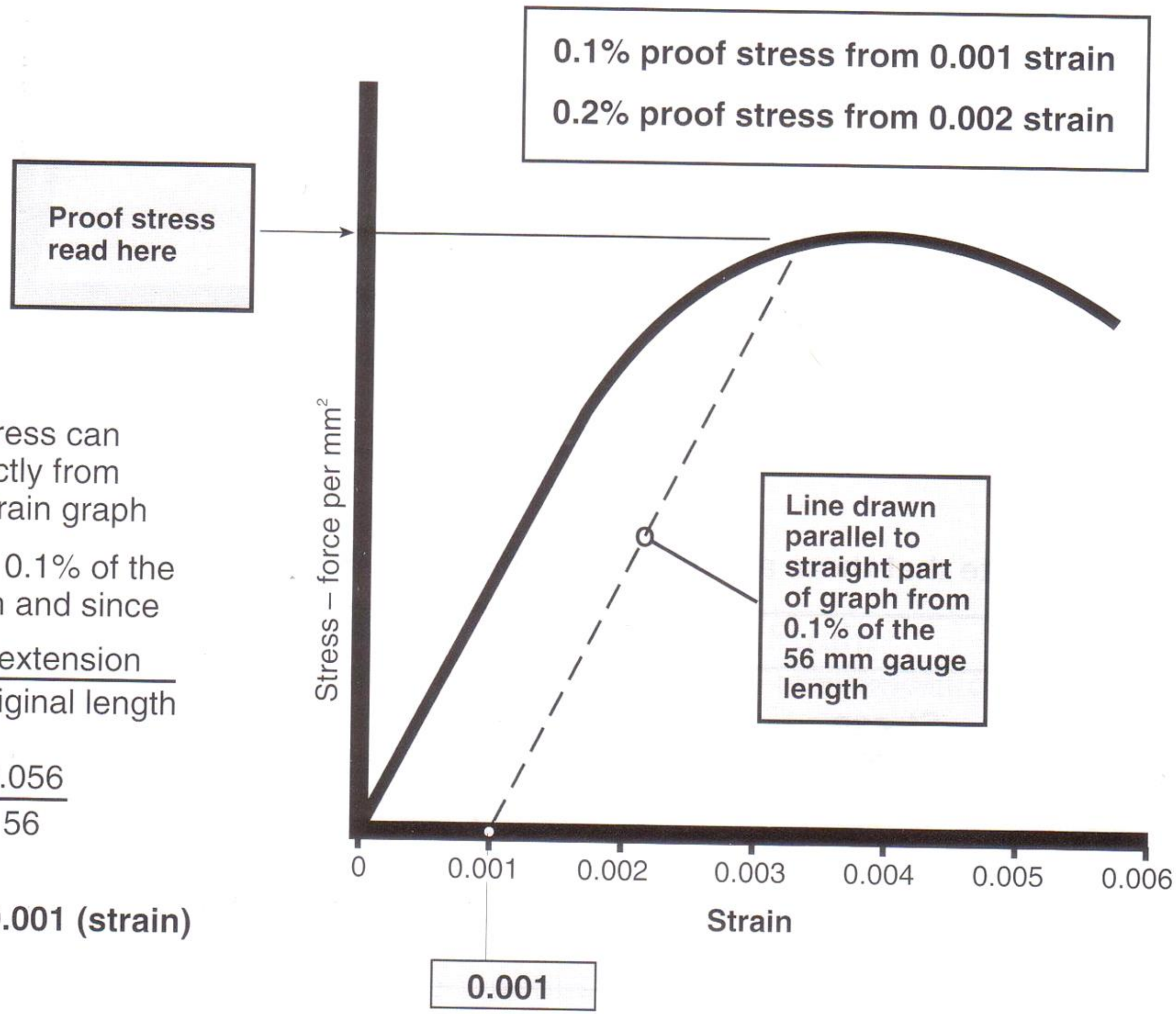
The proof stress can be read directly from the stress-strain graph

