National Exams December 2018

12-Mtl-A5, Phase Transformations of Metals, Glasses and Ceramics

3 hours duration

Notes:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. This is a CLOSED BOOK EXAM. An approved Casio or Sharp calculator is permitted.
3. FIVE (5) questions constitute a complete exam paper. The first five questions as they appear in the answer book will be marked.
4. Each question is of equal value.
5. Some questions require an answer in essay format. Clarity and organization of the answer are important.

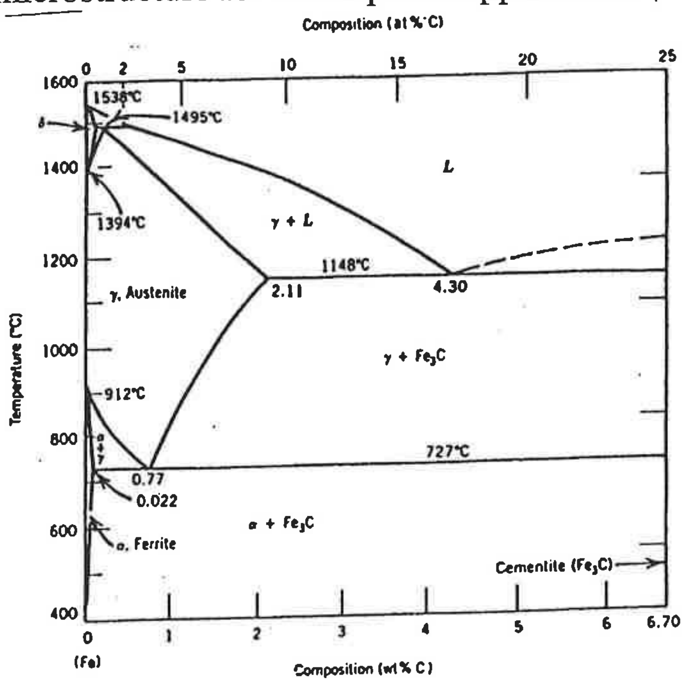
Question 1: (20 Marks)

The microstructural design of iron-carbon (Fe-C) alloys has led to the development of a vast range of steels for structural materials applications. The phase diagram provides a means for producing specific microstructures. Using the partial Fe-C phase diagram (attached), answer the following questions:

(a) If a liquid mixture of Fe-3.0 wt.%C is slowly cooled from 1600 °C to 1200 °C, indicate the phase(s) that are present at 1200 °C and the composition(s) of the phase(s). ***(4 marks)***

(b) Describe the sequence of <u>all</u> phase transformations that occur if a Fe-1.5 wt.%C is slowly cooled from 1600 °C to 400 °C. Use diagrams to describe the microstructures for each phase transformation. ***(10 marks)***

(c) Consider a hypereutectoid Fe-C alloy. For a certain structural steel application it is desired to have a room temperature microstructure containing less than 10 wt% total of the cementite phase (i.e. Fe3C). At Fe3C weight fractions > 10%, the steel becomes too brittle (i.e. has poor toughness) for the required application. Use the phase diagram to determine the critical hypereutectoid alloy composition (i.e. % C) below which the material will have a suitable microstructure for the required application. ***(6 marks)***



Question 2: (20 marks)

The solubility of carbides and nitrides in austenite can be described by an equation of the form:

$$\log_{10}[\text{wt.\% M}]\,[\text{wt.\% X}] = A - \frac{B}{T} \qquad (1)$$

where M and X represent any two solute species of interest.

