10620PME 300600 材料科學導論 Introduction to Material Science

期中考一 Midterm Exam I

AM 10:10-12:00, April 2, 2018

1. Answer following questions briefly: (55%)

(a) What are shape-memory alloys? How to use these alloys for artery stents 心血管支架.

Shape-memory alloys, once strained **1**, revert back to their original shape **1** upon an increase in temperature above T_c **1**.

Supporting weakened artery walls or expanding narrowed arteries **1**: The deformed stent is first delivered in the appropriate position in the artery using a probe **1**. The stent expands to its original shape and size after unfastening its bundle sheath and increasing its temperature to body temperature **1**.

(b) A 100-gram alloy of Fe and C consists of 99.2 wt% Fe and 0.8 wt% C. What are the atomic percentages of Fe and C in this alloy? (atomic mass: Fe 55.85 g/mol, C 12.01 g/mol)

C: $(0.8/12.01)/[(99.2/55.85)+(0.8/12.01)] \times 100\%$ **1.5** = 3.61 at% **1**

Fe: $(99.2/55.85)/[(99.2/55.85)+(0.8/12.01)] \times 100\%$ **1.5** = 96.39 at% **1**

(c) List the electronic configurations of Si (Z = 14) and Ag (Z = 47).

Si: $1s^2 2s^2 2p^6 3s^2 3p^2$ **2.5**

Ag: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^1$ **2.5**

(d) Describe the trends of atomic radius and electron affinity in the periodic table.

One moves from top to bottom in a group, the size of the atom, generally, increases. **1.5**

One moves across a period from left to right, the size of the atom, generally, decreases. **1.5**

Electron affinity increases as we move to right across a period **1**and decreases as we move down in a group. **1**

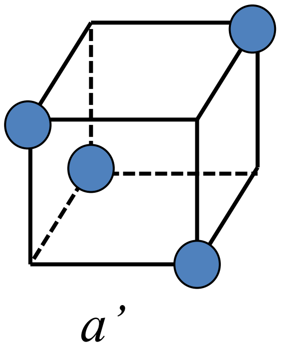
(e) Calculate the density of BCC iron metal. (atomic radius = 0.124 nm, atomic mass = 55.85 g/mol) *a*: lattice parameter, *r*: atomic radius $\Rightarrow$ $\sqrt{3}a = 4r$ **1** $\Rightarrow$ $a = \left(\frac{4}{\sqrt{3}}\right) r$ **1**

$$\rho = m/V = \left\{\frac{(2\ \text{atoms})(55.85\ \text{g/mol})}{6.02\times10^{23}\ \text{atoms/mol}}\left(\frac{10^{-6}\ \text{Mg}}{\text{g}}\right)\right\} / \left((4/\sqrt{3})\times 0.124\times10^{-9}\ \text{m}\right)^3$$

$$= 7.90\frac{\text{Mg}}{\text{m}^3}$$

1 1 1

(f) Calculate the atomic packing factor (APF) for the HCP unit cell, assuming the atoms to be perfect hard spheres.



$$\sqrt{2}a' = 2r \quad a' = \sqrt{2}r$$

$$\frac{1}{2}c = \frac{2}{3}\sqrt{3}a' = \frac{2r\sqrt{2}}{\sqrt{3}}$$

$$\frac{c}{2r} = \frac{c}{a} = \frac{2\sqrt{2}}{\sqrt{3}} = 1.633$$

1 **1**

$$\text{APF} = \frac{6\times\frac{4\pi}{3}r^3}{6\times\frac{1}{2}\times2r\times\sqrt{3}r\times1.633\times2r}\ \mathbf{1} = \frac{8\pi}{12\times1.633\times\sqrt{3}}\ \mathbf{1} = 0.7405\mathbf{1}$$

(g) List the indices of two planes and three directions in Fig. 1.

Plane 1: $(1\bar{1}00)$ **1**

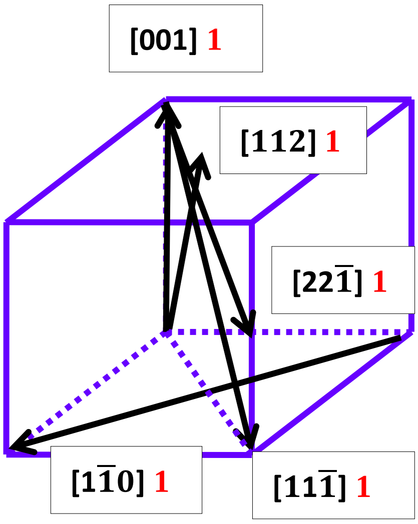
Plane 2: $(10\bar{1}1)$ **1**

Direction 1: $[01\bar{1}0]$ **1**

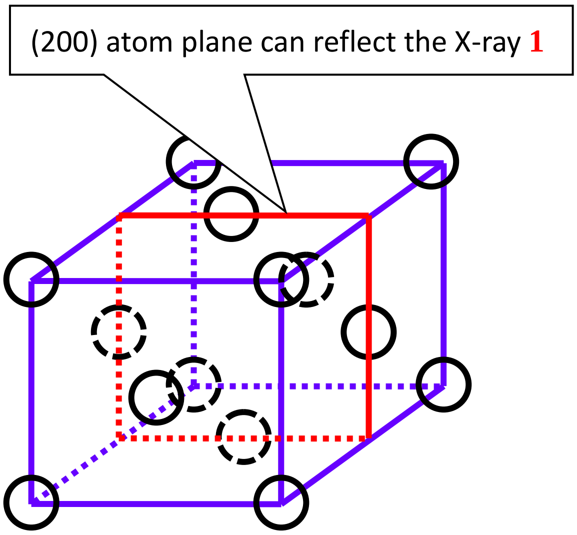
Direction 2: $[11\bar{2}1]$ or $[11\bar{2}3]$ **1**

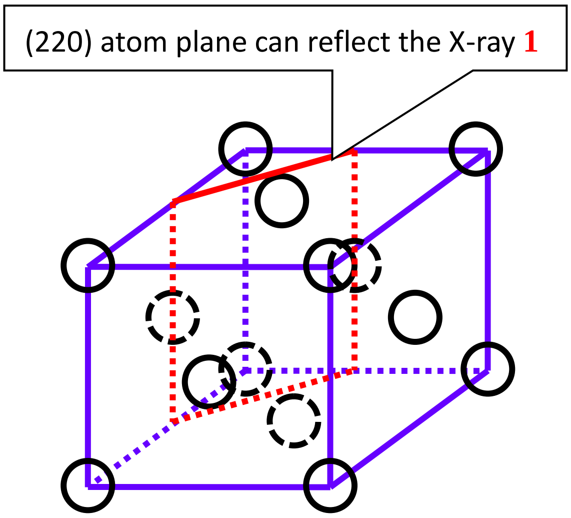
Direction 3: $[\bar{1}101]$ or $[\bar{1}102]$ **1**

(h) Draw the $[001]$, $[1\bar{1}0]$, $[11\bar{1}]$, $[112]$, and $[22\bar{1}]$ directions in a cubic unit cell.



(i) Prove that the diffraction peaks of {100} and {110} planes are not found for a FCC crystal.





The extra distance of travel of ray 2 for (100) planes is λ means that the extra distance of travel of ray 2 for (200) planes is λ/2 **1**, so that deconstructive interference occurs **1** and no (100) diffraction peak can be seen.

The extra distance of travel of ray 2 for (110) planes is λ means that the extra distance of travel of ray 2 for (220) planes is λ/2, **1** so that deconstructive interference occurs **1** and no (110) diffraction peak can be seen.

(j) Compare the differences between homogeneous and heterogeneous nucleation of solid particles in liquid metal.

	Homogeneous nucleation	Heterogeneous nucleation
Nucleation site: **2**	Metal itself	Surfaces of other agents e.g.: Container surface, Insoluble impurities.
Activation energy: **1**	Higher	Lower
Critical size: **1**	Larger	Smaller
Undercooling: **1**	Larger	Smaller

(k) Calculate the ASTM grain size number *n* in Fig. 2.

