National Exams December 2013

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.
   Any non-communicating 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)

(a) The Fe-C phase diagram allows the materials engineer to design a wide range of steels with specific properties for different applications. Using a hypoeutectoid steel composition of your choice, explain the following heat treatment processes and the microstructures that develop: ***(12 marks)***

(i) normalizing

(ii) spheroidizing

(iii) full annealing

(b) Differentiate between martensite and bainite structures and explain why neither of these phases appear on the equilibrium phase diagram. ***(8 marks)***

Question 2: (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 3: (20 marks)

In the thermomechanical processing (TMP) of steel, the resultant nonequilibrium phase transformations can be described using a time-temperature-transformation (TTT) curve or a continuous cooling transformation (CCT) diagram.

(a) Using a steel alloy of your choice, differentiate between a TTT curve and a CCT curve for the same alloy. ***(7 marks)***

(b) What is the primary objective of TMP? ***(4 marks)***

(c) Using your schematic TTT diagram in **(a)** illustrate the difference between the following heat treatment methods: ***(9 marks)***

(i) ausforming

(ii) martempering

(iii) marstraining

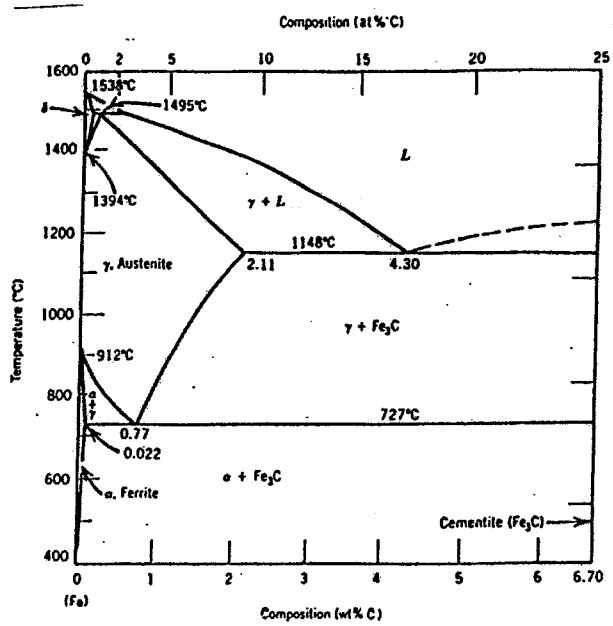
Question 4: (20 marks)

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 5: (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 6: (20 marks)

The microstructure of as-cast copper-based alloys can be modified using one of several heat treatments. Briefly describe each of the following treatments. (Note: Your answer should consider the heat treatment procedure and the resulting microstructural changes that develop).

(a) precipitation hardening
(5 marks)

(b) spinodal decompositon
(5 marks)

(c) homogenizing
(5 marks)

(d) stress-relieving
(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) In the development of an industrial-scale furnace for the heat treatment of Al-alloys, discuss the significance of the following in order to obtain an optimum result: ***(10 marks)***

(i) furnace type

(ii) temperature control

(iii) furnace atmosphere

Question 8: (20 marks)

(a) You have been asked to develop a more energy efficient processing schedule for the production of aluminum autobody panels. In order to prevent cracking the panels must be annealed during deformation to promote dynamic recovery and recrystallization of the microstructure. Discuss (2) methods to indicate how and why the recrystallization temperature (i.e. the annealing temperature) of the aluminum can be lowered. ***(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 <u>two</u> factors that control grain growth (i.e. ultimate grain size) during the annealing of a polycrystalline metal deformed to a specific strain. ***(10 marks)***