Name: ____**Solutions**__________ GTID: ___________________________

MSE 2001 A: Principles and Applications of Engineering Materials

Midterm exam 2, June 24, 2013, 10am – 11am

Please read this cover sheet carefully before continuing with the exam.

Please remove everything from your desk except this test itself, writing instruments, and a calculator.

All pages are numbered at the bottom center of the page. Make sure that you have all 8 pages including this cover page (p.1). Work all problems in the spaces below the problem statement. You can use the back side of the pages for scratch, but I will not grade answers written on the back side. Do not remove the staple or tear out any pages.

I will not grade your exam if you fail to sign on the line below.

I acknowledge the above terms for taking this exam. I commit to uphold the ideals of honor and integrity by refusing to betray the trust bestowed upon me as a member of the Georgia Tech community. I pledge my honor that I have not violated the Honor Code during this examination.

Student's signature: ______________________________________

You may find the following formulas useful for this test:

$\cos(angle) = \frac{A \cdot B}{|A||B|}$; $\tau = \sigma cos\theta cos\varphi$;

$D(T) = D_0 \exp(\frac{-Q}{RT})$;

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

$n = 2^{N-1}$ and $n = \frac{1}{(D_{100})^2}$, where n is the number of grains/in^2 at 100x magnification

Z	erf(Z)	Z	erf(Z)
0	0	0.55	0.563
0.05	0.056	0.60	0.604
0.1	0.113	0.65	0.642
0.15	0.168	0.70	0.678
0.20	0.223	0.75	0.711
0.25	0.276	0.80	0.742
0.30	0.329	0.85	0.771
0.35	0.379	0.90	0.797
0.40	0.428	0.95	0.821
0.45	0.476	1.00	0.843
0.50	0.521	1.05	0.862

MSE 2001
Exam 2
Summer 2013

Name Answers GTID

1. **Match the correct pairs (15 pts)**

A. strain hardening
B. amorphous
C. solute
D. surface tension
E. plastic deformation
F. diffusion coefficient
G. self-diffusion
H. flow stress
I. block copolymer
J. elastomer
K. solvent
L. viscosity
M. yield stress
N. Burger's vector
O. precipitation hardening

F contains information on temperature dependence of the jump frequency
C the species that is dissolved in a host
K the host species in dissolution
G movement of atoms within a pure material
N describes magnitude and direction of lattice distortion due to dislocations
H stress required to cause dislocation motion
E occurs due to dislocation movement
O strengthening of an alloy due to a uniformly distributed second phase
A increase in flow stress due to plastic deformation
B solid without atomic periodicity in space
D extra energy associated with free surfaces
M stress at which deformation becomes permanent
I molecule made up of multiple chemically bonded mers
J polymers above Tg, synonymous with rubber
L measure of energy dissipated in a flowing material

2. **List the defects categorized by the following types (11 pts)**

a. Point Defect
   i. vacancy
   ii. interstitial

b. Line Defect
   i. edge
   ii. screw

c. Planar Defect
   i. grain boundary
   ii. tilt boundary
   iii. twin boundary

iv. twist boundary

v. Free surface (external surface) stacking fault

d. Volume Defect

i. void

ii. precipitate

3. What are the four Hume-Rothery Rules? (4 pts)

a. size difference < 15%

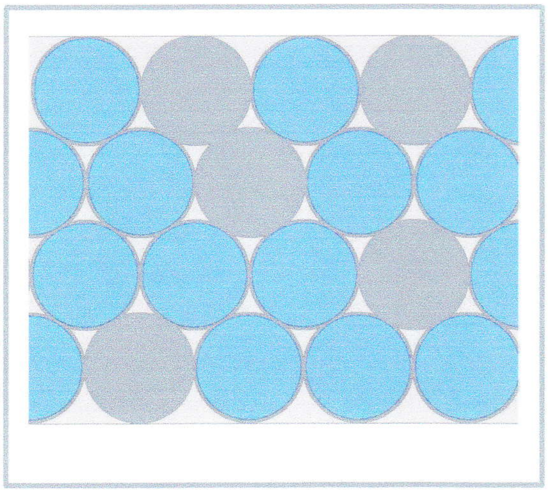
b. Similar electronegativities

c. similar valences

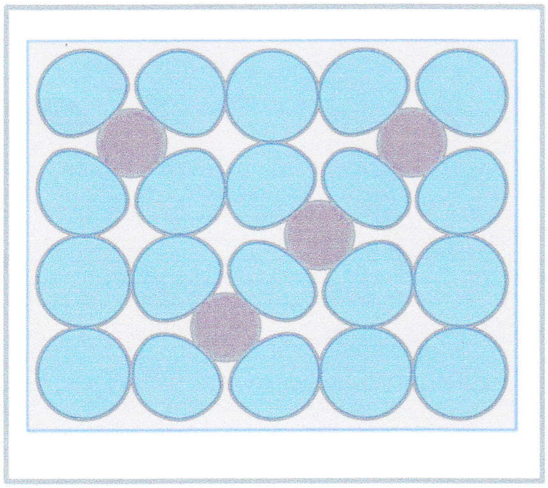
d. same crystal structures

Draw a schematic for (1) substitutional solid solution and (2) interstitial solid solution (8 pts)