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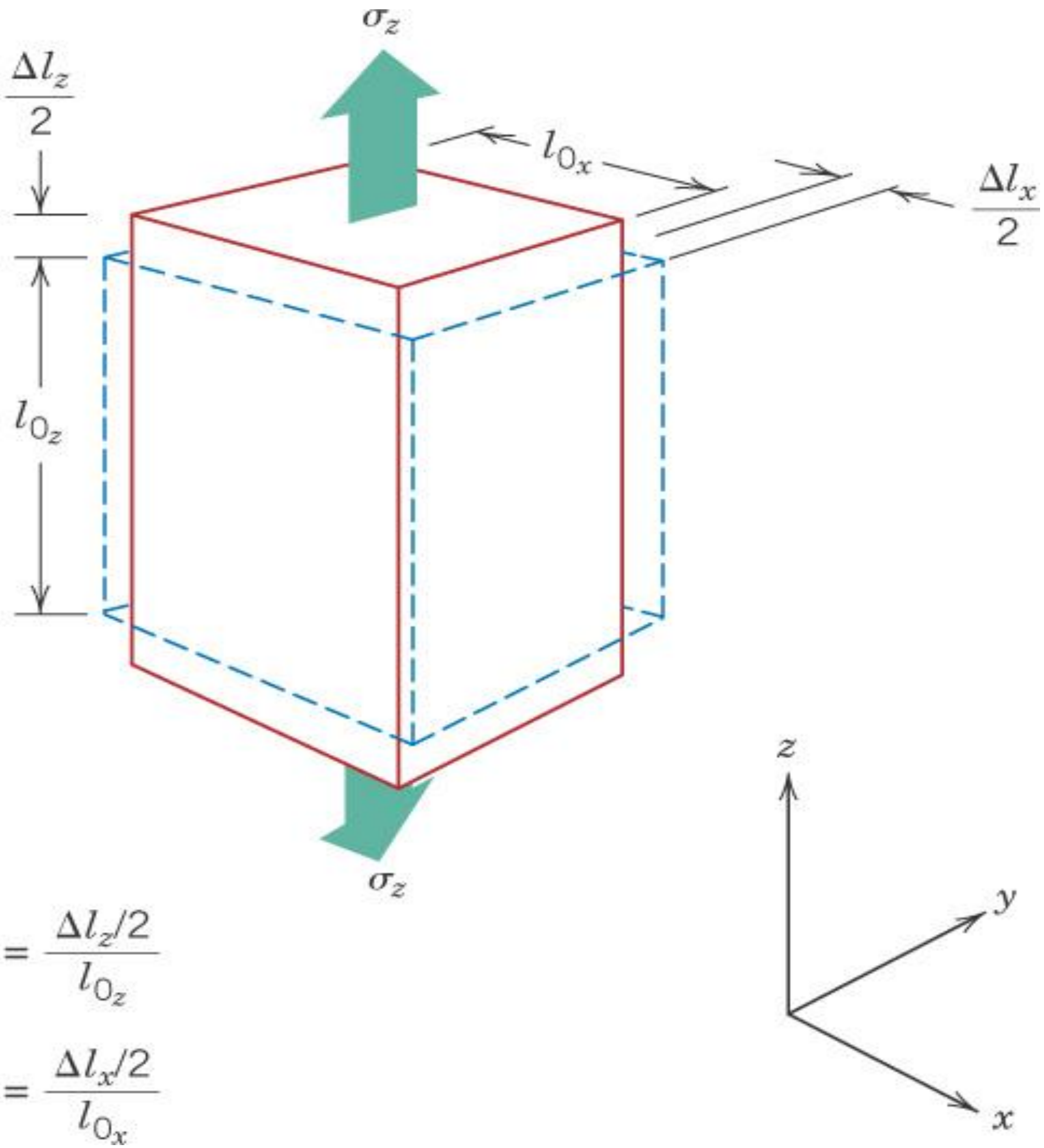
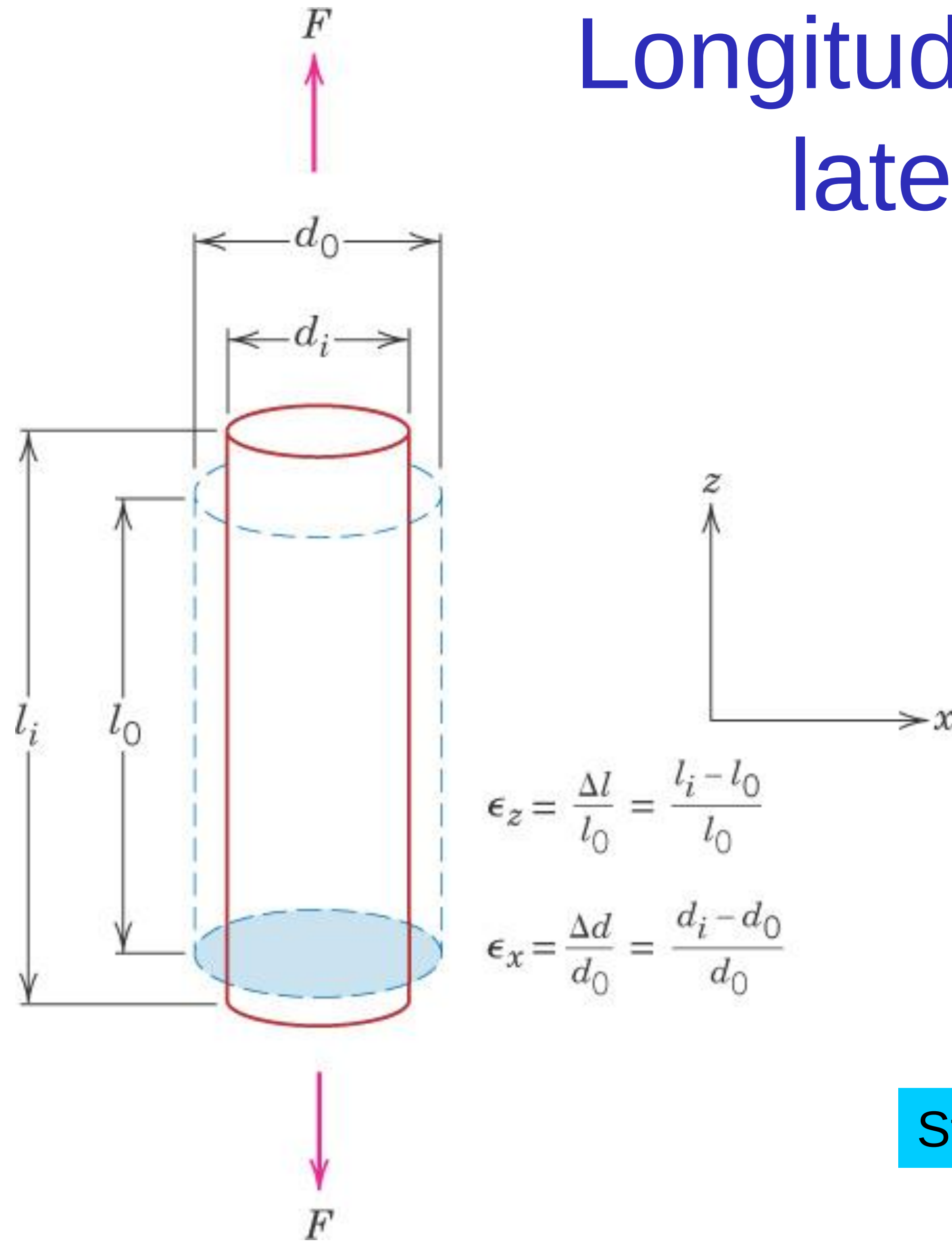
Axial (z) elongation (positive strain) and lateral (x and y) contractions (negative strains) in response to an imposed tensile stress.




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

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

# Longitudinal strain vs. lateral strain

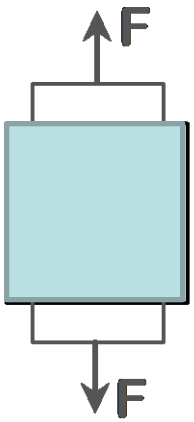



$$\epsilon_z = \frac{\Delta l}{l_0} = \frac{l_i - l_0}{l_0}$$

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

Strain is dimensionless.