Grain number in this photo: $4 \times 1/4 + 35 \times 1/2 + 61 \times 1 = 79.5$ **2**

200×, 8 cm × 8 cm , 79.5 grains change to 100×, 2.54 cm × 2.54 cm , N grains:

$N = 79.5 \times 4 \div (2.54^2/8^2) = 32$ **1**

$N = 32 = 2^{n-1}$ **1** $\Rightarrow n - 1 = 5 \Rightarrow n = 6 \Rightarrow$ ASTM grain size number is 6. **1**

2. Discuss the differences of the bonding-origins and material properties between the (a) ionic, (b) covalent, and (c) metallic bonds. (15%)

Bonding-origins

Ionic: Electrons are transferred **1** from electropositive to electronegative atoms and cations and anions are formed **1**. Ionic bonding is due to electrostatic force of attraction **1** between cations and anions.

Covalent: Takes place between elements with small electronegativity differences**1**. Outer s and p electrons are shared **1** between two atoms to obtain noble gas configuration. Covalent bonds are directional. **1**

Metallic: Loosely bounded valence electrons **1** are attracted towards nucleus **1** of other atoms, shared by many atoms, form electron clouds **1**, and overall energy of individual atoms are lowered.

Material properties

Ionic: Ionic solids are hard, rigid, strong **1**, and brittle **1**. Ionic solids are excellent insulators **1**.

Covalent: Covalent solids are hard, rigid, strong and brittle **1**. Covalent materials are poor conductors of electricity **1** not only in a network solid form but also in a liquid or molten form **1**.

Metallic: Metals are significantly more malleable **1** than ionic or covalent networked materials. Metals are excellent conductors **1** of heat and electricity.

3. Calculate the maximum interstitial atomic radius of the interstitial in FCC and BCC of Fe. The interstitials in FCC are at the edge-center of a unit cell and atomic radius of Fe = 0.129 nm. The interstitials in BCC are at the (1/2, 1/4, 0), (1/4, 1/2, 0), (1/2, 3/4, 0), (3/4, 1/2, 0), etc., type positions of a unit cell and atomic radius of Fe = 0.124 nm. (10%)

The interstitial in FCC:

$r + R = 1/2\ a$ **1** and $a = 4R/\sqrt{2}$ **1** $\Rightarrow$ $r + R = 2R/\sqrt{2} = \sqrt{2}R$ **1**

$r/R = \sqrt{2} - 1 = 0.414$ **1**

$r = 0.414 \times 0.129\ \text{nm} = 0.053\ \text{nm}$ **1**

The interstitial in BCC:

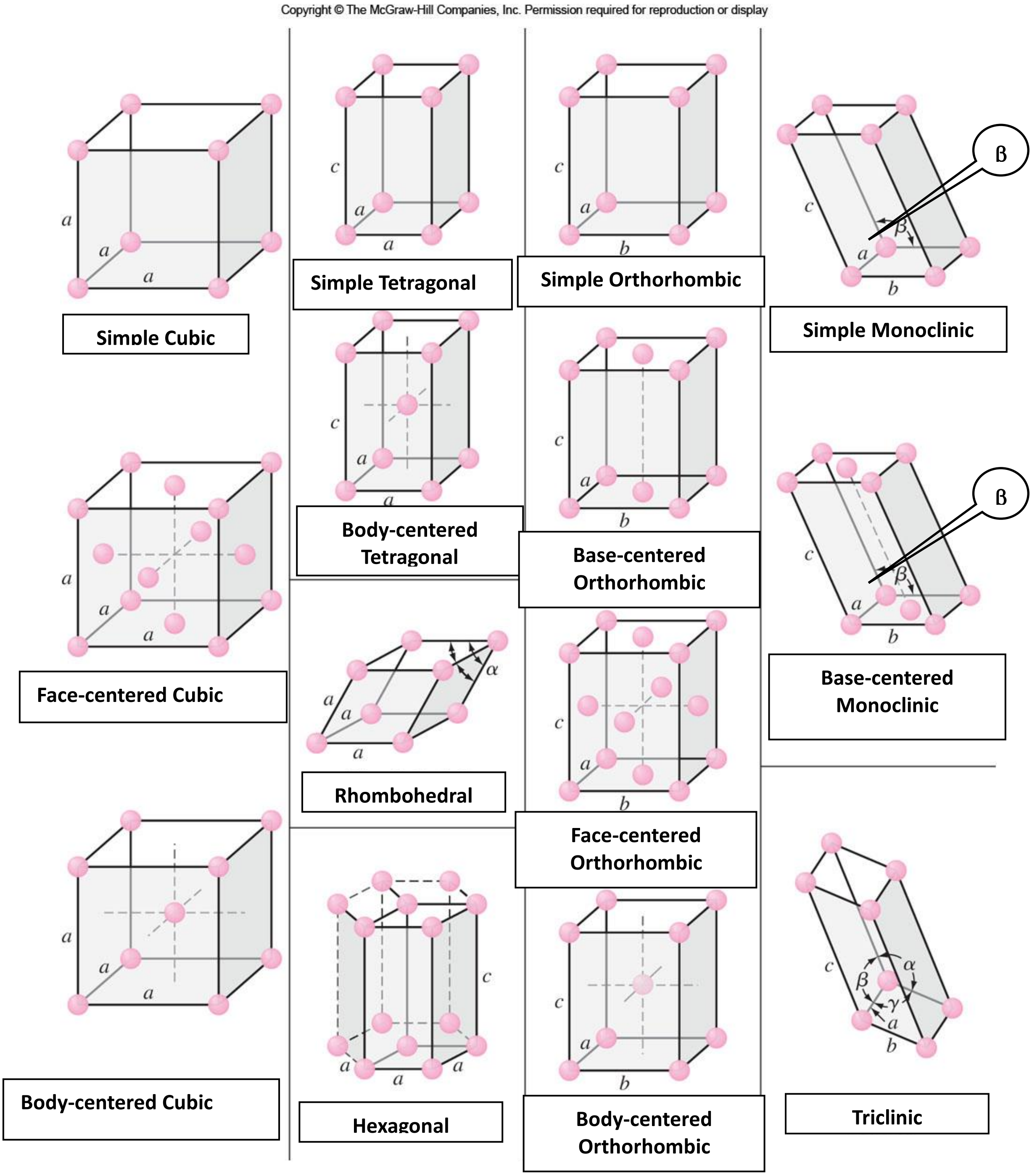
$r + R = \sqrt{(\frac{1}{2} - 0)^2 + (\frac{1}{4} - 0)^2 + (0 - 0)^2}\ a = \frac{\sqrt{5}}{4}a$ **1** and $a = 4R/\sqrt{3}$ **1**

$r + R = \sqrt{5}R/\sqrt{3} = 1.291R$ **1**

$r/R = 1.291 - 1 = 0.291$ **1**

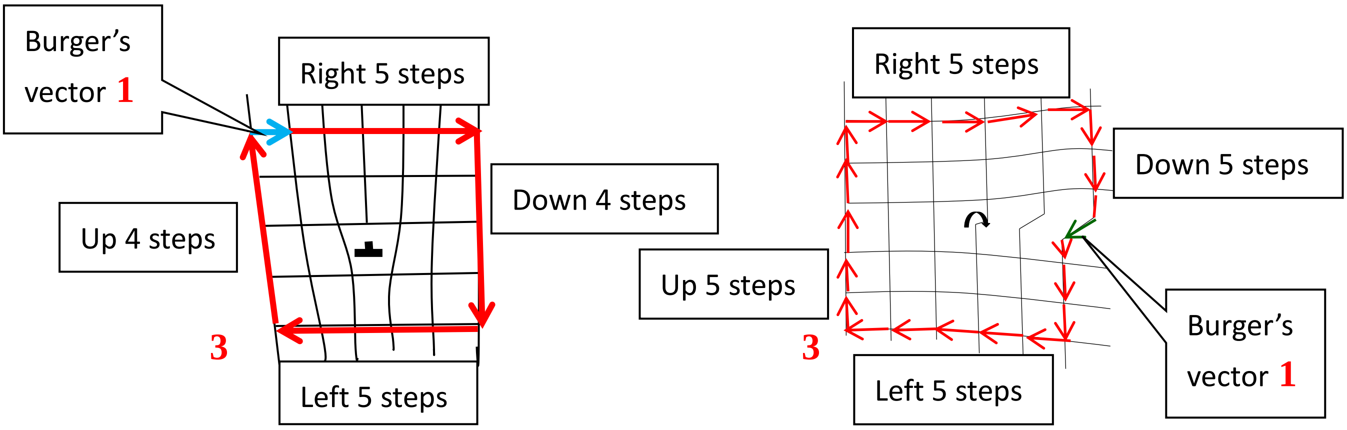
$r = 0.291 \times 0.124\ \text{nm} = 0.036\ \text{nm}$ **1**

