YILDIZ TECHNICAL UNIVERSITY

CIVIL ENGINEERING DEPARTMENT CONSTRUCTION MATERIALS DIVISION

MATERIALS SCIENCE AND ENGINEERING/ PRACTICE 1

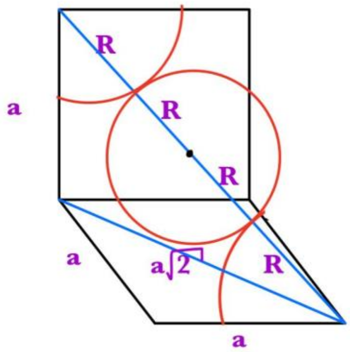
QUESTION 1

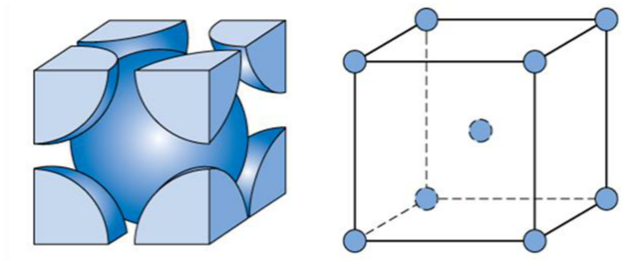
A material has a body-centered cubic (*BCC*) crystal structure with an atomic radius (*r*) of 1.857 Å and atomic mass of 23 g/mol. According to this:

a) Find the length of the unit cell (*a*), the specific gravity (*γ*), the atomic packing factor (*APF*).

Solution 1:

The body-centered cubic (BCC) crystal structure contains nine atoms: one on each corner of the cube and one atom in the center. Because the volume of each corner atom is shared between adjacent cells, **each BCC cell contains two atoms.**





Total number of atoms in the unit cell:

n = 1/8 * 8 + 1 = 2 atoms

a) $(4R)^2=a^2+(a\sqrt{2})^2$ $\qquad a=\frac{4R}{\sqrt{3}}$ $\qquad a_{KHM}=\frac{4R}{\sqrt{3}}=\frac{4.(1,857\,\AA)}{\sqrt{3}}=4,29\,\AA$

Since the entire crystal can be generated by the repetition of the unit cell, the theoretical density of a crystalline material can be calculated based on the density of the unit cell:

$$\boxed{\rho = \frac{nA}{V_c N_A}}$$

ρ : Density

n : Number of atoms in each unit cel

A : Atomic weight (g/mol)

V_c : Volume of the unit cell

N_A : Avogadro's number

$N_A = (0.602 \times 10^{24}$ atoms/mol)

n=8(1/8)+1=2 atom

$V=(a)^3=(4R/\sqrt{3})^3$

$$\gamma = \frac{2}{(4R/\sqrt{3})^3} \cdot \frac{23}{0.602x10^{24}} = 0.968 gr/cm^3$$

1,857x10^(-8)

Atomic packing factor shows us how dense the unit cell is:

$$APF = \frac{Volume\ of\ atoms\ in\ a\ unit\ cell}{Total\ unit\ cell\ volume}$$

$$ADF = \frac{2x\frac{4}{3}\pi.R^3}{a^3} = \frac{2x\frac{4}{3}\pi.(1.857x10^{-8})^3}{(4.29x10^{-8})^3} = 0.68$$

QUESTION 2

A 10 cm cube made of a stone with a unit weight of 2.34 g/cm^3 and a specific gravity of 2.72 g/cm^3, weighs 2445 g when it is saturated.

a) Calculate compactness (k) and porosity (p).

b) Calculate water absorption ratio by mass (a_m) and by volume (a_v).

c) The same material absorbs 25.2 g water from its base for 64th minutes by capillarity. According to this, calculate the time that water rises up to the top surface of a structural element with height of 3 m.