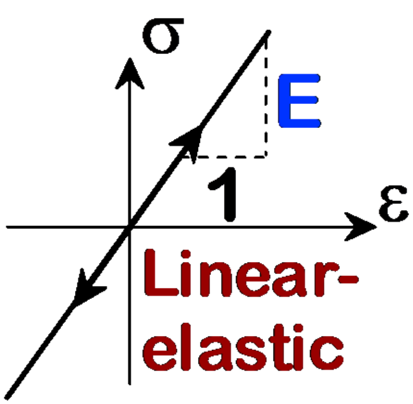
# Linear Elastic Properties

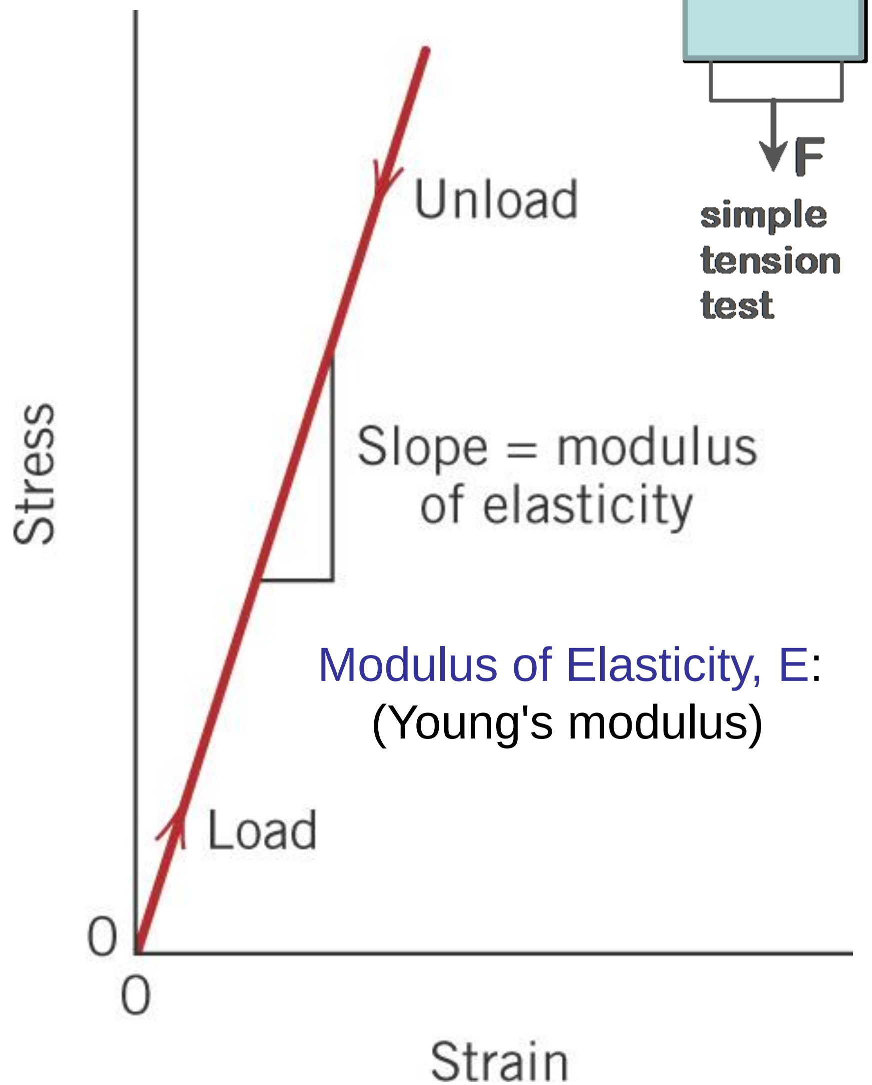



- **Hooke's Law**: $\sigma = E\,\varepsilon$

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

  **metals:** $\nu$ **~ 0.33**
  **ceramics:** $\nu$ **~0.25**
  **polymers:** $\nu$ **~0.40**




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

Units:
E: [GPa] or [psi]
$\nu$: dimensionless

# Modified Hooke’s law

**Generalised Hooke’s Law**

*Formula:*

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

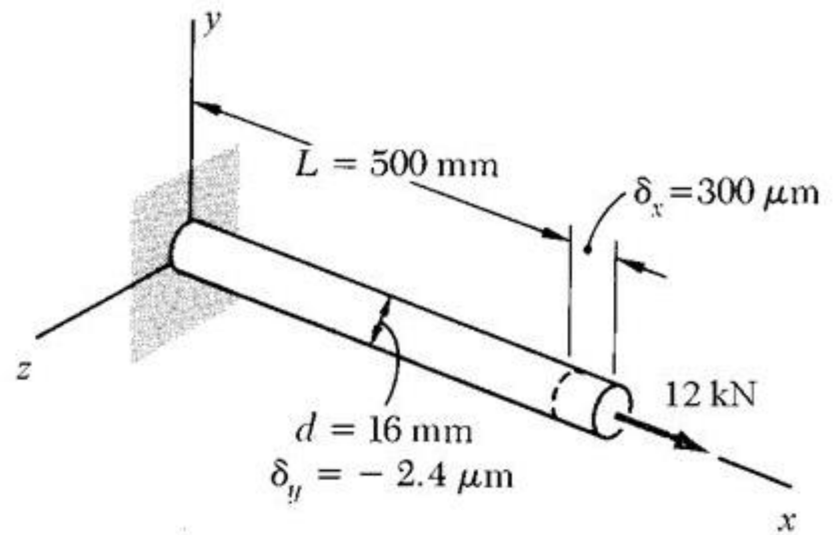
$$\varepsilon_y = \frac{1}{E}\left[\sigma_y - v(\sigma_x + \sigma_z)\right]$$

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

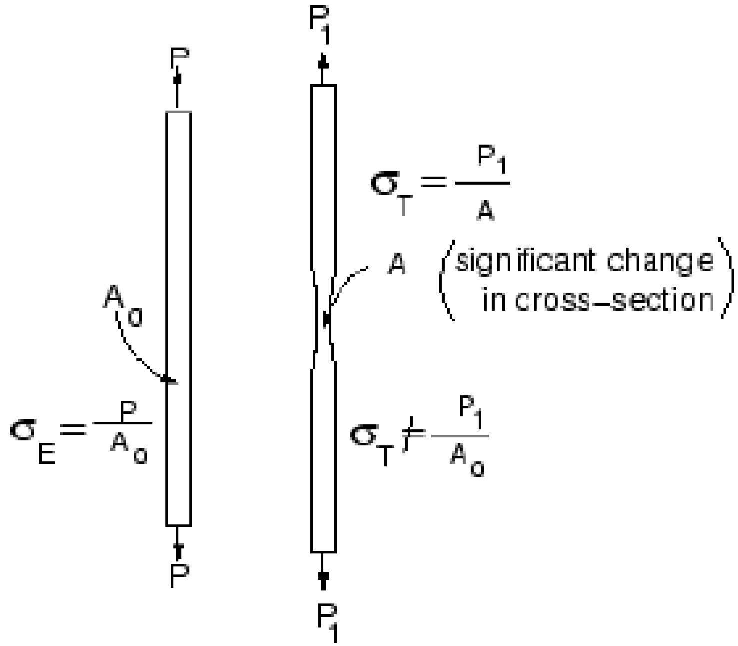
As you can see, the strain is affected by stresses in the perpendicular directions, via the Poisson’s ratio ($v$)

