Exam 2

Thursday, November 4, 2021 2:44 PM

"I pledge my honor I have abided by the Stevens Honor system."

- Alex Daskins

Part B.1:

Based on the following molecular weight data of a polypropylene $(C_3H_6)_n$ sample, determine the degree of polymerization based on the number-average molecular weight

Use of Microsoft Excel or the likes is allowed

Molecular Weight Range (g/mole)	Number Fraction (x_i)	Weight Fraction (w_i)
6,000 - 13,000	0.08	0.12
13,000 - 20,000	0.09	0.24
20,000 - 27,000	0.22	0.35
27,000 - 34,000	0.31	0.19
34,000 - 41,000	0.23	0.06
41,000 - 48,000	0.07	0.04

$$\overline{M_n} = \sum x_i M_i = 9500(0.08) + 16500(0.09) + 23500(0.22) + 30500(0.31) + 37500(0.23) + 44500(0.07)$$

$$= 28610 \text{ g/mol}$$

Molecular Weight:

$$C_3H_6 = 12(3) + 1(6) = 42 \text{ g/mol}$$

$$\text{Degree of Polymerization} = \frac{\overline{M_n}}{M_{C_3H_6}} = \frac{28610}{42} = \boxed{681.2}$$

Part B.2: A 3 mm thick slab of titanium alloy is placed in a hydrogen atmosphere at 800°C and achieves steady-state diffusion. The concentration of hydrogen at the low-pressure surface of the titanium is 0.9 kg/cm^3. The diffusion coefficient of hydrogen in this titanium alloy at this temperature is 1.6×10^{-5} cm^2/sec, and the diffusion flux is 3×10^{-4} kg/cm^2. Determine the concentration of hydrogen at the high-pressure surface of the titanium in kg/cm^3?

3 mm @ 800 °C = 1073.15 K

$$J = D_m \frac{\Delta \rho}{\Delta x}$$

$$3 \times 10^{-4}\ \text{kg/cm}^2 = 1.6 \times 10^{-5} \left(\frac{\rho_0 - 0.9}{0.3\text{cm}} \right)$$

$$\boxed{\text{High-Pressure} = 6.525\ \text{kg/cm}^3}$$

Part B.3: During the production of a transistor, an n-type silicon (Si) wafer containing phosphorous (P) dopants at a concentration of 7.0 x 10^{19} atoms/cm^3 was processed to create a pn junction by doping the wafer with boron (B) atoms using BCl_3. The wafer does not contain B atoms prior to the diffusion process. The activation energy and pre-exponential constant for estimating the diffusion coefficient of B in Si are 285 kJ/mole and 0.25 cm^2/s, respectively. If the solubility of B in Si at 1100°C is 1.4 x 10^{21} atoms/cm^3, sketch the concentration profile and determine the amount of time (in **seconds**) required to obtain a pn junction depth of 3.5 μm.

$C(x,t) = 7.0 \times 10^{19}$ atoms/cm^3 $x = 3.5\,\mu m = 3.5 \times 10^{-4}$ cm

$C_s = 1.4 \times 10^{21}$ atoms/cm^3 $x = 0$

$T = 1100 + 273 = 1373$ K

$C_0 = 0$ $x = \infty$

Activation Energy $= Q_d = 285 \times 10^3 \frac{J}{mol}$

$D_0 = 0.25\ cm^2/s$

$$\frac{C(x,t) - C_0}{C_s - C_0} = 1 - \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\frac{7.0 \times 10^{19}}{1.4 \times 10^{21}} = 0.05 \qquad -(0.05 - 1) = 0.95 = \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

Using table, $z = \frac{0.95 - 0.8802}{0.9103 - 0.8802} = \frac{z - 1.1}{1.2 - 1.1}$

$$z = 1.332$$

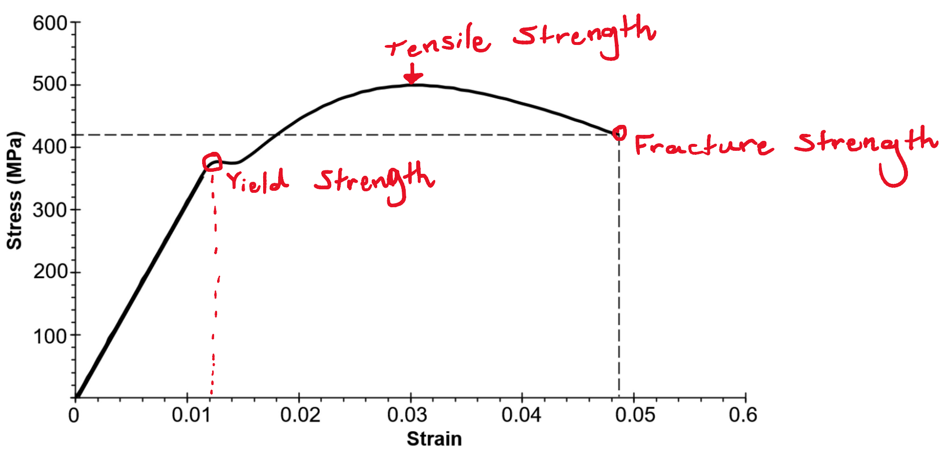
$$D = D_0 \exp\left(-\frac{Q_d}{RT}\right) = (0.25)\exp\left(-\frac{285 \times 10^3}{(8.314)(1373)}\right)$$