Solution 2:

a) Unit Weight (Density) (β)

Density (β) is defined as the dry weight (W_o) of a given volume (V_t) of a material. Density has a strong relation with strength and thermal conductivity.

$$\beta = \frac{W_o}{V_t}$$

b) Specific gravity (γ)

Specific gravity (γ) is the dry weight (W_o) of a given volume of the solid phase (V_s) of a material.

$$\gamma = \frac{W_o}{V_s}$$

c) Compactness ratio (k)

The ratio of solid volume of a material (V_s) to its total volume (V_t) and can also be calculated by dividing density (β) by specific gravity (γ).

$$k = \frac{V_s}{V_t} = \frac{\beta}{\gamma}$$

d) Porosity (p)

The ratio of the pore volume (V_p) to the total volume (V_t) of the material. Porosity (p) defines total pores, whereas effective porosity (p_e) defines open, interconnected and continuous pores.

$$p = \frac{V_p}{V_t} = 1 - k$$

$$\beta = 2,34 g / cm^3$$

$$\gamma = 2,72 g / cm^3$$

$$k = \frac{\beta}{\gamma} = \frac{2,34}{2,72} = 0.86 = \%86$$

$$p = 1 - k = 1 - 0,86 = 0.14 = \%14$$

e) Water absorption by mass (a_m): The ratio of the increase in mass to the mass of the dry sample.

$$a_m = \frac{W_{SSD} - W_o}{W_o}$$

SSD: **S**aturated and **S**urface **D**ry

W_{SSD}: The weight of the sample in the SSD state

W_o: The weight of the sample in dry state

f) Water absorption by volume (a_v): The ratio of the increase in volume to the total volume.

$$a_v = \frac{(W_{SSD} - W_o) / \rho_{water}}{V_t}$$

$\rho_{water} \approx 1\ g/cm^3$

$$\boxed{a_v = \beta \,.\, a_m}$$

$$\beta = 2.34 = \frac{W_0}{V_T} = \frac{W_0}{10x10x10} ===> W_0 = 2340g$$

$$a_m = \frac{2445 - 2340}{2340} = \%4.5$$

$$a_v = \frac{2445 - 2340}{10x10x10} = \%10.5$$

Capillarity can be defined as the tendency of a water in a capillary pores of a material to rise as a result of surface tension.

g) Capillary Water Absorption Coefficient (K, cm^2/s)

Defined as the "absorbed water amount (Q) from unit surface area (A) of a material in unit time (t)".

$$K_i = \frac{Q_i^2}{A^2 t_i}$$

$$Q_i = 25.2g$$

$$t = 64 \min$$

$$K_i = \frac{(25.2)^2}{(10x10)^2 x(64x60)} = 0,0000165 cm^2 / s$$

$$t = \frac{{Q_{\max}}^2}{A^2.K} ===>> Q_{\max} = a_v x V = (10x10x300)x(0.105) = 3150 cm^3$$

$$t = \frac{(3150)^2}{(10x10)^2 x0,0000165} = 60136363,645 sn = 696 days = 23,2 months$$

QUESTION 3

The capillarity experiment was performed on a stone sample with the dimensions of 10x10x10 cm and the results are given below:

t (min)	0	1	4	9	16	25	36
W (g)	620	622	624	627	629	631	632

a) According to the given data, draw the "absorbed water amount (Q, cm^3) – time (t, minute)" graphic of this material.

b) Calculate the capillarity coefficient of this material by considering amount of absorbed water at 36^{th} minutes.

Solution 3:

$$Q_n = W_n - W_0$$

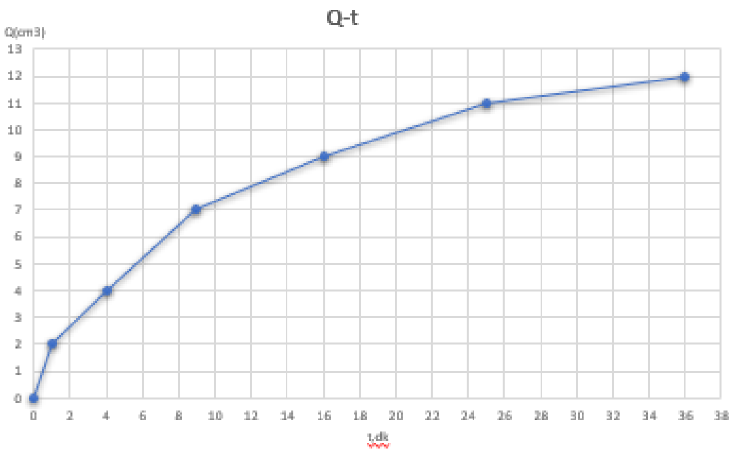
$$Q_1 = W_1 - W_0$$

$$Q_2 = W_2 - W_0$$

$$Q_1 = 622 - 620 = 2\ gr$$

$$Q_2 = 624 - 620 = 4\ gr$$

$$Q_9 = 627 - 620 = 7\ gr$$



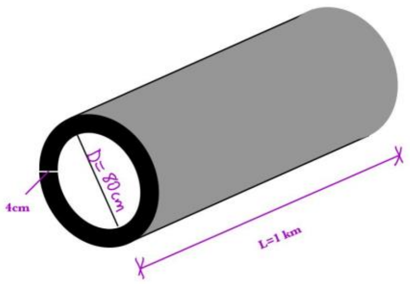
$$K = \frac{Q^2}{A^2.t} = \frac{(632-620)^2}{(10x10)^2 x36x60} = 6,7x10^{-6} cm^2 / sn$$