# Assignment

A 500 mm long, 16 mm diameter rod made of a homogenous, isotropic material is observed to increase in length by 300 $\mu$m, and to decrease in diameter by 2.4 $\mu$m 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:

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

- Conversion of engineering stress to True stress:

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

- True strain:

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

- Conversion of engineering strain to true strain:

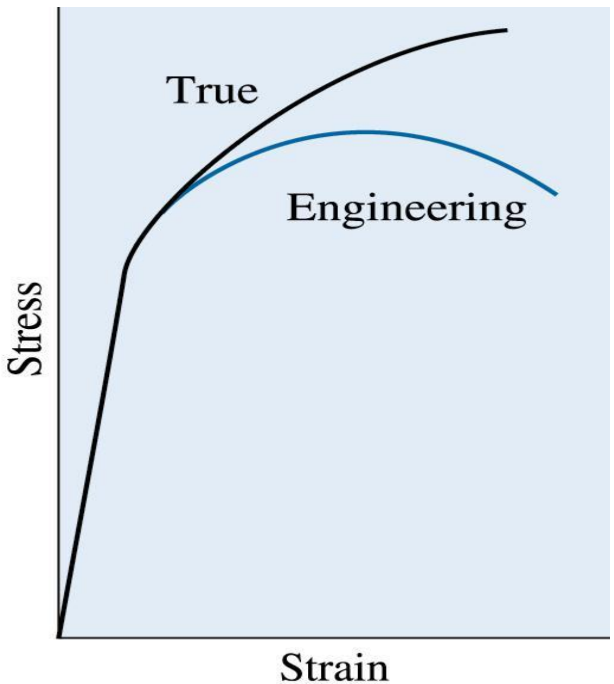
$$\epsilon_T = \ln(1 + \epsilon)$$

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

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

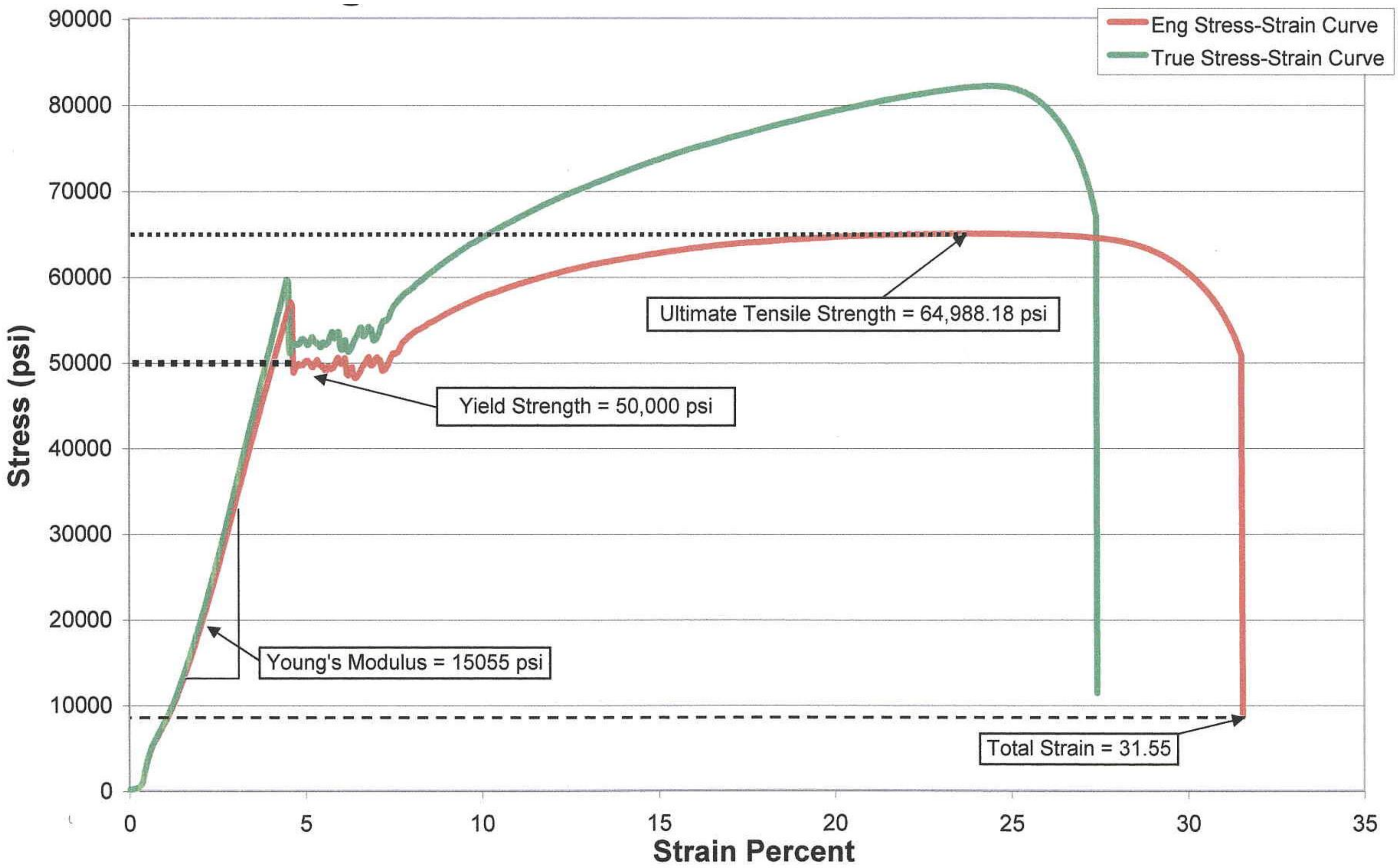
# True Stress and True Strain

- 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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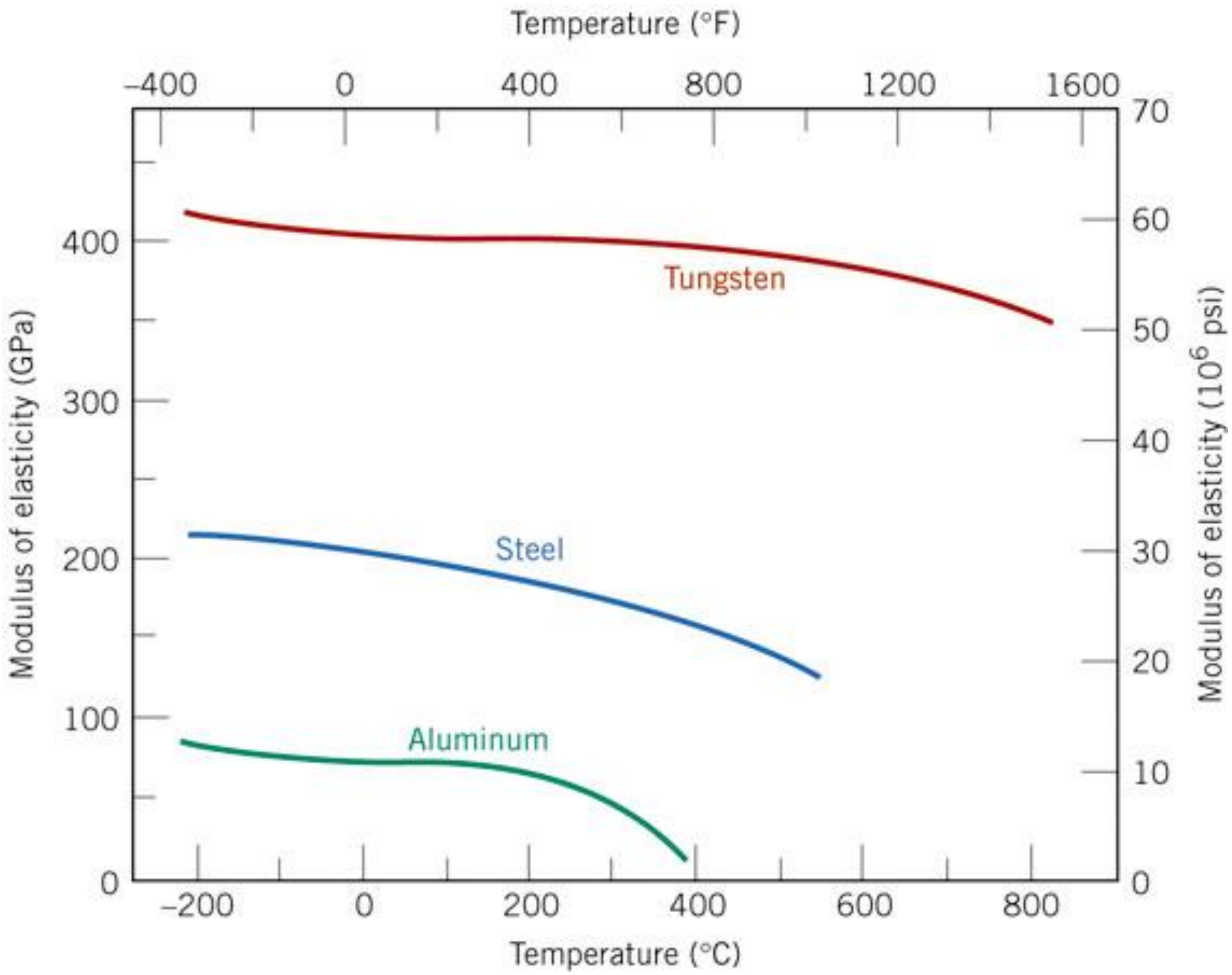
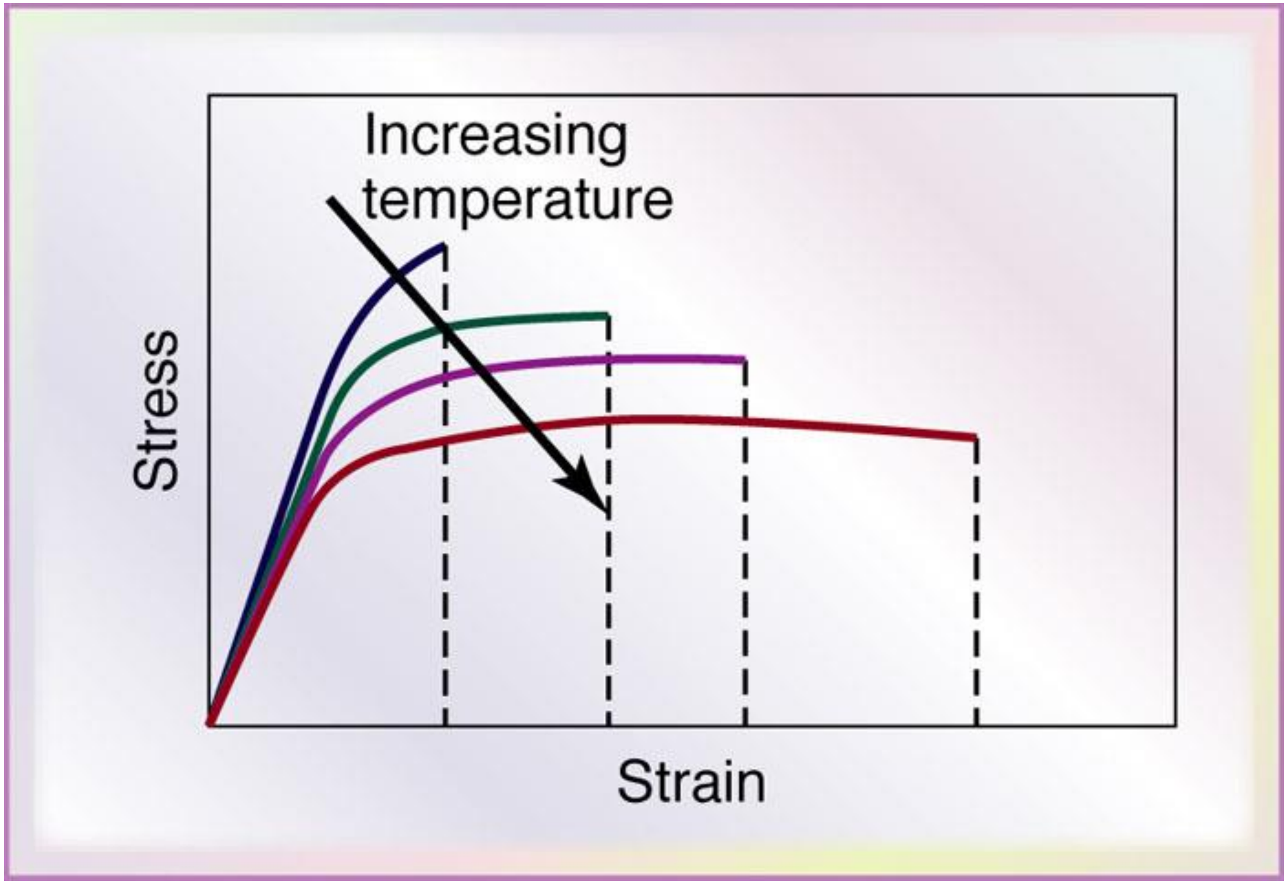
# Elasticity (E) 'v' Temperature

