National Exams December 2017

10-MET-A6: Phase Transformation and Thermal Treatment of Metals and Alloys

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.
   One of two calculators is permitted - any Casio or Sharp approved model..
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.

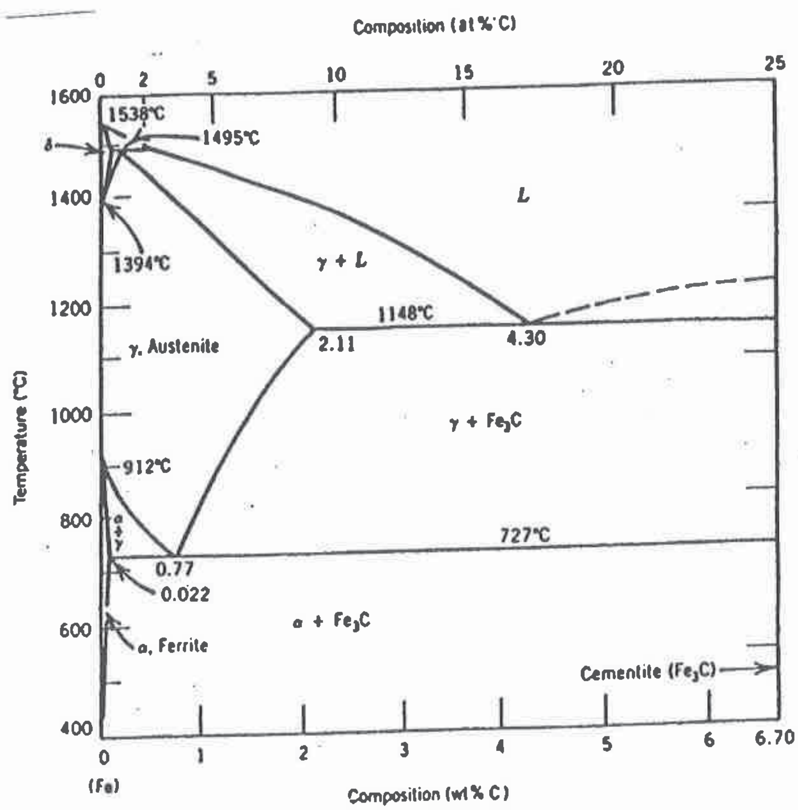
Question 1: (20 marks)

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 all 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)

(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 3: (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 4: (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 5: (20 marks)

The annealing of cold worked metals involves three stages: recovery, recrystallization and grain growth.

(a) Use a general schematic diagram to show how the following mechanical properties change during the three stages of annealing: (i) yield strength, (ii) ductility and (iii) elastic modulus. ***(6 marks)***

(b) Briefly explain why grain boundaries move toward their centre of curvature during grain growth but away from their centre of curvature during recrystallization. ***(8 marks)***

(c) In light of your considerations in **(b)** describe the difference between strain-induced boundary migration and secondary recrystallization in annealing transformations. ***(6 marks)***

Question 6: (20 marks)

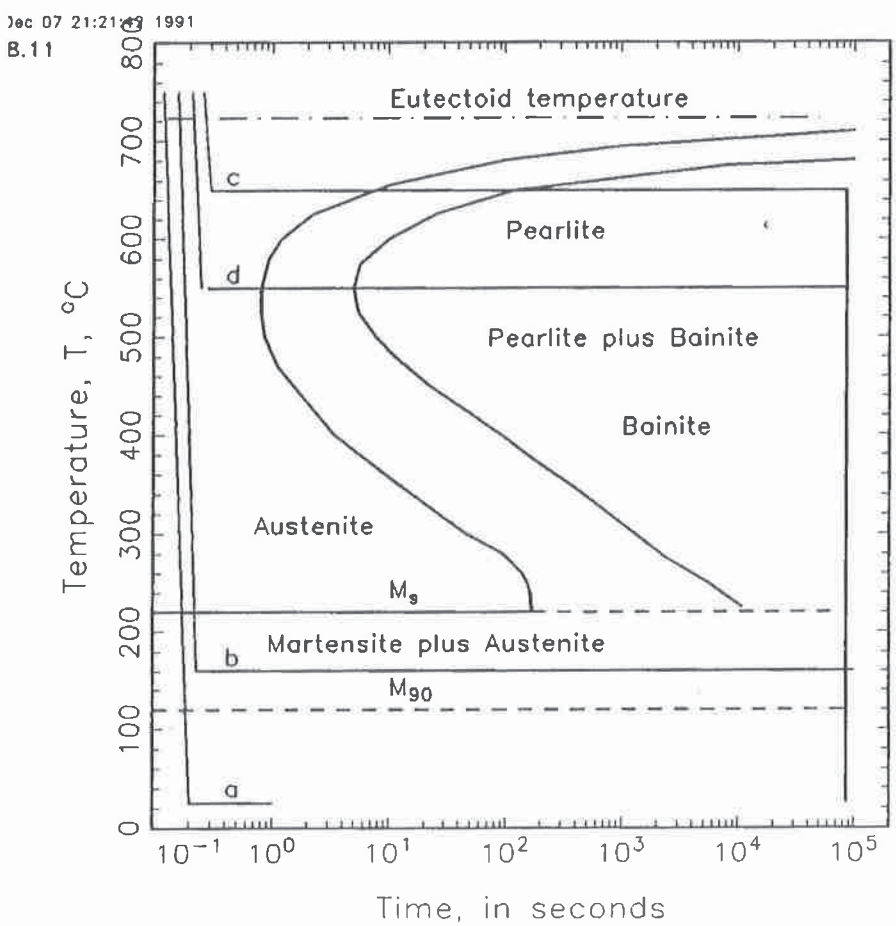
The TTT diagram below is for a steel of eutectoid composition. Assuming that the specimens involved in the various cooling paths were cut from a thin sheet and austenitized at 750 ˚C before cooling, describe (including sketches) the microstructures resulting from the following heat treatments:

(a) Cooling to room temperature in less than 1 second ***(5 marks)***

(b) Cooling to 160 ˚C in less than 1 second and then maintained at this temperature for several years ***(5 marks)***

(c) Quenched to 650 ˚C and held at this temperature for 1 day, then quenched to room temperature ***(5 marks)***

(d) Quenched to 550 ˚C and held at this temperature for 1 day, then quenched to room temperature ***(5 marks)***



Question 7: (20 marks)

(a) The heat treatment of hardenable aluminum alloys normally involves a three-stage procedure. Briefly describe the nature of the three stages and the microstructures that result following each stage. ***(10 marks)***

(b) The production of sheet material for structural applications requires careful control of annealing-induced transformations, either during rolling (i.e. hot working) or after cold rolling. Discuss two factors that control grain growth (i.e. ultimate grain size) during the annealing of aluminum alloy deformed to a specific strain. ***(10 marks)***

Question 8: (20 marks)

(a) In the solidification of metals, describe three (3) effects of increasing undercooling. ***(6 marks)***

(b) Why do metals not solidify exactly at the melting temperature, that is, where the Gibbs free energies of the liquid and solid phases are equal? What determines the range of temperature over which metals are observed to solidify? ***(8 marks)***

(c) Differentiate between the equilibrium distribution coefficient (k_o) and the effective distribution coefficient (k_{eff}) in connection with segregation during freezing of a metal alloy. ***(6 marks)***