

National Exams May 2003

98-MET-A6: 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. Candidates may use one of two calculators, the Casio or Sharp approved models. This is a closed book exam.
 3. Any five (5) questions constitute a complete paper (100 marks total). Only the first five questions as they appear in your answer book will be marked.
 4. All questions are of equal value.
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Question 1: (20 Marks)

- (a) Using an equilibrium phase diagram description, indicate how a range of metastable precipitate structures can be produced from a binary alloy (e.g. Al-Cu) 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 2: (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

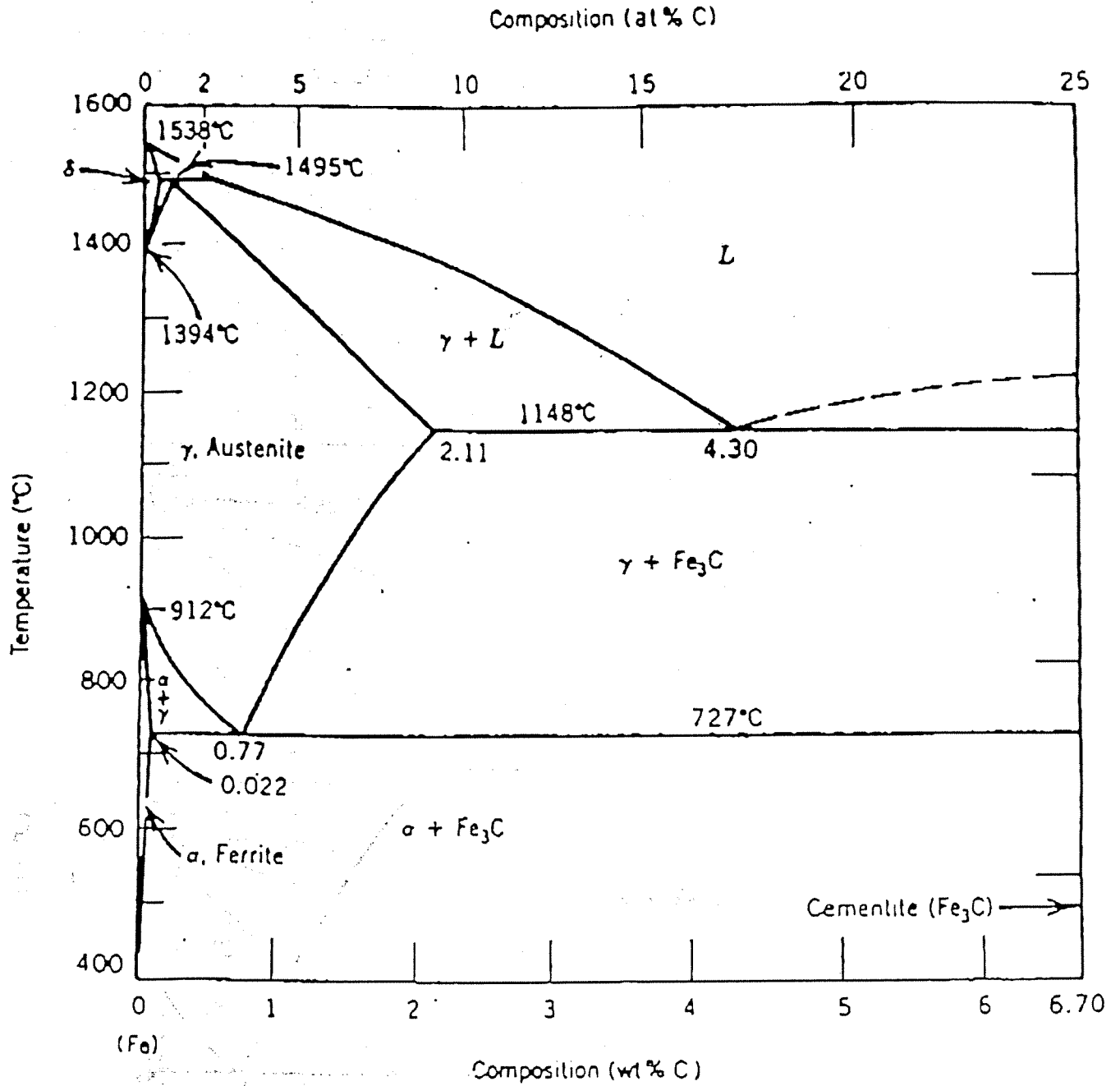
Question 3: (20 marks)

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 4: (20 marks)

- (a) The Fe-C phase diagram (attached) 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 and explain why neither of these phases appear on the equilibrium phase diagram. *(8 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)*