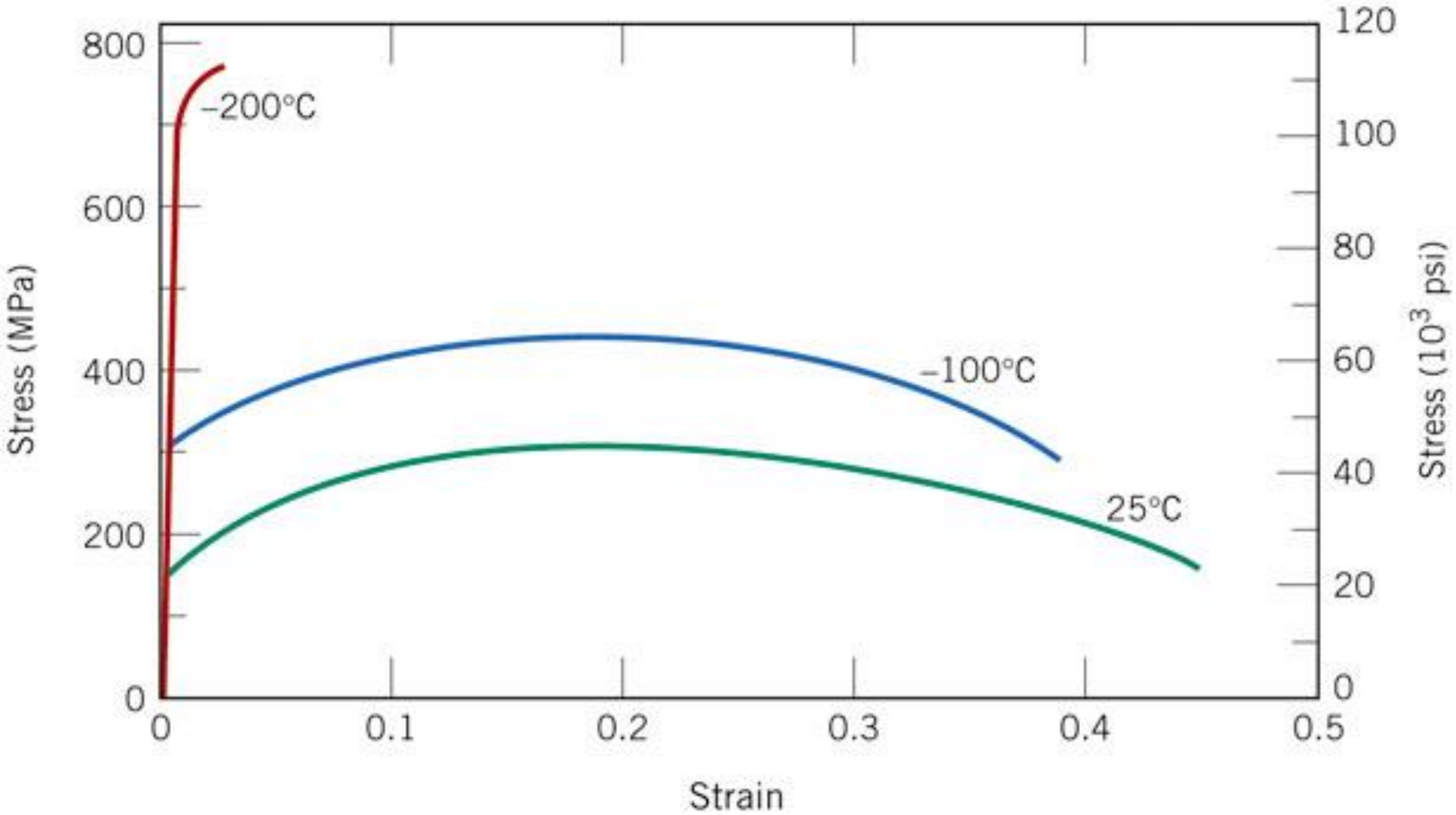


# Temperature Effects on Stress-strain Curves




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*

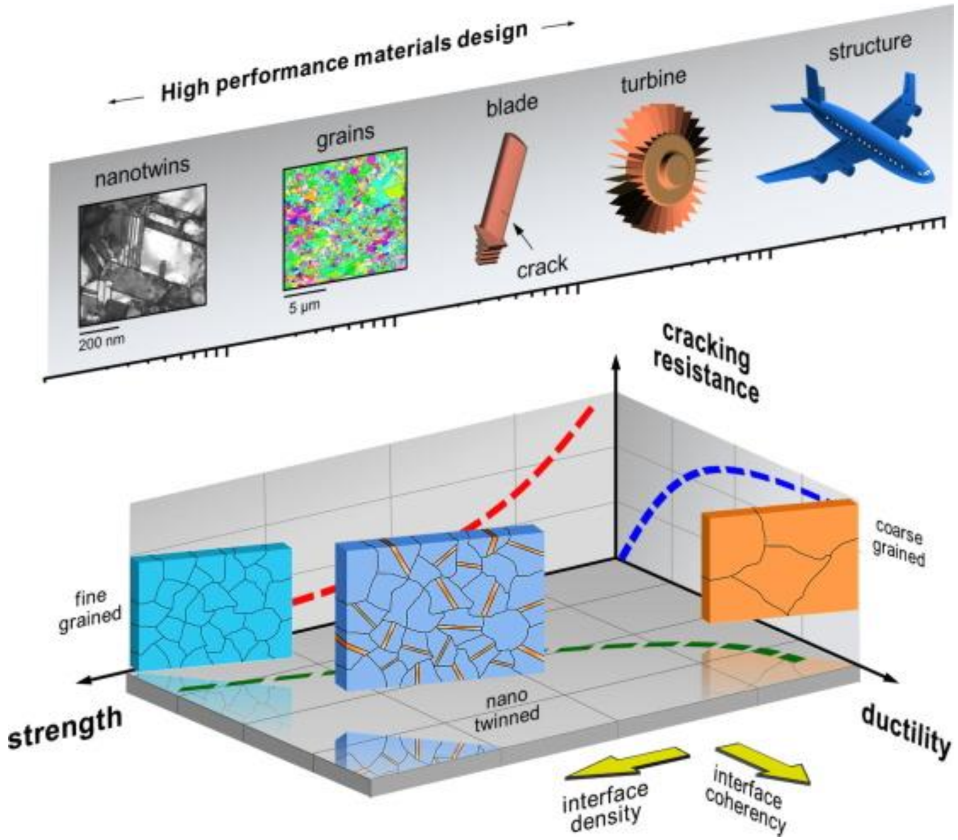


Figure 1.4. Increases of the strength, ductility and cracking resistance enhance achieving superior mechanical attributes



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.

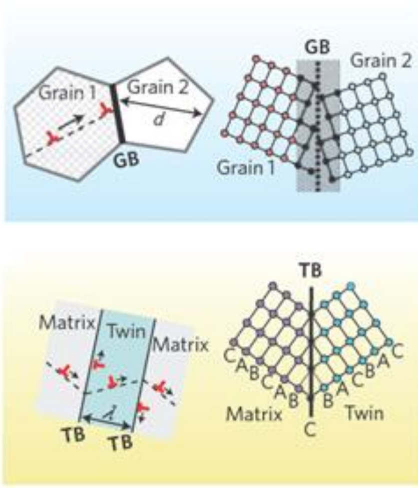


Figure 1.5 TBs hinder dislocation motion similar to GBs.