QUESTION 4

A concrete pipe has internal diameter of 80 cm and wall thickness of 4 cm. Permeability coefficient (K_p) of the concrete is 2x10^{-8} cm/sec. Calculate the amount of water loss daily under 6 atm pressure for a length of 1 km?

Note: 1 atm ≈ 1000 cm-water column

Solution 4:



4.6. Permeability

Water permeability of a material is expressed by the coefficient of water permeability (K_p, cm/sec), which is measured by determining the rate of water flow through the material **under pressure**.

$$K_p = \frac{Qxh}{PxAxt}$$

In the equation,
Q is the amount of water that flows through the sample (cm^3),
h is the thickness of the sample that water flows through (cm),
P is the pressure in
A is the cross- section of the sample (cm^2) and *t* is time in seconds.

$P = 6 \text{ atm} = 6000$ cm-hydraulic column (water-column),

$$A = 2.\pi.r.L = \pi.80.10^5 = 25120000 \text{ cm}^2$$

$$Q = \frac{\Delta P.A.t}{h}.k_p = \frac{2x10^{-9}x6000x86400x25120000}{4}:$$

$$= 6511104 \text{ cm}^3 = 6{,}511 \text{m}^3$$

QUESTION 5

A S420 class steel sample with a nominal diameter of 16 mm (ϕ16) was subjected to the uniaxial tension test. The gauge length of the extensometer (l_o) is 100 mm and the results are given below:

P (Load, N)	0	20100	40200	60300	80400	88400	108500	124600	115600
Δl (Displacement, mm)	0	0.045	0.090	0.135	0.180	0.280	6.30	9.20	Fracture

According to the given data:

a) Draw the stress-strain (σ-ε) curve and calculate the limit of proportionality (σ_p), the yield strength (σ_y), the tensile strength (σ_t).

b) Calculate the modulus of elasticity (E)

c) Calculate the ductility (ε_k) if the final gauge length is measured as 90.0 mm after the fracture.

d) Calculate the resilience (W_R) and the toughness (W_T) of this specimen.

Solution 5:

Stress and strain data points can be determined by using load and deformation measurements

$d_o = 16$ mm
$l_o = 10$ cm $= 100$ mm

$$A_0 = \frac{\pi \times d_0^2}{4} = \frac{\pi.16^2}{4} = 201 mm^2 \quad (201\ mm^2)$$

$$\sigma_i = \frac{P_i}{A_0} \qquad\qquad \varepsilon_i = \frac{l - l_0}{l_0} = \frac{\Delta l}{l_0}$$

$\sigma_1 = 20100 / 201 = 100$ N/mm² $= 100$ MPa — $\varepsilon_1 = 0,045 / 100 = 4,5\text{x}10^{-4}$
$\sigma_2 = 40200 / 201 = 200$ MPa — $\varepsilon_2 = 0,090 / 100 = 9,0\text{x}10^{-4}$
$\sigma_3 = 60300 / 201 = 300$ MPa — $\varepsilon_3 = 0,135 / 100 = 13,5\text{x}10^{-4}$
$\sigma_4 = 80400 / 201 = 400$ MPa — $\varepsilon_4 = 0,180 / 100 = 18,0\text{x}10^{-4}$
$\sigma_5 = 88400 / 201 = 440$ MPa — $\varepsilon_5 = 0,280 / 100 = 28,0\text{x}10^{-4}$
$\sigma_6 = 108500 / 201 = 540$ MPa — $\varepsilon_6 = 6,300 / 100 = 630\text{x}10^{-4}$
$\sigma_7 = 124600 / 201 = 620$ MPa — $\varepsilon_7 = 9,200 / 100 = 920\text{x}10^{-4}$

$\sigma_8 = 115600 / 201 = 575$ MPa $\longrightarrow$ Kopma

- **PL: Proportional limit (σ_p)**

In the stress level up to PL (i.e., the linear elastic limit), Hooke's law is obeyed.