(1)



(2)



4. **Given that $D_0 = 1.2 \times 10^{-4}\ m^2/sec$ and the activation energy for diffusion of Mg in Al is 131 kJ/mol, calculate the following (16 pts)**

a) What is the diffusivity for Mg in Al at 500°C? (4 pts)

$$D(T) = D_0 \exp(-Q/RT)$$

$$D(500) = (1.2\times10^{-4})\exp\left(\frac{-131,000}{8.314\cdot(500+273)}\right) = 1.68\times10^{-13}\ m^2/s$$

b) Starting with pure Al, what time will be required at 500°C to obtain a composition of 0.3 wt% Mg at a depth of 0.1 mm if we start out with a concentration of 2.0 wt% on the surface? (8 pts)

$C_i = 0\ \%$

$C_x = 0.3\ \%$

$C_s = 2\%$

$x = 0.1\,mm$

$$\frac{C(x,t) - C_0}{C_s - C_0} = 1 - erf(z)$$

$$\frac{0.3}{2} = 1 - erf(z)$$

$$0.15 = 1 - erf(z)$$

$$erf(z) = 0.85$$

$$Z = \frac{x}{2\sqrt{Dt}}$$

$z \approx 1.02$ from table

$$t = \frac{1}{D}\left(\frac{x}{2z}\right)^2 = \left(\frac{1}{1.68\times10^{-13}}\right)\left(\frac{0.1\times10^{-3}}{2\cdot1.02}\right)^2 = 14303\ s$$

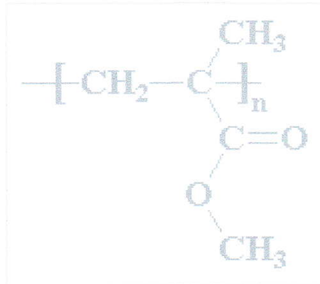
c) Given that Mg crystallizes in the hcp structure and has an average atomic radius of 0.160 nm and Al has an fcc structure and its atomic radius is 0.143 nm, what kind of solid solution would you expect them to make? partial substitutional

Why? size is ±15%, but different crystal structures limit fully substitutional

If we instead added Si (diamond cubic structure with a radius of 0.118 nm) into Al, what kind of solid solution would be expect? interstitial solid solution

Why? Si is much smaller than Al

5. **Poly(methyl methacrylate) also known as PMMA is used in place of glass when transparent containers are needed due to its excellent transparency and strength. A monomer of PMMA has the following structure (15 pts)**



a) Determine the molecular weight of a monomer of PMMA?
(MW_O = 16, MW_C= 12, MW_H= 1) (5 pts)

$MW_{monomer} = 5(M_C) + 8(M_H) + 2(M_O)$
$= 5(12) + 8(1) + 2(16)$
$= 100$ g/mol

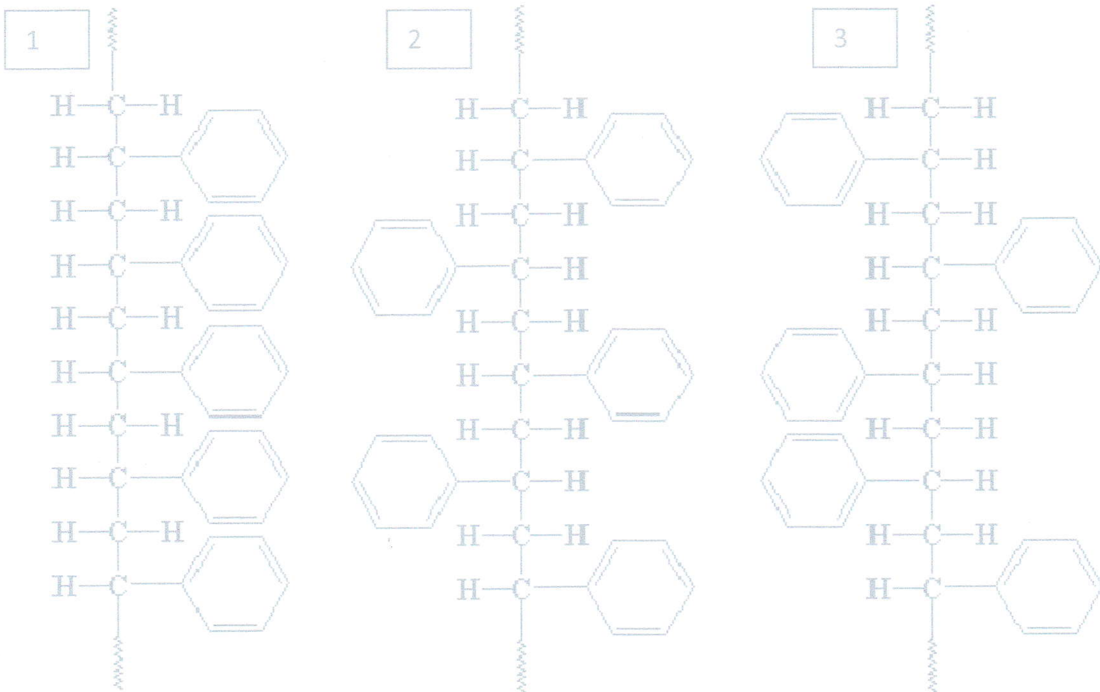
b) If our PMMA polymer has a degree of polymerization of 2000, what is the total polymer molecular weight? (5 pts)