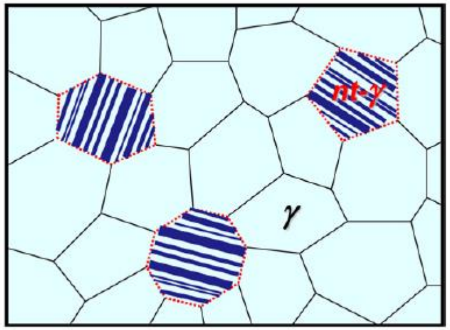


Figure 1.6 Embed TWIP steels with CTBs.

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.

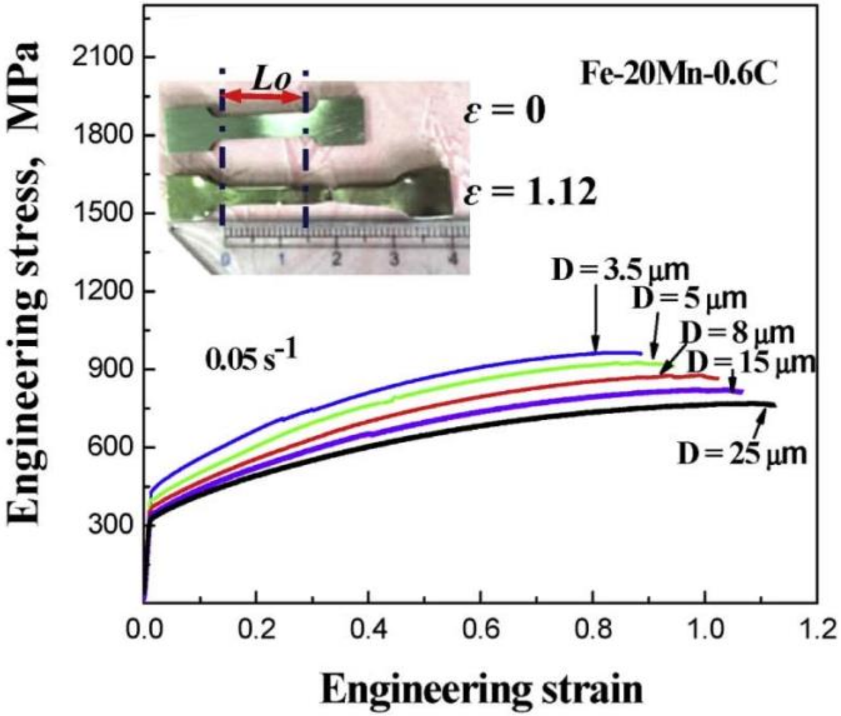


Figure 2.14. Reduction of grain sizes in ternary Fe-C-Mn steel increases its strength.

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

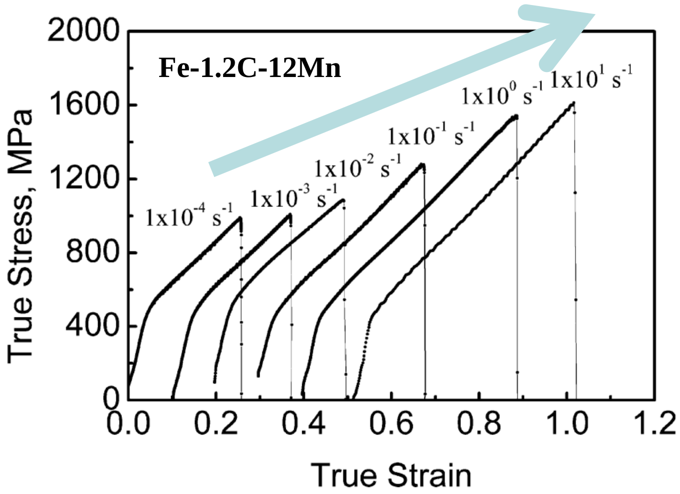


Figure 2.6 the strength and ductility of ternary Fe-1.2C-12Mn increase with a strain rate increase.

