National Exams May 2011

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. This is a CLOSED BOOK EXAM.
   One of two calculators is permitted any Casio or Sharp approved models.

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)

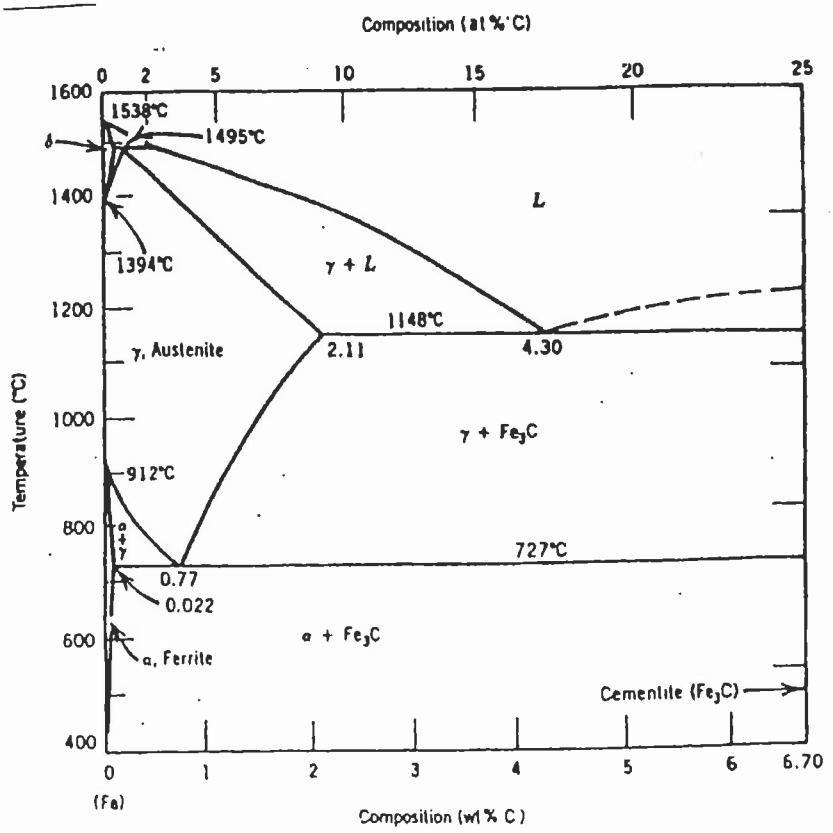
The iron-carbon phase diagram allows the engineer to design a wide range of steels with specific properties for different applications. Using the partial Fe-C phase diagram below as required, explain, as quantitatively as possible, how you would obtain the following by heat treatment:

(a) a hypoeutectoid steel composition which contains less than 10 wt.% of cementite *(5 marks)*

(b) spheroidite in a 1090 steel *(5 marks)*

(c) a normalized 1040 steel *(5 marks)*

(d) a 1020 steel to give an equiaxed dispersion of the MA phase (martensite/retained austenite) in ferrite *(5 marks)*



Question 2: (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)***

Question 3: (20 marks)

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

(a) Draw a schematic TTT curve for a eutectoid steel (e.g. 0.79 wt.% C) labelling all the phase fields including austenite, pearlite, bainite and martensite. ***(7 marks)***

(b) What is the main function of TMP during controlled rolling of a eutectoid steel? How is this effect shown on the TTT curve? ***(6 marks)***

(c) Using your TTT diagram, differentiate between: (i) conventional tempering, (ii) austempering and (iii) martempering, following quenching. Briefly describe the advantages of each type of heat treatment. ***(7 marks)***

Question 4: (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 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)

You have been given the task of designing an industrial-scale furnace for the heat treatment of an alloy of your choice at temperatures between 425-750 °C. Develop an economical design, which considers the optimum choice of:

(a) furnace type *(4 marks)*

(b) temperature control *(4 marks)*

(c) furnace atmosphere type *(4 marks)*

(d) furnace atmosphere control *(4 marks)*

(e) cooling chamber to yield the best surface finish. *(4 marks)*

Question 8: (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)***