Name (PRINT): ______________________ Signature: ________________________ PID: ______________

MSE 2034 - Elements of Materials Engineering
Big Gift 2 – Formula Sheet

Brinell to tensile strength

$TS = 3.45 \cdot HB$

$$\tau_R = \sigma \cos(\phi) \cos(\lambda)$$

$$\sigma_y = \sigma_0 + k_y d^{-1/2}$$

$$\%CW = \left(\frac{A_o - A_d}{A_0}\right) X\ 100 \qquad r_0 = \frac{r_d}{\sqrt{1 - \frac{CW\%}{100}}}$$

$$d^n - d_0^n = Kt \qquad \sigma = \frac{16FL}{\pi d_0^3}$$

$$\sigma_m = 2\sigma_0 \left(\frac{a}{\rho_t}\right)^{1/2} \qquad \frac{\sigma}{N} = \frac{16FL}{\pi d_0^3}$$

$$\sigma_c = \left(\frac{2E\gamma_s}{\pi a}\right)^{1/2}$$

make it be in terms of meters

$$K_{IC} = Y\sigma_c\sqrt{\pi a}$$ (If no data, Y = 1)

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

$$X = X_0 \exp\left(-\frac{Q}{RT}\right)$$

R = 8.314 J/(mol K)

k = 1.38 x 10^{-23} J/(atom K)

N_a = 6.023 X 10^{23} atom/mol

$$\sigma = \frac{F}{A}$$

$$\sigma_{allow} = \frac{\sigma_{actual}}{FoS}$$

$$\sigma_r = \sigma_{max} - \sigma_{min}$$

$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{max} - \sigma_{min}}{2}$$

$$R = \frac{\sigma_{min}}{\sigma_{max}}$$

$$LM = T(20 + log(t_r))$$

$$\dot{\epsilon}_s = K_1\sigma^n$$

$$\dot{\epsilon}_s = K_2\sigma^n exp\left(-\frac{Q_c}{RT}\right)$$

$$y = 1 - \exp(-kt^n)$$

Consider a single crystal of silver oriented such that a tensile stress is applied along a [001] direction. If slip occurs on a (111) plane and in a $[\bar{1}01]$ direction, and is initiated at an applied tensile stress of 1.1 MPa (160 psi), compute the critical resolved shear stress.

$$\lambda = \cos^{-1}\left[\frac{(0)(-1)+(0)(0)+(1)(1)}{\sqrt{(0^2+0^2+1^2)((-1)^2+0^2+1^2)}}\right] \quad \phi = \cos^{-1}\left[\frac{(0)(1)+(0)(1)+(1)(1)}{\sqrt{(0^2+0^2+1^2)(1^2+1^2+1^2)}}\right]$$

$$1.1(\cos\lambda)(\cos\theta) = 0.449 = \tau_{crss}$$

-Chapter 10

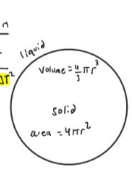
- Homogeneous Nucleation

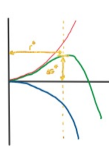
$r^* = \frac{-2\gamma T_m}{\Delta H_f \Delta T}$ $\quad G^* = \frac{16\pi\gamma^3 T_m^2}{3\Delta H_f^2 \Delta T^2}$