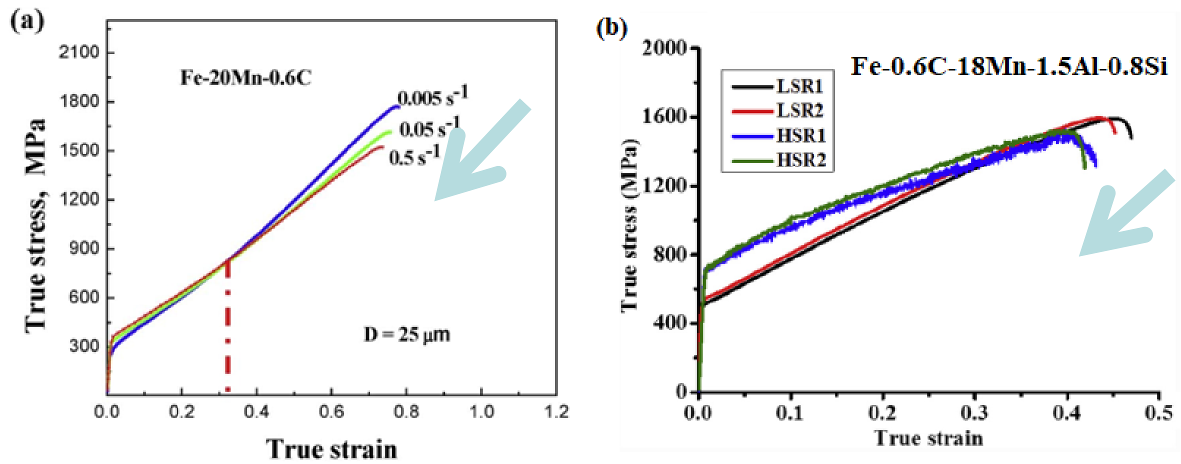


Figure 2.7 Effect of a strain rate rise on the mechanical behavior of: (a) 0.6C-20Mn-steel, (b) 0.6C-18Mn-1.5Al-0.6Si .

**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.

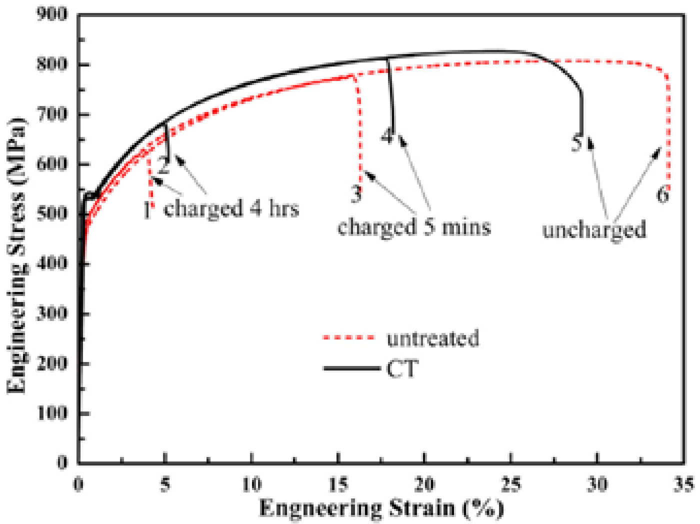


Figure 1.7. H-charging of TRIP steels severely decreases its strength and ductility.

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.

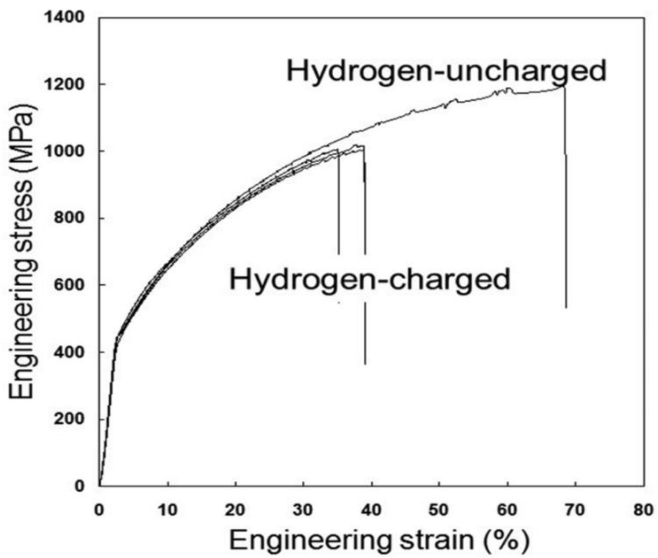


Figure 1.8. Stress-strain curves with and without hydrogen: (a) Fe-0.6C-18Mn

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.

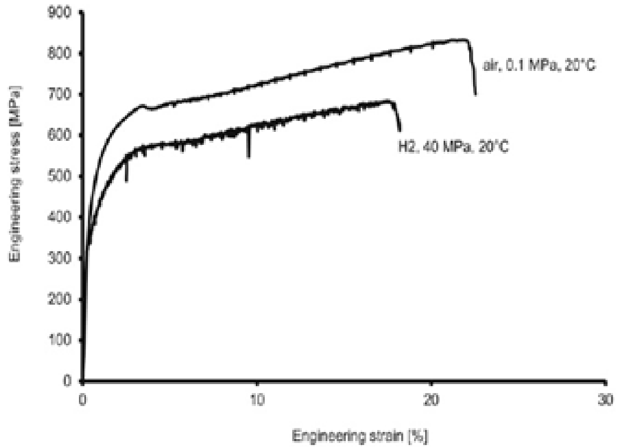


Figure 2.17 H-charging decreases the strength and ductility of Hadfield steel.

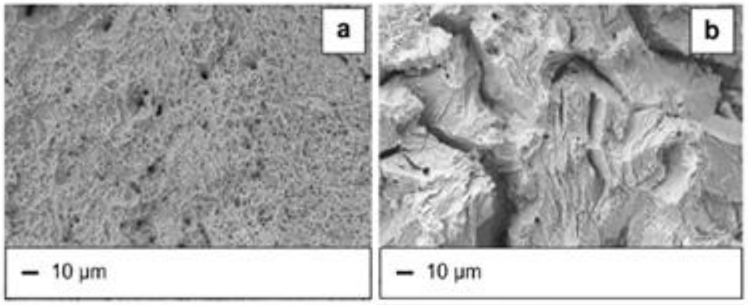


Figure 2.18 fractured surfaces of Hadfield steel (a, b) without and with H, .



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