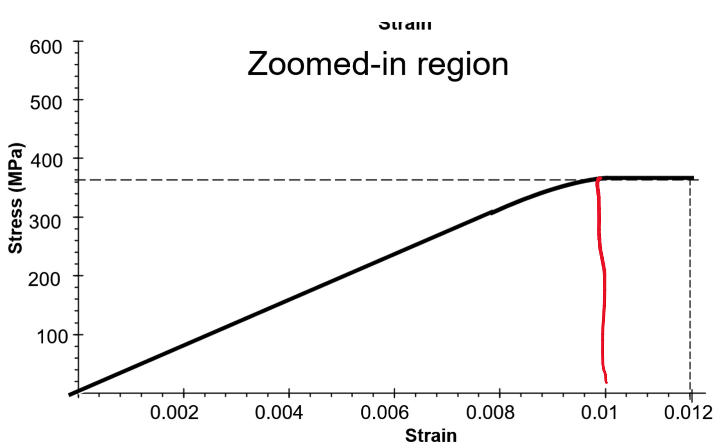
$$= 3.584 \times 10^{-12}\ cm^2/s$$

$$t = \left(\frac{x}{2\sqrt{D}\cdot 1.32}\right)^2 = \boxed{6464.59\ s}$$

Part B.4: From the stress-strain curve below obtained from the tensile test on a cylindrical sample, determine the sample's (a) elastic modulus **in GPa**, (b) yield strength **in MPa**, (c) tensile strength **in MPa**, (d) fracture strength **in MPa**, and (e) ductility in terms of **%EL** (elongation).

Note that there will be sufficient tolerance will be used for grading. Hence, approximations is allowed





$\sigma = E\varepsilon$ $E = \frac{\sigma}{\varepsilon}$ Using Stress-Strain Curve:

$\sigma \approx 360$ MPa $\varepsilon \approx 0.01$

A.) $E = \frac{\sigma}{\varepsilon} = \frac{360}{0.01} = 36000$ MPa $= \boxed{36 \text{ GPa}}$

B.) Changes from elastic to plastic deformation at $\approx \boxed{360 \text{ MPa}}$

C.) Maximum point $\approx \boxed{510 \text{ MPa}}$

D.) Material Breaks at $\approx \boxed{420 \text{ MPa}}$

E.) $\% EL = (\text{Fracture} - \text{Max. Elastic}) \cdot 100$

$= (0.05 - 0.012) \cdot 100$

$= \boxed{3.8\%}$

Part B.5: If a cylindrical rod made of the same material with the stress-strain curve shown in Problem 4 is pulled in tension, calculate the force in **Newtons** that is required to impart a strain of 0.006 on the material if the original diameter of the rod is 15 mm.

Please note that 5% tolerance will be used for grading.

b.) If a 30 mm long sample of the rod is elongated by 5 mm, will the original length of the rod be recovered when the tensile load is removed?

A.) Strain $= 0.006$ $\sigma = E(\text{strain})$

$= (36000)(0.006) = 216$ MPa

$\sigma = \frac{F}{A}$ $F = \sigma A = (216)\left(\frac{\pi}{4}(15^2)\right) = \boxed{38170.35 \text{ N}}$

B.) $L_0 = 30$ mm

$\Delta L = 5$ mm

Strain $= \frac{\Delta L}{L_0} = \frac{5}{30} = 0.17$

$$Strain = \frac{\Delta L}{L_0} = \frac{5}{30} = 0.17$$

$$0.17 > 0.006$$

Original length will not be recovered

Part B.6: A brass alloy rod originally has a diameter of 16.00 mm. A tensile load is applied along the long axis of the rod, changing the diameter to 15.92 mm. What was the magnitude of the tensile load in **kN**?

$d_0 = 16\ mm$ $\quad d = 15.92\ mm$ $\quad V = 0.34$ For Brass

$E = 100 \times 10^3\ MPa$

$$\text{Poisson's Ratio} = v = \left(\frac{\Delta d}{d}\right) / \left(\frac{\Delta L}{L}\right)$$

$$0.34 = \left(\frac{16 - 15.92}{16}\right) / \left(\frac{\Delta L}{L}\right)$$

$$\left(\frac{\Delta L}{L}\right) = 0.0147$$

FLEA

$$0.0147 = \frac{FL}{AE} = \frac{F}{\frac{\pi}{4}(16^2)} \left(\frac{1}{100 \times 10^3}\right)$$

$$F = 20106192.98\,(0.0147) = 295679.31\ N$$

$$\boxed{F = 295.679\ kN}$$

A tensile load of 315 kN is to be applied to a cylindrical rod that measures 900 mm in length and 35 mm in diameter. It is required that the rod should neither be plastically deformed nor experience an elongation of more than 4 mm. Identify all the alloys that can be used for this application from the table of mechanical properties in Useful Information.

$$FLEA = \Delta L = \frac{FL}{AE}$$

ΔL = Elongation

$$E = \frac{FL}{A\Delta L} = \frac{(315 \times 10^3)(400\ mm)}{\frac{\pi}{4}(35^2)\ (4\ mm)} = 73666\ MPa$$

$$\boxed{E = 73.67\ GPa}$$

List of Mechanical Properties

Materials (Alloy)	Yield Strength (MPa)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Shear Modulus (GPa)	Poisson's Ratio
Aluminum	255	420	70	25	0.33
Brass	345	420	100	37	0.34
Copper	250	290	110	46	0.34
Steel	450	550	207	83	0.30
Nickel	138	480	207	76	0.31
Titanium	450	520	107	45	0.34
Molybdenum	565	860	325	50	0.38

$E > 73.67\ GPa$ can be applied