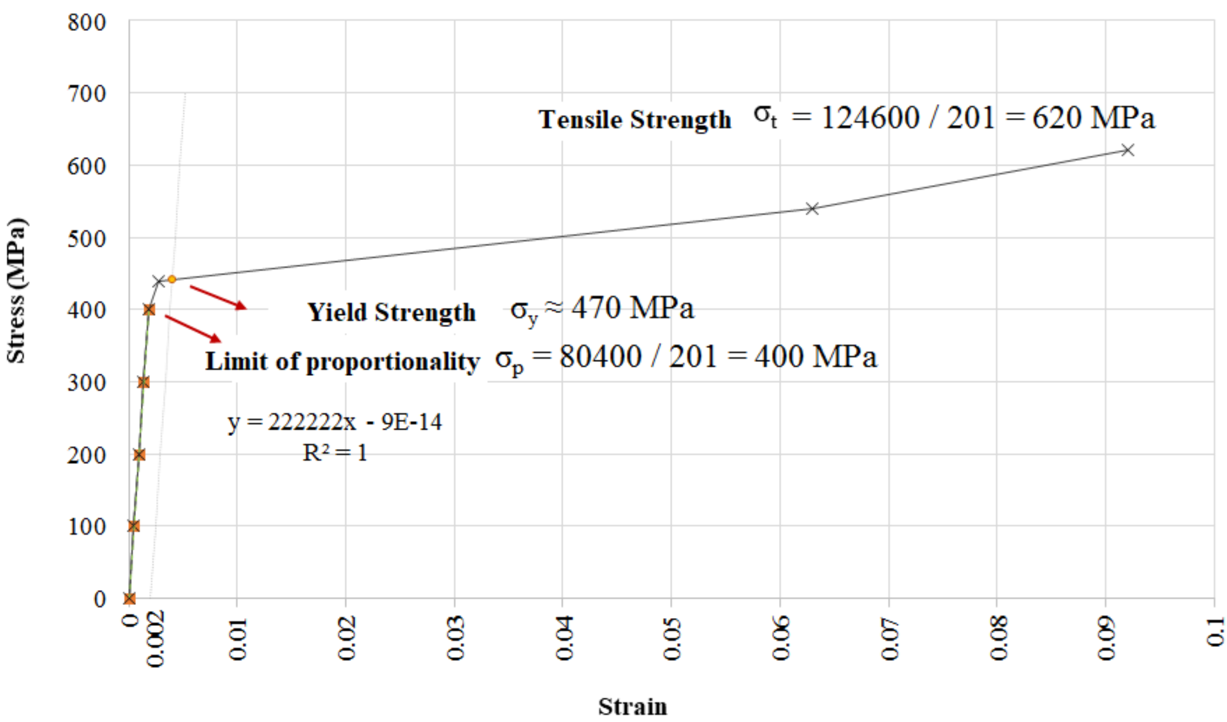
- **YS: Yield Strength (σ_y)**

For engineering applications, it is desirable to know the stress level at which plastic deformation begins, or where the phenomenon of **yielding** occurs. For metals that experience

- **TS: Tensile Strength (σ_t)**

When stress continues in the plastic regime, the stress-strain passes through a maximum (*point M*), called the tensile strength, and then falls as the material starts to develop a neck and it finally breaks at the fracture point (*F*).

$$\sigma_t = \frac{P_{max}}{A_o}$$



The slope of this linear segment corresponds to the modulus of elasticity (E).

This modulus may be thought of as stiffness, or a material's resistance to elastic deformation.

Çözüm b)

$$E = \Sigma\sigma_i.\varepsilon_i \,/\, \Sigma\, \varepsilon_i^2$$

σ_i (MPa)	ε_i	σ_i x ε_i (MPa)	ε_i^2
0	0	0	0
100	$4,5 \times 10^{-4}$	0,045	$20,2 \times 10^{-8}$
200	$9,0 \times 10^{-4}$	0,180	$81,3 \times 10^{-8}$
300	$13,5 \times 10^{-4}$	0,405	182×10^{-8}
400	18×10^{-4}	0,720	324×10^{-8}
440	28×10^{-4}	$\Sigma = 1,35$	$\Sigma = 607,5 \times 10^{-8}$
540	630×10^{-4}		
620	920×10^{-4}		
575	–		

<u>Elastisite Modülü</u>

$$E = \Sigma\sigma_i.\varepsilon_i \,/\, \Sigma\, \varepsilon_i^2$$

$$E = 1,35 \,/\, (607,5 \times 10^{-8}) = 222222 \text{ MPa} = 222,2 \text{ GPa}$$

c) Calculate the ductility (ε_k) if the final gauge length is measured as 90.0 mm after the fracture.