4. Sketch and explain the characteristics of the 14 Bravais convectional unit cells. (10%)



Every unit cell = 0.75

4. Draw the schematic diagrams of edge and screw dislocations and determine their Burger's vectors. (10%)



Edge dislocation Screw dislocation

5. Sketch and explain the principles for scanning electron microscope (SEM) and atomic force microscope (AFM). (10%)

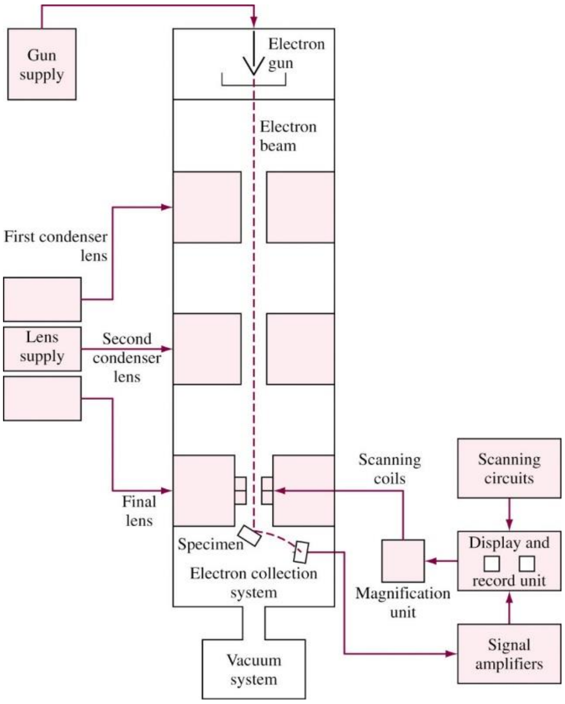
SEM:

Electron gun generates electrons that are accelerated (10-50 kV), focused, and hit the sample surface and secondary electrons are produced.1 The secondary electrons are collected to produce the signal. The signal is used to produce the image1.

Depth of field: 300 times that of OM. 10 μm at 10,000× 1

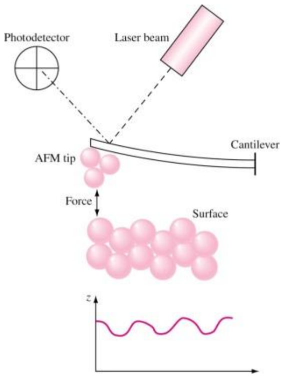
Magnification: 15× - 500,000×

Chemical analysis: SEM is always equipped with an X-ray spectrometer. 1 2



AFM:

Similar to STM but tip attached to cantilever beam 1. When tip interacts with surface, van der Waals forces deflect the beam. Deflection detected by laser and photodetector 1. Short-range repulsive force (contact mode) or long-range attractive force (non-contact mode) can be detected 1. Non-conductive materials can be scanned 1.



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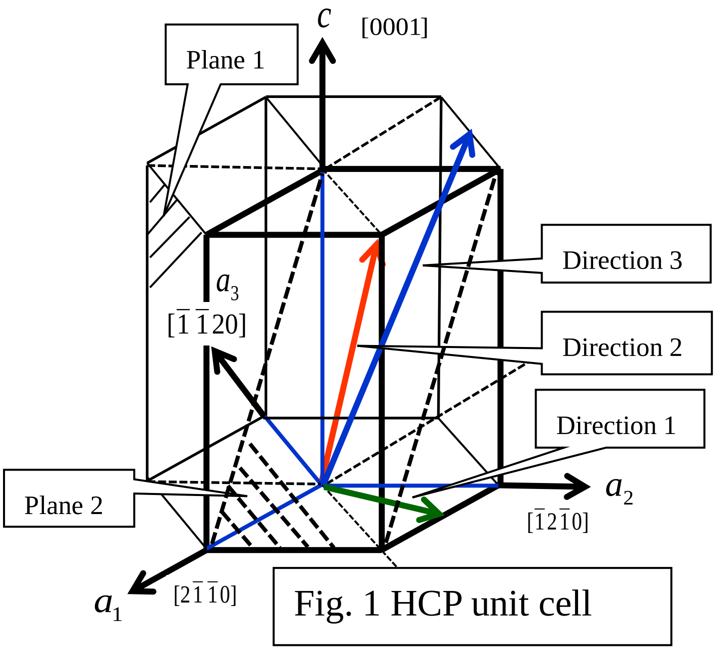


Fig. 1 HCP unit cell

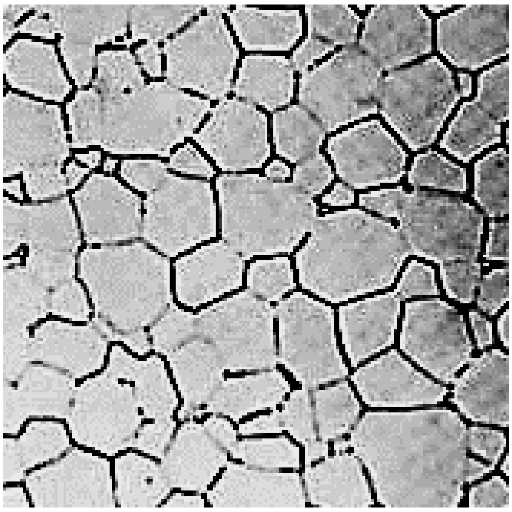


Fig. 2 Grain structure in the optical microscope. 200×
(The size of this photo is 8 × 8 cm.)

10520PME 300600 材料科學導論 Introduction to Material Science

期中考二 Midterm Exam II

10:10-12:00, May 8, 2017

1. Answer following questions briefly: (70%)

(a) Calculate the vacancy fraction at 657 °C in pure aluminum. Assume: $E_v = 0.74$ eV, $C = 1$ and $k = 8.62 \times 10^{-5}$ eV/K.

$\frac{n}{N}$ ❶ $= Ce^{-E_v/kT}$ ❶ $= \; e^{-0.74/[8.62\times10^{-5}(657+273)]}$ ❶❶ $= 9.797 \times 10^{-5}$ ❶

(b) The diffusivity of copper atoms in solid copper is 10^{-18} cm²/s at 500 °C and 2×10^{-13} cm²/s at 1000 °C. Calculate the activation energy (J/mol) for the diffusion of Cu in Cu in the temperature range 500 °C to 1000 °C. [$R = 8.314$ J/(mol·K)]

$$\frac{D_{1000}}{D_{500}} = \frac{\exp(-Q/RT_2)}{\exp(-Q/RT_1)} = \exp\left(\frac{-Q}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)\right) *$$

$$\frac{2\times10^{-13}}{1\times10^{-18}} = \exp\left(-\frac{Q}{R}\left(\frac{1}{1273} - \frac{1}{773}\right)\right) *$$

$$\ln\,(2.0\times10^{5}) = -\frac{Q}{R}(7.855\times10^{-4} - 12.94\times10^{-4}) = \frac{Q}{8.314}(5.08\times10^{-4}) *$$

$$12.21 = Q(6.11\times10^{-5}) \;\; * \Rightarrow \; Q = 199{,}770 \text{ J/mol} = 200 \text{ kJ/mol} *$$

(c) List Fick's first law and Fick's second law and explain their physical meanings.