$r^* \downarrow$ when $\Delta T \uparrow$

T_m = melting temp

$\Delta T = T_m - T$ = supercooling





Surface free energy → $\Delta G_s = 4\pi r^2 \gamma$

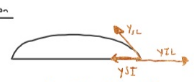
γ = surface tension

Total free Energy → $\Delta G_s + \Delta G_v$

Volume (Bulk) of Free Energy → $\Delta G_v = \frac{4}{3}\pi r^3 \Delta G_v$

$\Delta G_v = \frac{\text{Volume of Free Energy}}{\text{unit volume}}$

- Heterogeneous Nucleation



$\gamma_{IL} = \gamma_{SI} + \gamma_{SL}\cos\theta$

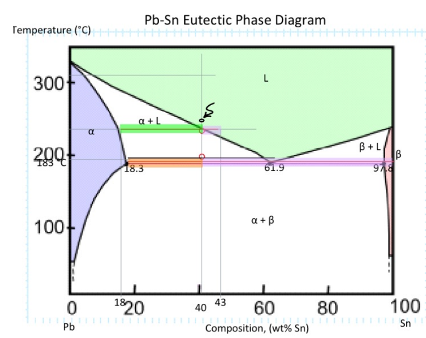
$r^* = \frac{-2\gamma_{SL}}{\Delta G_v}$

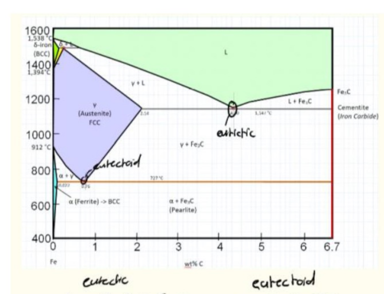
$\Delta G^* = \left(\frac{16\pi\gamma_{SL}^3}{3\Delta G_v^2}\right) \cdot S(\theta)$

- Growth $\quad G = C\exp\left(-\frac{Q}{kT}\right)$

- Rate of Phase Transformations

Avrami Equation → $y = 1 - \exp(-kt^n)$





eutectic: $L \rightleftharpoons \gamma + Fe_3C$

eutectoid: $\gamma \rightleftharpoons \alpha + Fe_3C$

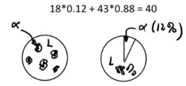
Label the regions on the Eutectic Phase Diagram.

Then answer the 4 questions for each of the following:

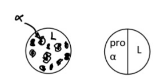
For a 40 wt% Sn alloy:

18*0.12 + 43*0.88 = 40

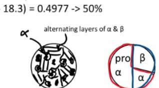
1. 300 °C
2. 220 °C
   a. α + L
   b. Compositions
      i. α -> 18 wt% Sn
      ii. L -> 43 wt% Sn
   c. Amounts
      i. α -> (43 - 40)/(43 - 18) = 0.12 -> 12%
      ii. L -> (40 - 18)/(43 - 18) = 0.88 -> 88%



3. 184 °C
   a. α + L
   b. Compositions
      i. α -> 18.3 wt% Sn
      ii. L -> 61.9 wt% Sn
   c. Amounts
      i. α -> (61.9 - 40)/(61.9 - 18.3) = 0.50 -> 50%
      ii. L -> (40 - 18.3)/(61.9 - 18.3) = 0.4977 -> 50%



4. 182 °C
   a. α + L
   b. Compositions
      i. α -> 18.3 wt% Sn
      ii. β -> 97.8 wt% Sn
   c. Amounts
      i. α -> (97.8 - 40)/(97.8 - 18.3) = 0.727 -> 73%
      ii. β -> (40 - 18.3)/(97.8 - 18.3) = 0.273 -> 27%



Test 2 review

Monday, April 1, 2024 8:22 PM

Color Reset Per Chapter

- **Equations:**
  - Chapter 7 Parts 1, 2

Angle between: ϕ — Ex: Normal to slip plane $[1\bar{1}1]$, Tensile Axis → $[\bar{1}10]$

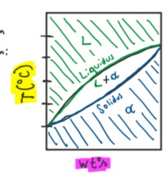
Angle between: λ — Ex: $[\bar{1}10]$, Slip Direction → $[0\bar{1}1]$

$$\cos(\phi) = \frac{(1)(1)+(-1)(-1)+(1)(0)}{\sqrt{(1)^2+(-1)^2+(1)^2}\sqrt{(1)^2+(-1)^2+(0)^2}}$$

$$\cos(\lambda) = \frac{(1)(0)+(-1)(-1)+(1)(0)}{\sqrt{(1)^2+(-1)^2+(0)^2}\sqrt{(0)^2+(-1)^2+(1)^2}}$$