- **D: Ductility (%ε_f):**

Ductility may be expressed quantitatively as either percent elongation (%ε_f) or percent reduction in area (%R_A). The percent elongation %ε_f is the percentage of plastic strain at fracture point:

$$\%\varepsilon_f = \frac{l_f - l_i}{l_i} \times 100$$

$l_i = 5 \times d_o = 5 \times 16 = 80$ mm

$l_{final} = 90$ mm

$\varepsilon_f = (90 – 80) / 80 = 0,125 = \%12,5$

Resilience

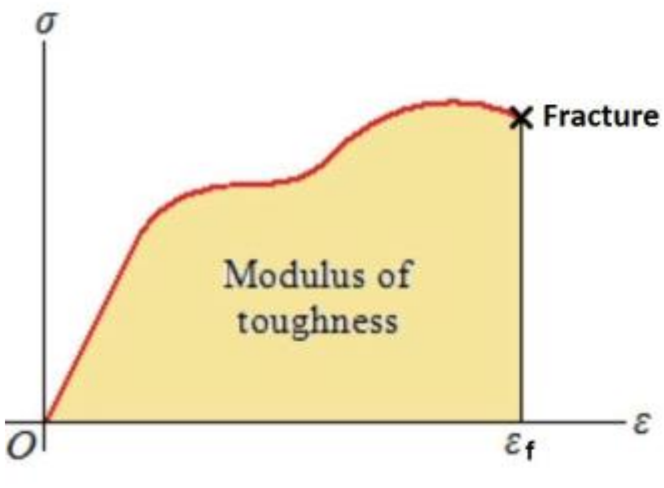
Resilience is the capacity of a material to absorb energy when it is deformed elastically.

$$W_R = \frac{\sigma_y \times \varepsilon_y}{2} = \frac{\sigma_y}{2} \times \frac{\sigma_y}{E} = \frac{\sigma_y^2}{2E} = \frac{470^2}{2 \times 222222} = 0,50MPa$$

Toughness

Toughness is a measure of the ability of a material to absorb energy up to fracture.

Modulus of toughness (W_T) is the area under the stress-strain curve up to the fracture point. In other words, toughness is the energy per unit volume is the *total area under the strain-stress curve*.



$$W_T = \int_0^{\varepsilon_f} \sigma \, d\varepsilon$$

- Assuming a right trapezoid:

$$W_T = \frac{\sigma_y + \sigma_t}{2} \times \varepsilon_f$$

$$veya \qquad W_T = \frac{(\sigma_y + \sigma_t)}{2} \times \varepsilon_f = \frac{470 + 620}{2} \times 0,125 = 68,13MPa$$

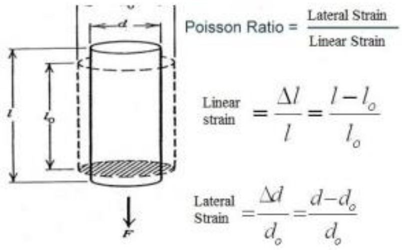
QUESTION 6

A tensile stress is to be applied along the long axis of a cylindrical brass rod that has a diameter of 10 mm. Determine the magnitude of the load required to produce a $2.5.10^{-3}$ mm change in diameter if the deformation is entirely elastic. (For brass, the modulus of elasticity is 97 GPa and the Poisson's ratio is 0.34).

Solution 6:

- A parameter termed Poisson's ratio (v) is defined as the ratio of the lateral and axial strains:

$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{axial}}$$



The negative sign is included in the expression so that (ν) will always be positive, since ($\varepsilon_{lateral}$) and (ε_{axial}) will always be of opposite sign.

$$0.34 = -\frac{\xi_{lateral}}{\xi_{axial}} ===>> \xi_{lateral} = \frac{\Delta l}{l} = \frac{2,5x10^{-3}}{10} = 2,5x10^{-4}$$

$$0,34 = \frac{2,5x10^{-4}}{\xi_{axial}} ===> \xi_{axial} = 7,35x10^{-4}$$

$$\sigma = E\varepsilon$$

$$\sigma = 97000x7,35x10^{-4} = 71,323\,Mpa$$

$$\sigma = 71,323 = \frac{P}{A} = \frac{P}{\pi x 10^2 / 4}$$

$$P = 5598,9\,N$$