Fick´s first law: $\mathrm{J} = -\mathrm{D}\frac{dC}{dx}$ ❶

The net flow of atoms by atomic diffusion (from rich to rare positions ❶) is equal to diffusion coefficient (diffusivity) *D* times the concentration gradient *dC/dx*. ❶

Fick´s first law: $\frac{dC}{dt} = \frac{d}{dx}\left(\mathrm{D}\frac{dC}{dx}\right)$ ❶

Rate of compositional change is equal to the rate of change ❶of diffusivity times concentration gradient. ❶

(d) A sheet of a 70% Cu-30%Zn alloy is cold-rolled 25 percent to a thickness of 2.80 mm. The sheet is then further cold-rolled to 2.0 mm. What is the total percent cold work?

$\frac{t_0 - t_f}{t_0} \times 100\% = \%$ roll reduction ❶→ $\frac{t_0 - 2.80 \text{ mm}}{t_0} \times 100\% = 25\%$❶

$t_0 = 3.733$ mm ❶ → $\frac{t_0 - t_f}{t_0} \times 100\% = \frac{3.733 - 2}{3.733} \times 100\%$❶ $= 46.42\%$❶

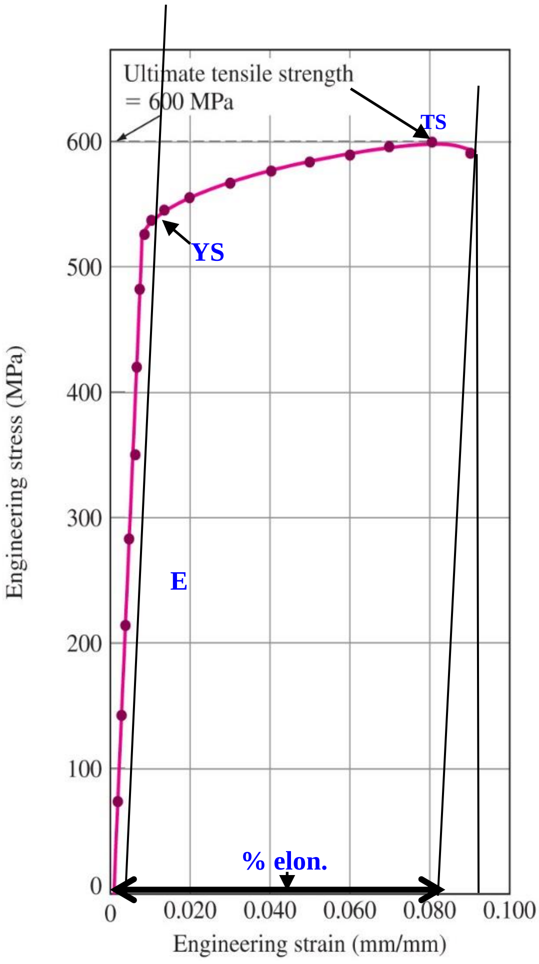
(e) Sketch to explain how to define the elastic modulus, yield strength, tensile strength, elongation, and toughness in the engineering stress-engineering strain curve.

Elastic modulus: The slope of initial stress-strain curve (elastic deformation range). E = σ/ε ❶

Yield strength: The corresponding stress of a small certain plastic deformation (such as 0.2%). ❶

Tensile strength: The maximum stress for a stress-strain curve. ❶

Elongation: Draw a line that is parallel to elastic range from the end point of the stress-strain curve and intercept with abscissa at a specific strain. This specific strain is elongation. ❶



Toughness: The area below the stress-strain curve. ❶ ❶ ❶

(f) Compare the engineering stress and strain with the true stress and strain for the tensile test of a low-carbon steel. Load: 60,000 N, Instantaneous diameter (60,000 N): 1.15 cm, Initial diameter: 1.25 cm.

$$A_0 = \frac{\pi}{4}(0.0125\text{ m})^2 = 0.0001227\text{ m}^2\text{ ; } A_i = \frac{\pi}{4}(0.0115\text{ m})^2 = 0.0001039\text{ m}^2$$

$$\text{Assuming no volume change during extension, } l_0 A_0 = l_i A_i \Rightarrow \frac{l_i}{l_0} = \frac{A_0}{A_i} *$$

$$\sigma = \frac{F}{A_0} = \frac{60{,}000\text{N}}{0.0001327\text{ m}^2} = 489\text{ MPa}*;\ \sigma_t = \frac{F}{A_i} = \frac{60{,}000\text{N}}{0.0001039\text{ m}^2} = 577\text{ MPa}*$$

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{l_i - l_0}{l_0} = \frac{A_0}{A_i} - 1 = \frac{0.0001227\text{ m}^2}{0.0001039\text{ m}^2} - 1 = 0.181*$$

$$\varepsilon_t = \ln\frac{l_i}{l_0} = \ln\frac{A_0}{A_i} = \ln\frac{0.0001227\text{ m}^2}{0.0001039\text{ m}^2} = 0.166*$$

(g) List all the slip systems in FCC {111}<$1\bar{1}0$> crystal structure.

$(111)[1\bar{1}0], (111)[10\bar{1}], (111)[01\bar{1}], (\bar{1}11)[110], (\bar{1}11)[101], (\bar{1}11)[01\bar{1}],$

$(1\bar{1}1)[110], (1\bar{1}1)[10\bar{1}], (1\bar{1}1)[011], (11\bar{1})[1\bar{1}0], (11\bar{1})[101], (11\bar{1})[011]$.

(h) A stress of 10 MPa is applied in the [001] direction of a unit cell of a BCC iron single crystal. Calculate the resolved shear stress for the following slip systems: (i) $(101)[\bar{1}11]$, (ii) $(211)[\bar{1}11]$.

$\tau = \sigma \times \cos\lambda \times \cos\phi$ ❶ ⇒

(i) $(101)[\bar{1}11]$

$$\tau = 10\ \text{MPa} \cdot \frac{1}{\sqrt{1} \times \sqrt{1^2+1^2}} \cdot \frac{1}{\sqrt{1} \times \sqrt{1^2+1^2+1^2}} = 10\ \text{MPa} \cdot \frac{1}{\sqrt{6}} = 4.08\ \text{MPa}$$ ❶❶

(ii) $(211)[\bar{1}11]$

$$\tau = 10\ \text{MPa} \cdot \frac{1}{\sqrt{1} \times \sqrt{2^2+1^2+1^2}} \cdot \frac{1}{\sqrt{1} \times \sqrt{1^2+1^2+1^2}} = 10\ \text{MPa} \cdot \frac{1}{\sqrt{18}} = 2.36\ \text{MPa}$$ ❶❶

(i) Sketch and compare the differences between slip and twinning deformation in (i) atomic move distance, (ii) lattice orientation.

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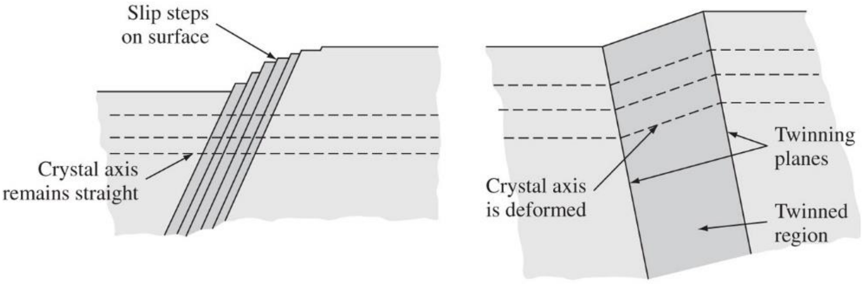


(a) (b)

❶ ❶

(i) In slip the atoms on one site of the slip plane all move equal distances❶, whereas in twinning the atoms move distances proportional to their distance from twinning plane. ❶

(ii) Slip does not reorient lattice. ❶ However, twinning reorients lattice and may place new slip systems. ❶

(j) Describe the general procedure to measure the hardness.