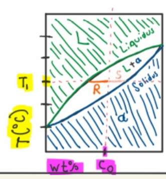
- Critical resolved shear stress → $\tau_{RSS} = \frac{F}{A_0}\cos(\phi)\cos(\lambda)$ (Schmid Factor)
- macroscopic tensile yield stress → $\sigma_y = \frac{\tau_{RSS}}{\cos\phi\cos\lambda}$
- $\tau_{RSS} = \sigma_y \cos(\phi)\cos(\lambda)$
- Hall Petch Equation $\sigma_y = \sigma_0 + k_y d^{-1/2}$ — material constants
- Chapter 7 Part 3
  - cold work % → $CW\% = \frac{A_0 - A_d}{A_0} \times 100$
  - Dislocation Density $\rho_d = \frac{\text{total dislocation}}{\text{Unit volume}}$
- Chapter 8
  - Stress at crack tip → $\sigma_m = 2\sigma_0\left(\frac{a}{\rho_t}\right)^{1/2}$
    - ρ_t = radius of curvature
    - σ_0 = applied stress
    - a = fracture length
  - Stress concentration → $k_t = \frac{\sigma_m}{\sigma_0}$
  - Fracture Toughness → $k_c = Y\sigma_c\sqrt{\pi a} = MPa\sqrt{m}$
    - Y dimensionless parameter
    - σ_c = critical stress for crack propagation = MPa
  - mean stress → $\sigma_m = \frac{\sigma_{max}+\sigma_{min}}{2}$
  - Range of stress → $\sigma_r = \sigma_{max} - \sigma_{min}$
  - Stress amplitude → $\sigma_a = \frac{\sigma_{max}-\sigma_{min}}{2}$
  - Stress Ratio → $R = \frac{\sigma_{min}}{\sigma_{max}}$
  - Steady state creep → $\dot{\epsilon}_s = K\sigma^n e^{\left(-\frac{Q_c}{RT}\right)}$
    - K = material constant
    - n = stress exponent (material parameter)
    - Q_c = Activation energy for creep
    - T = temperature
  - Prediction of Creep Rupture Lifetime → $T(C + \log t_r) = m$
    - C = constant (normally 20)
    - t_r = time to failure
    - m = function of applied stress aka Larson-Miller parameter
- Chapter 9 Part 1

Binary System Phase Diagram:



T = temperature

C_0 = starting wt%



Weight fraction $L = W_L = \frac{S}{R+S} = \frac{C_\alpha - C_0}{C_\alpha - C_L}$

Weight fraction $\alpha = W_\alpha = \frac{R}{R+S} = \frac{C_0 - C_L}{C_\alpha - C_L}$

- **Definitions**
  - Chapter 7 Part 1+2 : Dislocations
    - Dislocations: Linear Defects (one-dimensional) that cause misalignment of nearby atoms
      - Types: edge, screw, mixed
    - Plastic Deformation by Dislocation Motion
      - called slip
        - Slip Systems
          - Combination of slip plane and slip Direction
            - Slip Plane: crystallographic plane where slip occurs
            - Slip Direction: crystallographic direction in which slip occurs.
          - For FCC crystal structure
            - Dislocation motion on {111} family of planes
            - Dislocation motion in <110> family of directions
            - 12 independent slip systems for FCC
  - Chapter 7 Part 3: Strategies for Strengthening
    - 4 Strategies for Strengthening Materials (make dislocation motion difficult)
      1. Reduce Grain Size
         - increases # of slip orientations, which increases barrier strength
      2. Form Solid Solutions
         - Impurity atoms distort the lattice and generate lattice strains (Fill in holes where material can fracture)
      3. Precipitation Strengthening
         - hard Precipitates are difficult to shear
      4. Cold Work (Strain hardening)
         - $CW\% = \frac{A_0 + A_d}{A_0} \cdot 100$
         - Dislocations entangle with one another
         - Dislocation Density $(\rho_d) = \frac{\text{total dislocation length}}{\text{Unit volume}}$
         - Impact of Cold Work
           - As CW ↑...
             - yield strength (σ_y) ↑
             - Tensile Strength (TS) ↑
             - Ductility (%EL) ↓
         - Effect of Heat treating after Cold Work
           - Cold work nullified
           - TS↓ %EL↑
    - 3 Stages during heat Treatment
      1. Recovery
         - reduction of dislocation density by annihilation
      2. Recrystallization
         - New grains formed w/ low dislocation densities, small in size
         - grains replace CW grains
      3. Grain Growth
         - Small grains disappear and big grains grow
         - $d^n - d_0^n = Kt$
    - Grain Size influences Properties
      - Metals w/ small grains → strong and tough at low temperatures
      - metals w/ large grains → good creep resistance at high temperatures