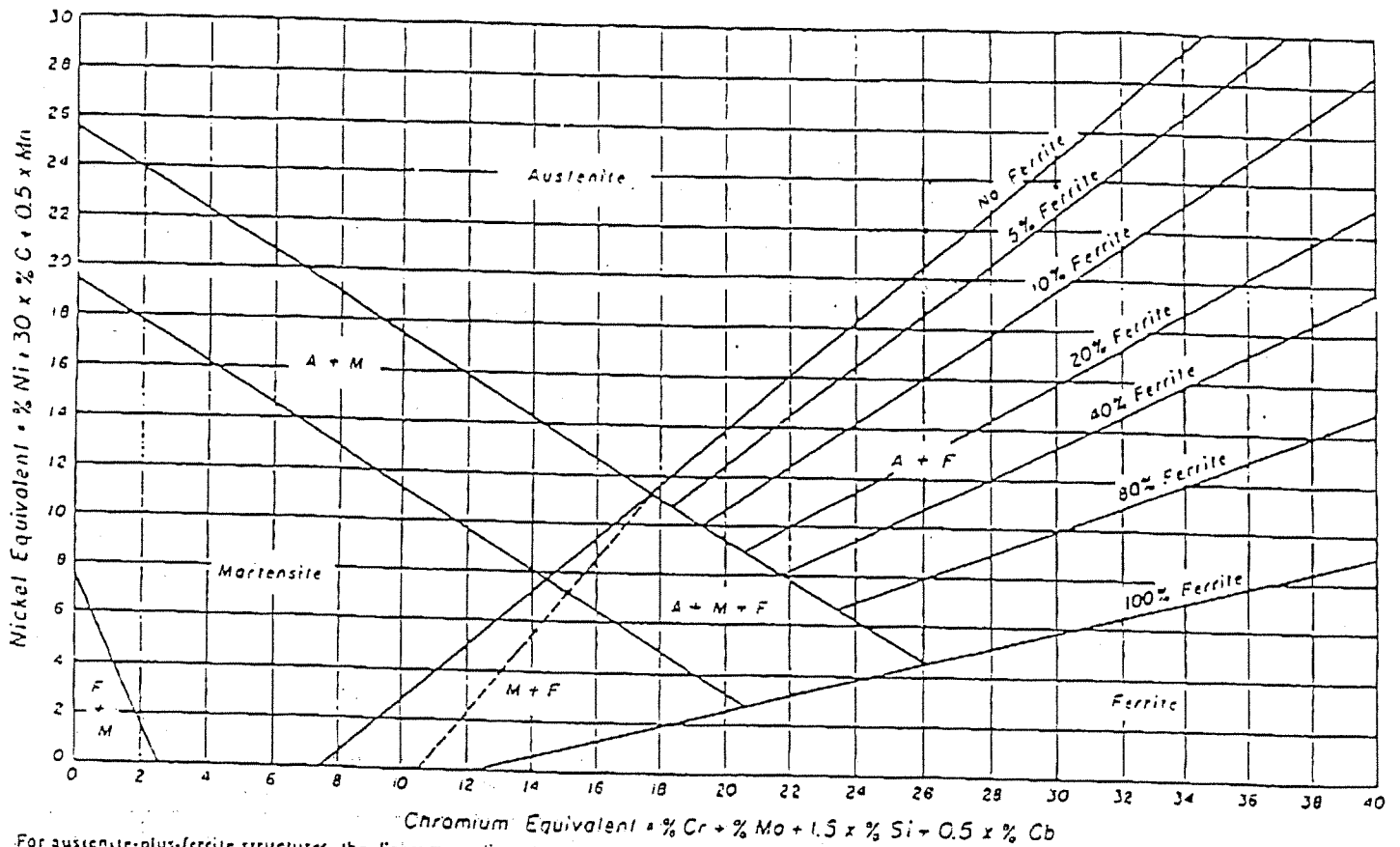
- (c) In light of your considerations in (b) describe the difference between strain-induced boundary migration and secondary recrystallization in annealing transformations. *(6 marks)*

Question 6: (20 marks)

- (a) The Schaeffler diagram (attached) can be used to predict the room temperature microstructure of air-cooled weld deposits in stainless steels. The diagram defines nickel equivalent and chromium equivalent weight fractions.

A stainless steel weld overlay is to be made with 309L (0.03% C, 1.5% Mn, 12.5% Ni, 24% Cr, 0.75% Mo and 0.5% Si) electrodes deposited onto the surface of a low carbon structural steel (0.24% C, 0.8% Mn and 0.4% Si). Assuming an arc welding process is employed which results in 30% dilution of the weld metal, determine the microstructure of the weld and indicate whether it would be susceptible to cracking. *(10 marks)*

- (b) Considering an arc welding process of your choice, illustrate the nature of the microstructural changes in the heat affected zone and base metal regions of a eutectoid steel weld. *(10 marks)*



For austenite-plus-ferrite structures, the diagram predicts the percentage ferrite within 4% for the following stainless steels: 308, 309, 309 Ch, 310, 312, 316, 317, 318 (316 Cb), and 347. Dashed line is the martensite/M + F boundary modification by Eberhard Leinhos. "Mechanische Eigenschaften und Gefügeausbildung von mit Chrom und Nickel legiertem Schweissgut." VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, 1966.

Figure Constitution diagram (Schaeffler diagram) for stainless steel weld metal (Metal Progress Data Book, vol. 112, 1977, Am. Soc. Met., Metals Park, Ohio, by permission.)

Question 7: (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 8: (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 decomposition
(5 marks)

- (c) homogenizing
(5 marks)

- (d) stress-relieving
(5 marks)