1. Press the indenter that is harder than the metal ❶ into metal surface. ❶
2. Withdraw the indenter ❶
3. Measure hardness by measuring depth ❶ or width of indentation. ❶

(k) Describe three distinct stages of ductile fracture and brittle fracture.

Ductile fracture: (1) Specimen forms neck and cavities within neck. ❶ (2) Cavities form crack and crack propagates towards surface, perpendicular to stress. ❶ (3) When the crack nears the surface, direction of crack changes to 45° resulting in cup-and-cone fracture. ❶

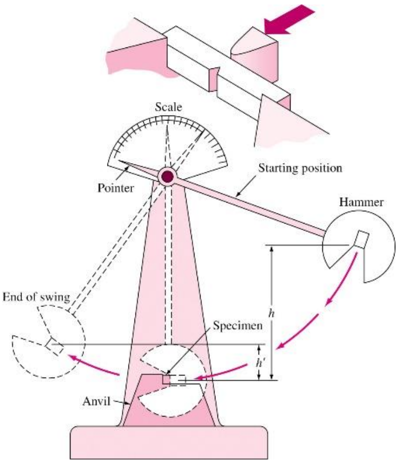
Brittle fracture: (1) Plastic deformation concentrates dislocation along slip planes at obstacles. ❶ (2) Microcracks nucleate due to shear stress where dislocations are blocked. ❶ (3) Crack propagates to fracture. ❶

(l) Sketch and describe the experimental procedure of Charpy V-notch impact-testing.

(1) Place a special Charpy V-notch specimen (shown in the upper part of Fig.) across parallel jaws in the impact-tester. ❶

(2) Release the hammer to strike the specimen on its downward swing and fracture the specimen. ❶

(3) The energy absorbed by the fracture can be measured by the difference between the hammer's initial and final heights. ❶ ❶❶

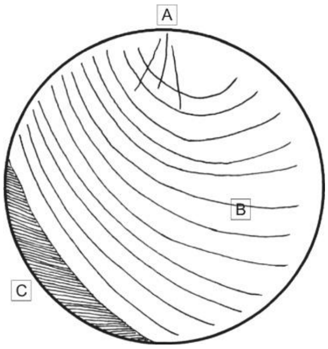


(m) Sketch and explain the characteristics of the fatigue fracture surface.

A: Crack nucleates at region of stress concentration near surface (sharp corner, notch inclusion or flaw) and propagates due to cyclic loading. ❶

B: Clamshell or "beach" markers are created with cyclic loading. (smooth region). ❶

C: Failure occurs when cross sectional area of the metal too small to withstand applied load. (rough surface area) ❶



❶ ❶❶

(n) Equiaxed MAR-M 247 MFB alloy is to support a stress of 207 MPa (Fig. 7.31). Determine the time to stress rupture at 927 °C.

From Fig. 7.31: $P(\text{L.M.}) = [26.7 + (27.8–26.7)5/10] \times 10^3$ ❶ $= 27250$ ❶

$P(\text{L.M.}) = 27250 = [T(°\text{C}) + 273](20 + \log t_r)$ ❶$= (927 + 273)\ (20 + \log t_r)$

$20 + \log t_r = 22.708$ ❶ $\Rightarrow t_r = 10^{2.708} = 510.5$ (h) ❶

2. The diffusivity values depend on 5 variables. Discuss how to affect? (10%)

Diffusivity depends upon

Type of diffusion: Whether the diffusion is interstitial or substitutional. Small interstitial atoms are easy to move ❶ and interstitial diffusion rates are always faster than that of substitutional diffusion. ❶

Temperature: As the temperature increases diffusivity increases. ❶ Melting point ↑ ⇒ Diffusivity ↓. ❶

Type of crystal structure: BCC crystal has lower APF ❶ than FCC and hence has higher diffusivity. ❶

Type of crystal imperfection: More open structures (such as grain boundaries) increases diffusion ❶. Grain boundary diffusion rates are far faster than that of lattice diffusion. ❶

The concentration of diffusing species: Higher concentrations ❶ of diffusing solute atoms will affect diffusivity. ❶

3. (a) Calculate the value of the diffusivity D for the diffusion of carbon in γ iron at 950 °C. Use values of $D_0 = 2.0 \times 10^{-5}\ \mathrm{m^2/s}$, $Q = 142$ kJ/mol, and $R = 8.314$ J/(mol·K). (b) Consider the gas carburizing of a gear of 1040 steel at 950 °C. Calculate the time in minutes necessary to increase the carbon content to 0.60% at 0.35 mm below the surface. $C_s = 1.20\%$ C. (10%)

(a)

$D = D_0 e^{-Q/RT}$ ❶ $= 2.0 \times 10^{-5}\ \mathrm{m^2/s}\left\{\exp\dfrac{-142000\ \mathrm{J/mol}}{[8.314\ \mathrm{J/mol{\cdot}K}](950+273)\mathrm{K}}\right\}$ ❶❶❶

$D = 1.7517 \times 10^{-11}\ \mathrm{m^2/s}$ (at 950 °C) ❶

(b)

$\dfrac{C_s - C_x}{C_s - C_0} = \mathrm{erf}\left(\dfrac{x}{2\sqrt{Dt}}\right) \rightarrow \dfrac{1.20 - 0.60}{1.20 - 0.40} = \mathrm{erf}\left(\dfrac{0.40\ \mathrm{mm}}{2\sqrt{1.3174 \times 10^{-11}\ \mathrm{m^2/s} \times t}}\right)$ ❶

$0.75 = \mathrm{erf}\left(\dfrac{0.40\ \mathrm{mm}}{2\sqrt{1.72 \times 10^{-11}\ \mathrm{m^2/s} \times t}}\right)$ ❶

From error function Table: z = 0.80 → erf z = 0.7421 and = 0.85 → erf z = 0.7707❶

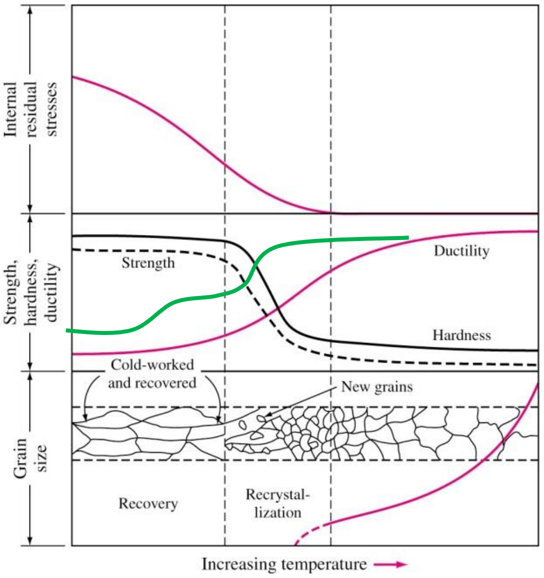
∴ erf z = 0.75 → $\dfrac{0.7707-0.7421}{0.85-0.80} = \dfrac{0.75-0.7421}{z-0.80}$

$\rightarrow z = 0.8138 = \dfrac{0.40\ \mathrm{mm}}{2\sqrt{1.7517 \times 10^{-11}\ \mathrm{m^2/s} \times t}}$❶

$t = 3448$ s = 57.5 min ❶

4. Sketch and discuss (from the microstructure change) the annealing temperature effect on the tensile strength, elongation, and electrical conductivity of a heavily cold-worked 70Cu-30Zn alloy. (10%)

Low temperature recovery:



Vacancies are eliminated❶. Dislocations are moved into lower energy configuration and form subgrain structure (polygonization). ❶ The quantity of dislocation is not obvious decreased.