- Chapter 8: Failure
  - Types of Failure
    - Fracture
      - Simple Fracture: Separation of body into 2+ pieces in response to static stress
      - 2 general types of Fracture
        - Ductile Fracture
          - slow crack propagation
          - significant plastic deformation
          - Fails with warning
        - Brittle Fracture
          - Rapid crack propagation
          - no plastic deformation
          - Fails w/out warning
    - Fracture Mechanics
      - Fractures occur due to crack propagation
    - Fatigue
      - Failure under lengthy period of repeated stress/strain
      - Improving Fatigue
        - reducing magnitude of mean stress
        - Surface Treatments
          - compress spots where crack propagation is prevalent
        - Design Changes to remove stress concentrators
    - Creep
      - permanent, time dependent deformation caused by constant stress
      - becomes important for metals that have heated 0.4°C above melting temp
  - Many Equations !!!

$G_v = \frac{4}{3}\pi r^3 \Delta G_v$

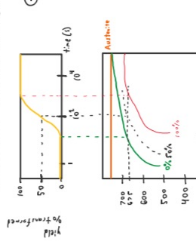
G_v = Volume of Free Energy / unit volume

- Chapter 9 Phase Diagrams
  - Eutectic = $L \to S_1 + S_2$ (super cooling)
  - Eutectoid = $S_1 \to S_2 + S_3$
  - Peritectic = $S_1 + L \to S_2$ (superheating)
  - Hypo = left of tie line
  - Hyper = right of tie line
  - tie line = isotherm
- look at phase diagram to left for most information

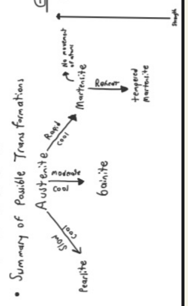
- Chapter 10 Phase Transformation
  - Kinetics of phase transformation
    - Nucleation
      - nuclei (seeds) act as templates where crystals grow
      - rate of addition of atoms to nucleus must be faster than loss rate
      - growth proceeds until equilibrium
      - ΔT↑, then nucleation↑
      - Superheating (peritectic)
      - Supercooling (eutectic, eutectoid)
        - Small supercooling: slow nucleation rate, few nuclei, large crystals
        - large supercooling: rapid nucleation, many nuclei, small crystals
    - Solidification: Nucleation types
      - Homogeneous Nucleation
        - nuclei form in bulk of liquid metal
        - large supercooling
      - Heterogeneous Nucleation
        - Form on the surface
        - Small supercooling
        - more prevalent
  - Nucleation and energy effects
    - thermodynamic parameter called free energy or Gibbs free energy
    - for transformation to occur, ΔG < 0
  - Energy Contribution
    1. $-\Delta G_v$: free energy difference between solid and liquid phases → Volume free energy
    2. γ: positive surface free energy ∝ surface area

- Isothermal Transformation diagram

Given: Transformation Temp: 675°C, $C_0 = 0.76$ wt%



- Summary of Possible Transformations



General Trends

Martensite

T Martensite

Bainite

Fine Pearlite

Coarse Pearlite

Spheroidite