$MW_{polymer} = n \cdot MW_{monomer}$
$= 2000 \cdot 100 \approx 200{,}000$ g/mol

c) Would it be possible to make contact lenses with this material? Why or why not? (2 pts)

No, such a high mw would lead to a rigid material which would be inappropriate for contact lenses

d) Given three different polystyrene chains, label their tacticity (3 pts)



1. Isotactic 2. syndiotactic 3. atactic

6. Circle the correct answer (6 pts)

a. Oxides which are unable to form an extended primary bond network in glass networks are referred to as (network formers/network modifiers).

b. (Conformation/Configuration) is used to describe the arrangement of rotatable bonds in a molecule.

c. Solving (Fick's 1st Law/Fick's 2nd Law) yields solutions in which the concentration is a function of position and time.

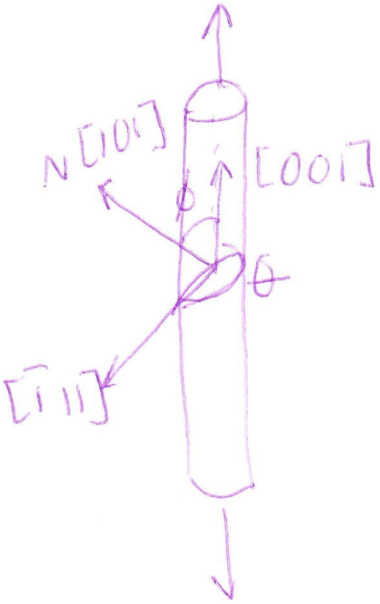
d. The (Schottky Defect/Frenkel Defect) involves the formation of a vacancy/interstitial pair.

e. (Dislocation climb/dislocation glide) allows an edge defect to move perpendicular to its slip plane.

f. A force in the direction perpendicular to the plane normal is the (normal stress/shear stress).

7. Schmid's Law (15 pts)

Calculate the resolved shear stress on the slip system (101)[$\bar{1}$11] of a bcc single crystal specimen when a load of 15 MPa is applied along the [001] direction. Hint: it may be helpful to draw the directions of the load, the normal to the slip plane, and the slip direction.



$$\cos\phi = \frac{[101]\cdot[001]}{\sqrt{1^2+0^2+1^2}\cdot\sqrt{0^2+0^2+1^2}} = \frac{1}{\sqrt{2}}$$

$$\cos\theta = \frac{[001]\cdot[\bar{1}11]}{\sqrt{1^2}\cdot\sqrt{\bar{1}^2+1^2+1^2}} = \frac{1}{\sqrt{3}}$$

$$\tau = \sigma\cos\phi\cos\theta$$

$$= \left(15\text{ MPa} \times \frac{1}{\sqrt{2}}\right)\left(\frac{1}{\sqrt{3}}\right)$$

$$\tau = 6.12\text{ MPa}$$

8. Grain Size Measurement (10 points)

Estimate the average grain size in microns of a material whose ASTM grain size numbers are 2 and 8 for two different conditions. Assume that the grains have a square shape and the edge length is 100 x D_{100} (or the grain size at 1x is 1/100 of D_{100}). There are 2.54 cm/in.

$$n = \frac{1}{(D_{100})^2} = 2^{N-1}$$

$$D_{100} = 2^{\frac{(1-N)}{2}} \text{ in}$$

grain size at 1x = $\frac{1}{100} D_{100}$

$$D_{100} = \frac{2^{(1-N)/2}}{100} \text{ in} \cdot \frac{2.54 \text{ cm}}{\text{in}} \cdot \frac{10^4 \text{ } \mu m}{\text{cm}}$$

$D_{100}(N=2) = 180 \ \mu m$ $\quad$ $D_{100}(N=8) = 22.5 \ \mu m$