The strength is reduced slightly and the ductility is increased slightly, but its electrical conductivity (green curve) is significantly increased. ❶

Intermediate temperature recrystallization:

The cold worked structure is completely replaced with recrystallized grain structure (new strain-free grain) ❶. The quantity of dislocation is obvious decreased and recover to the un-worked condition. ❶❶❶

The strength is reduced obviously and the ductility is increased obviously❶, its electrical conductivity (green curve) is significantly increased again. ❶

High temperature grain growth:

The grain size becomes larger in order to reduce the area of grain boundary❶. The strength is reduced slightly and the ductility is increased slightly, its electrical conductivity (green curve) is slightly increased. ❶

5. A 7075 aluminum plate is subjected to a tensile stress of 165 MPa. The fracture toughness of the materials is given to be 24.2 MPa·m$^{1/2}$. (*a*) Determine the critical crack length to assure the plate will not fail under the static loading conditions (assume $Y = 1$). (*b*) Consider the same plate under the action of cyclic tensile/compressive stresses of 165 MPa and 65 MPa respectively. Under the cyclic conditions, a crack length reaching 50% of the critical crack length under static conditions (part *a*) would be considered unacceptable. If the component is to remain safe for 1 million cycles, what is largest allowable initial crack length? (10%)

$$\text{Hint}: \quad N_f = \frac{a_f^{-(m/2)+1} - a_0^{-(m/2)+1}}{AY^m \sigma^m \pi^{m/2}[-(m/2)+1]} \qquad (\text{Where} \quad m = 3,\ Y = 1,\ A = 2.0 \times 10^{-12})$$

(*a*)

$$K_{\mathrm{IC}} = Y\ \sigma_f\ \sqrt{\pi a}❶❶ \ \rightarrow\ 24.2\ \text{MPa·m}^{1/2} = 1 \times 165\ \text{MPa}\ \sqrt{\pi a}❶❶ \ \rightarrow a = 0.006847\ \text{m}❶$$

(*b*)

σ = 165 MPa, $a_f = a/2$ = 0.003424 m, $N_f = 1 \times 10^6$, $m = 3$, $A = 2.0 \times 10^{-12}$.

$$N_f = \frac{a_f^{-\left(\frac{m}{2}\right)+1} - a_0^{-\left(\frac{m}{2}\right)+1}}{A\sigma^m \pi^{m/2} Y^m[-\left(\frac{m}{2}\right)+1]} \text{ ❶ } \rightarrow \quad 1\times 10^6 = \frac{0.003424^{-0.5} - a_0^{-0.5}}{2.0\times 10^{-12}165^3\pi^{3/2}1^3[-\left(\frac{3}{2}\right)+1]} \text{ ❶}$$

$-25.014 = 17.09 - a_0^{-0.5}$ ❶

$a_0^{-0.5} = 42.104$ ❶

$a_0 = 5.641 \times 10^{-4}$ m ❶

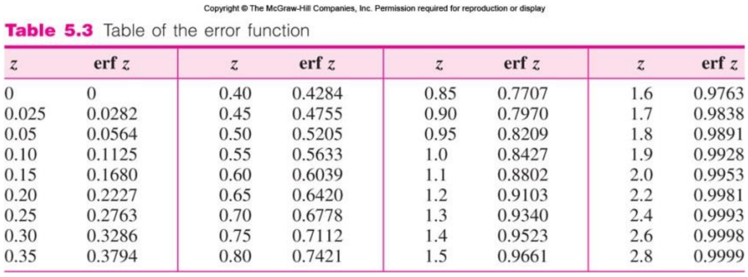


Table 5.3 Table of the error function

z	erf z	z	erf z	z	erf z	z	erf z
0	0	0.40	0.4284	0.85	0.7707	1.6	0.9763
0.025	0.0282	0.45	0.4755	0.90	0.7970	1.7	0.9838
0.05	0.0564	0.50	0.5205	0.95	0.8209	1.8	0.9891
0.10	0.1125	0.55	0.5633	1.0	0.8427	1.9	0.9928
0.15	0.1680	0.60	0.6039	1.1	0.8802	2.0	0.9953
0.20	0.2227	0.65	0.6420	1.2	0.9103	2.2	0.9981
0.25	0.2763	0.70	0.6778	1.3	0.9340	2.4	0.9993
0.30	0.3286	0.75	0.7112	1.4	0.9523	2.6	0.9998
0.35	0.3794	0.80	0.7421	1.5	0.9661	2.8	0.9999

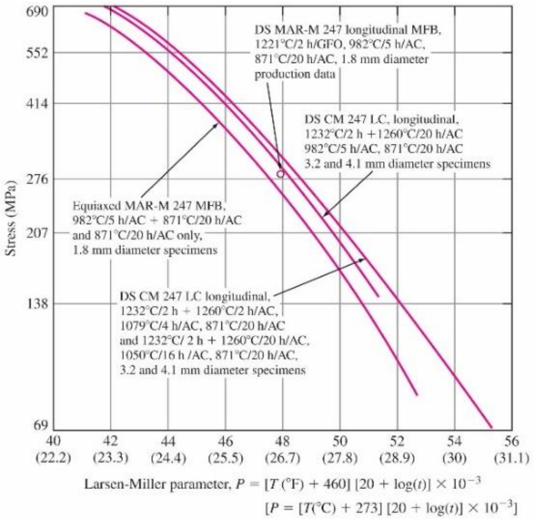


Fig. 7.31

10620PME 300600 材料科學導論 Introduction to Material Science

期末考 Final Exam

11:10-13:00, June 21, 2018

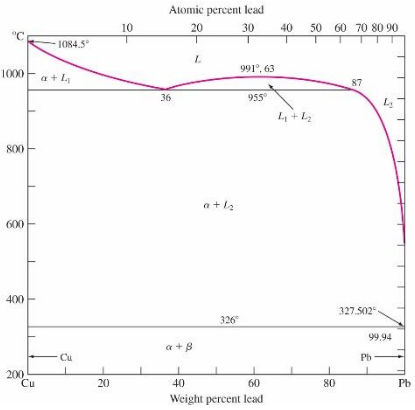
1. Answer following questions briefly: (70%)

(a) List the Gibbs phase rule and explain how to construct a ternary phase diagram.

$P + F = C + 2$ ❶ (P = number of phases that coexist in a system, C = Number of components, F = Degrees of freedom) ❶. Generally, the pressure is set at 1 atm, then Gibbs phase rule becomes to $P + F = C + 1$. ❶

Ternary phase diagrams ($C = 3$ and $P = 1$, → $F = 3 + 1 - 1 = 3$) can be constructed by using an equilateral triangle as a base with temperature on a vertical axis❶. Pure components are at each end of triangle and any composition can locate in this triangle❶.

(b) Draw the monotectic invariant reaction in a phase diagram.



955°C: $L_1(36\%Pb) \rightarrow Cu(0\%Pb) + L_2(87\%Pb)$

or T_1: $L_1 \rightarrow S + L_2$ ❶

❶❶❶❶

(c) List the name, temperature, and composition of the all invariant reactions in the Ti-Ni phase diagram.

Eutectoid: 765°C, $\beta Ti(5.5\%Ni) \rightarrow \alpha Ti(0.5\%Ni) + Ti_2Ni(37\%Ni)$ ❶

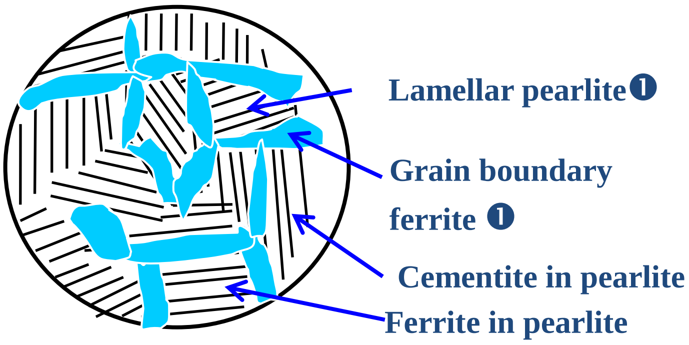
Eutectic: 942°C, $L(27.9\%Ni) \rightarrow \beta Ti(11.5\%Ni) + Ti_2Ni(37\%Ni)$ ❶

