

## National Exams May 2016

### 10-MET-A6: Phase Transformations 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) 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 2: (20 Marks)**

- (a) You have been asked to develop a more energy efficient processing schedule for the production of aluminum automobile 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 two 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)**

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 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 (Note: 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 decomposition  
*(5 marks)*
  
- (c) homogenizing  
*(5 marks)*
  
- (d) stress-relieving  
*(5 marks)*

**Question 7: (20 marks)**

- (a) Differentiate between thermal supercooling (i.e. undercooling) and constitutional supercooling in the solidification of metallic alloys and list the effects of increasing supercooling. *(10 marks)*
- (b) In the development of an industrial-scale furnace for the heat treatment of cast irons, 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) 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)*