(a) By writing an equation describing the free energy of the reaction: $[M]_\gamma + [X]_\gamma = [MX]_\gamma$, show what assumptions must be involved in Eq. (1). ***(10 marks)***

(b) The solubility of AlN is given by Eq. (1) with A= 1.55 and B= 7060. What is the maximum amount of Al that could be tolerated in hot rolling a steel at 900 °C if precipitation of AlN is to be avoided in a steel containing 40 ppm N? ***(10 marks)***

Question 3: (20 marks)

(a) Using an equilibrium phase diagram description for a precipitation hardening alloy of your choice, indicate how a range of metastable precipitate structures can be produced from a binary alloy of a single composition. ***(7 marks)***

(b) In what ways does precipitation differ from spinodal decomposition of a solid solution. ***(7 marks)***

(c) Why do certain materials systems result in ordered 'domains'. Sketch one example of an ordered crystal structure. ***(6 marks)***

Question 4: (20 marks)

(a) With respect to solid-state phase transformations explain: (i) the difference between coherent, semi-coherent and incoherent interfaces, (ii) why their interfacial energies are quite different and (iii) the driving force for a change from coherent to incoherent interfaces as the particle dimensions increase. ***(9 marks)***

(b) Precipitate free zones (PFZ) can form by one of two distinct mechanisms. Briefly explain both mechanisms. ***(6 marks)***

(c) Explain why fine precipitates restrict grain growth in metallic alloys held at sufficiently high temperatures and long time periods. ***(5 marks)***

Question 5: (20 marks)

(a) Why do configurations that comprise six or more grain boundary intersections promote grain growth when the polycrystalline material is held at high temperature? ***(2 marks)***

(b) When cold-worked steel is heat-treated recrystallization occurs and the direction of movement of the grain boundary regions can be opposite to that occurring during grain growth. Explain the two different grain boundary motion mechanisms. ***(6 marks)***

(c) If the driving force for grain growth is $2\gamma/D$ where γ is the interfacial energy of the grain boundary and D is the average grain diameter, deduce the relation between the final grain size (D_{max}), the volume fraction (f) and radius of precipitates (r) in the base material. ***(8 marks)***

(d) Using the relation derived above, indicate the conditions that will produce minimum grain growth when a high-strength low alloy steel containing Nb(C,N) precipitates is subjected to high temperature. ***(4 marks)***

Question 6: (20 marks)

Most phase transformations result from a nucleation and growth process. Describe in sufficient detail the most likely nucleation mechanism for the following transformations (Hint your description should consider homogeneous versus heterogeneous nucleation):

(a) recrystallization of a heavily deformed polycrystalline material ***(5 marks)***

(b) interphase precipitation in high strength low-alloy (HSLA) steel ***(5 marks)***

(c) formation of Guinier-Preston zones ***(5 marks)***

(d) athermal nucleation of martensitic plates ***(5 marks)***

Question 7: (20 marks)

(a) A spherical nucleus of radius r* forms during a liquid/solid transformation. Deduce the relation between the critical radius dimension, the activation energy ΔG^* required for the nucleation process and the surface energy γ_{SL}. ***(6 marks)***

(b) Explain why undercooling below the melting point and the $2\gamma/r^*$ term are so important during the liquid/solid transformation. ***(4 marks)***

(c) Explain why heterogeneous nucleation on the wall of the containing vessel is much more likely to occur than homogeneous nucleation in spite of the fact that the critical radius r* is unchanged when both nucleation events occur. ***(4 marks)***

(d) Using a simple binary phase diagram describe the conditions that lead to (i)) planar growth at the solid/liquid interface, (ii)) cellular growth at the solid/liquid during solidification. Explain why the temperature gradient in the liquid and constitutional supercooling are so important. ***(6 marks)***

Question 8: (20 marks)

The production of SiO_2 glass based products relies on manipulation of the composition and thermal history to control the structure and properties of the material.

(a) Sketch curves showing how the specific volume varies with temperature over the temperature range where the liquid changes into a solid, for a crystalline solid and a glass of the same composition. Draw two curves for the glass, one curve for a fast cooling rate and a second curve for a slow cooling rate. Label the curves for the crystalline solid, the fast cooled glass, and the slow cooled glass. Indicate the position of the equilibrium melting point, the temperature at which crystallization occurs (for the crystalline solid), and the glass transition temperatures. Pay attention to the slopes of the lines, as the slopes represent the thermal expansion coefficients. ***(10 marks)***

(b) To produce a glass-ceramic material, a temperature versus time cycle is followed during processing, Sketch a typical temperature-time profile and explain what is done or what happens at each step of the processing cycle. ***(10 marks)***