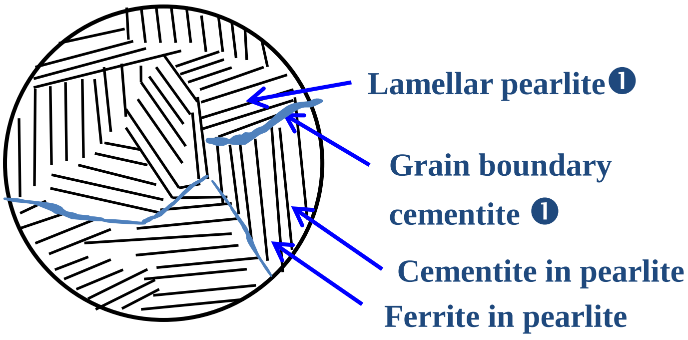
Peritectic: 984°C, $L(37.5\%Ni) + TiNi(54.4\%Ni) \rightarrow Ti_2Ni(37.8\%Ni)$ ❶

Eutectic: 1118°C, $L(65.7\%Ni) \rightarrow TiNi(61.8\%Ni) + TiNi_3\ (78.3\%Ni)$ ❶

Eutectic: 1304°C, $L(86.1\%Ni) \rightarrow TiNi_3\ (78.3\%Ni) + Ni(88.6\%)$❶

(d) Sketch and compare the slow-cooling microstructures of the Fe-0.2%C and Fe-1.0%C plain carbon steels.

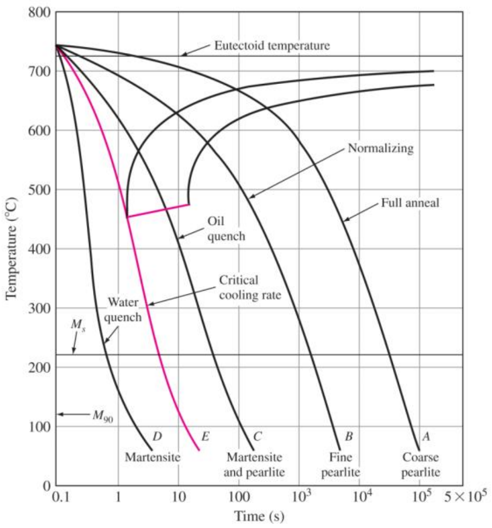




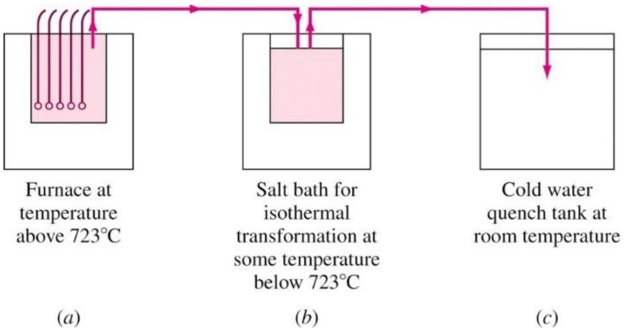
Microstructure of Fe-0.2%C	Microstructure of Fe-1.2%C
Grain boundary ferrite ≈ 25 wt% ❶	Grain boundary cementite ≈ 3.5 wt%❶
Lamellar pearlite ≈ 75 wt%	Lamellar pearlite ≈ 96.5 wt%

(e) Draw the cooling curves of full anneal, normalizing, oil quench, water quench and critical cooling rate in the continuous-cooling diagram of eutectoid plain-carbon steel.

❶❶❶❶❶



(f) Describe the typical experimental procedures to get an isothermal transformation diagram for a eutectoid plain carbon steel.



Several samples are first austenitized above eutectoid temperature (723 °C) in a salt bath ❶ and rapidly cooled to desired temperature (< 723 °C) in another salt bath ❶ and then quenched in water at various time intervals ❶. The transformed pearlite quantity after each transformation time can be calculated from metallography photos ❶ and an isothermal transformation diagram can be constructed ❶.

(g) List the limitations of plain-carbon steels comparing with alloy steels.

(1) Cannot be strengthened beyond 690 MPa without losing ductility and impact strength. ❶
(2) Not deep hardenable.❶
(3) Low corrosion resistance. ❶
(4) Rapid quenching leads to crack and distortion. ❶
(5) Poor impact resistance at low temperature. ❶

(h) Describe the carbon-related microstructural changes in martensite upon tempering for a eutectoid plain-carbon steel.

Tempering Temperature:	Carbon-related Microstructure
20 – 200 °C:	Carbon segregation ❶
Below 200 °C:	Epsilon Carbide (Fe$_{2.4}$C) ❶
200 – 700 °C:	Cementite Carbide (Fe$_3$C) ❶
200 – 300 °C:	Cementite (Rod-like) ❶
400 – 700 °C:	Cementite (Spheroidite) ❶

(i) List the major alloy elements for the 2xxx, 3xxx, 5xxx, 6xxx, and 7xxx aluminum alloys.

2xxx: Cu-Mg ❶, 3xxx: Mn ❶, 5xxx: Mg ❶,
6xxx: Mg-Si ❶, 7xxx: Zn-Mg-Cu ❶

(j) Describe and explain the heat treatment process of precipitation hardening.

(1) Solution heat treatment: Alloy sample heated to a temperature between solvus and solidus❶ and got the maximum quantity of solutes in matrix. ❶
(2) Quenching: Sample then quenched to room temperature in water❶ and formed a supersaturated solid solution. ❶
(3) Sample then aged at intermit temperature❶ and formed finely dispersed particles in matrix. ❶

(k) Compare the differences (composition, corrosion resistance) between the ferritic (e.g. 430), mantensitic (e.g. 440A), and austenitic (e.g. 304) stainless steels.

SS 430: Fe + 17% Cr ❶+ 0.012%C. Good corrosion resistance. ❶
SS 440A: Fe + 17% Cr + 0.7%C. ❶ Poor or fair corrosion resistance. ❶

SS 304: Fe + 19% Cr + 10%Ni. ❶ Excellent corrosion resistance. ❶

(l) How to prevent the intergranular corrosion of 304 stainless steel? Why?

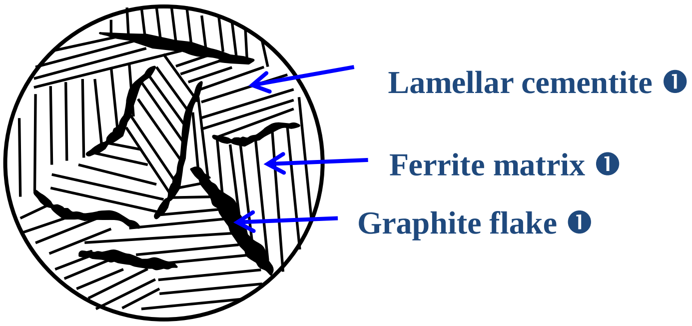
The intergranular corrosion of 304 stainless steel is resulted from the Cr-deficiency at grain boundary. No Cr-deficiency at grain boundary prevents intergranular corrosion. The methods to prevent the intergranular corrosion are following:

Decreasing carbon content to below 0.03%❶: Due to the low quantity of carbon, the Cr-carbide will not obvious form ❶ and no Cr-deficiency exists.

Adding Nb or Ti element❶: Carbon prefer to combine with Nb or Ti than with Cr and no Cr-deficiency exists.❶.

Fast cooling between 870 °C and 600 °C❶: Do not have enough time to form Cr-carbide❶ and no Cr-deficiency exists.

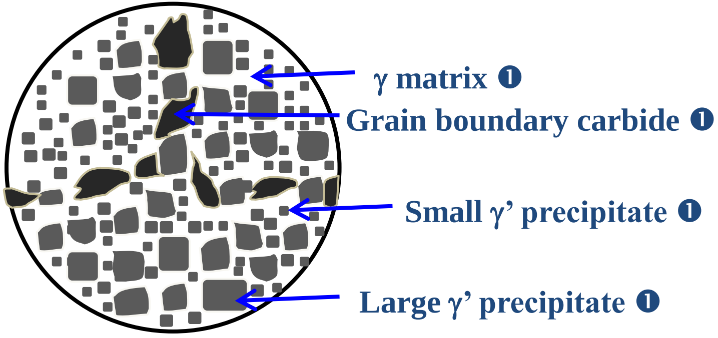
(m) Sketch and explain the microstructure of an as-cast pearlitic grey iron.



❶❶

(n) Sketch the typical microstructure (γ + γ’ + carbides) of a nickel-based superalloy.

❶



2. Calculate the relative amount of each phase at 184, 182, 60 °C of a Pb-45wt%Sn alloy from the Pb-Sn phase diagram. Sketch the microstructures of this alloy at 184 °C and 182 °C. (15%)

From Lever rule:

184 °C: $W_\alpha = (61.9 - 45) / (61.9 - 18.3)$; $W_L = (45 - 18.3) / (61.9 - 18.3)$ ❶

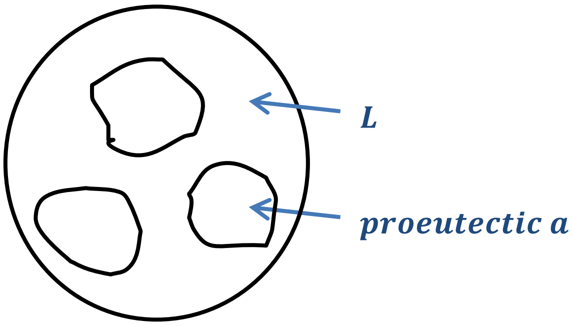
$\Rightarrow$ $W_\alpha = 38.8\%$❶ ; $W_L = 61.2\%$ ❶

182 °C: $W_\alpha = (97.8 - 45) / (97.8 - 18.3)$; $W_\beta = (45 - 18.3) / (97.8 - 18.3)$ ❶

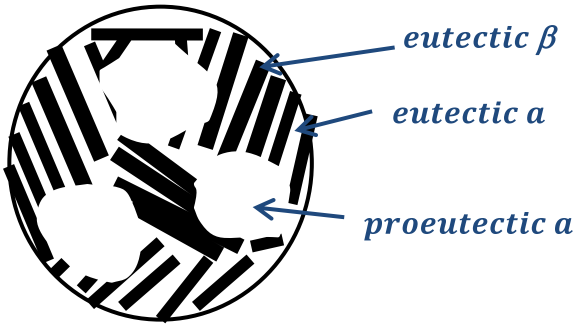
$\Rightarrow$ $W_\alpha = 66.4\%$ ❶; $W_\beta = 33.6\%$ ❶

60 °C: $W_\alpha = (98.7 - 45) / (98.7 - 2.6)$; $W_\beta = (45 - 2.6) / (98.7 - 2.6)$ ❶

$\Rightarrow$ $W_\alpha = 55.9\%$ ❶; $W_\beta = 44.1\%$ ❶



Microstructure at 184 °C ❶❶❶



Microstructure at 182 °C❶❶❶

3. Two austenite 80 mm diameter 5140 alloy bars are quenched in agitated water and agitated oil, respectively. Predict what the Rockwell C (RC) hardness of the bars will be at (a) its surface and (b) its center. Change 5140 alloy to 4340 alloys and predict RC hardness again. (10%)

From Fig. 9.40:

Water quenched: $D_{surface} = 3.1$ mm ❶ ; $D_{center} = 18.0$ mm ❶

Oil quenched: $D_{surface} = 11.0$ mm ❶ ; $D_{center} = 27.5$ mm ❶

From Fig. 9.38:

5140 steel (± 0.5 RC):	4340 steel (± 0.5 RC):
$S_{water} = 52$ RC ❶	$S_{water} = 53.5$ RC ❶
$C_{water} = 28$ RC ❶	$C_{water} = 51$ RC ❶
$S_{oil} = 35$ RC ❶	$S_{oil} = 52.5$ RC ❶
$C_{oil} = 24$ RC ❶	$C_{oil} = 47.5$ RC ❶

4. Compare the differences in cost, density, strength, corrosion resistance, and major application between 1045 carbon steel (Fe-0.45%C), 2024Al (Al-4.5%Cu-1.5%Mg), and C82400 (Cu-1.7Be-0.3Co). (15%)

Cost: 1045 carbon steel << 2024Al < C82400 ❶❶❶

Strength: 1045 carbon steel < 2024Al < C82400 ❶❶❶

Density: 2024Al << 1045 carbon steel < C82400 ❶❶❶

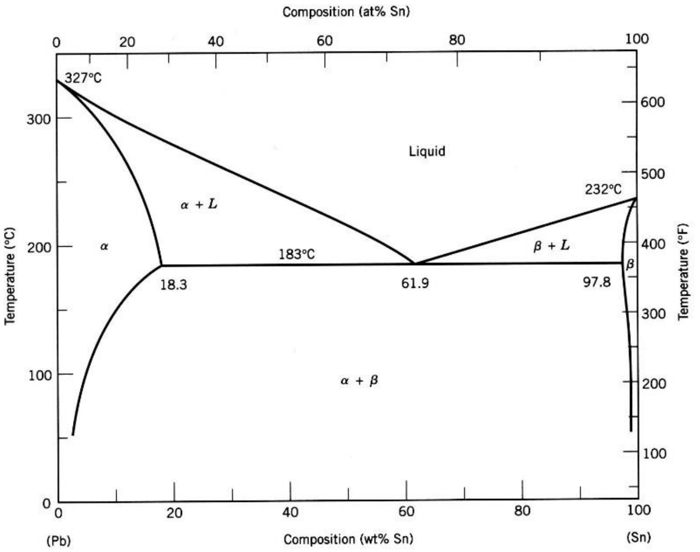
Corrosion Resistance: 1045 carbon steel < 2024Al < C82400 ❶❶❶

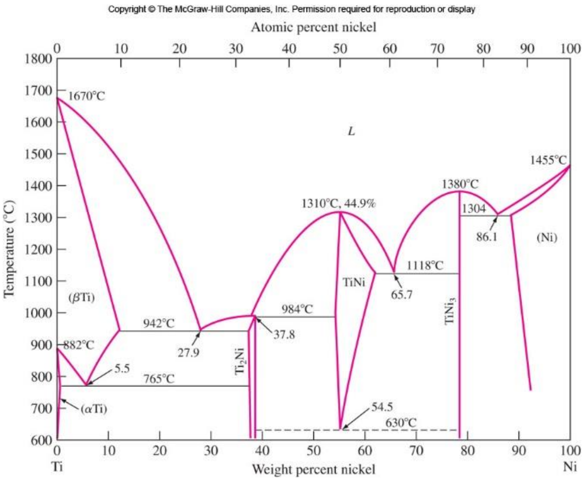
Major application

1045 carbon steel: Bridge or ship structures. ❶

2024Al: Airplane structures. ❶

C82400: Safety tools. ❶





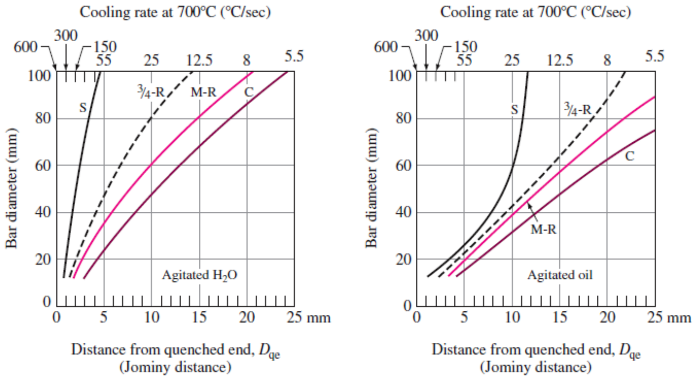


Figure 9.40

Cooling rates in long round steel bars quenched in (i) agitated water and (ii) agitated oil. Top abscissa, cooling rates at 700°C; bottom abscissa, equivalent positions on an end-quenched test bar. (C = center, M-R = midradius, S = surface, dashed line = approximate curve for $\frac{3}{4}$-radius positions on the cross section of bars.)

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