GWANDA STATE UNIVERSITY

2023 NOVEMBER EXAMINATIONS

Faculty:	Engineering and The Environment
Department:	Metallurgical Engineering
Paper Code and Title:	EMG 3104 Physical Metallurgy
Duration:	3 Hours
Authorized Materials:	Scientific calculator
Examiner's Name:	**MR. P CHAMBOKO**

INSTRUCTIONS AND INFORMATION FOR THE CANDIDATES

1. Answer any **five (5)** questions
2. Each question carries **twenty (20**) marks and there are **six (6)** questions in total.
3. Use good engineering language and clear presentation in your answers.
4. Start each question on a new page
5. This paper comprises **six (6)** printed pages
6. Do not communicate with other students or use unauthorized materials during this exam.
7. Good luck!

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NB: DO NOT TURN OVER THE QUESTION PAPER OR COMMENCE WRITING UNTIL INSTRUCTED TO DO SO

Question 1:

a) As a metallurgist specializing in physical metallurgy, consider a hypothetical scenario involving ZIMASCO, a major ferrochrome producer. ZIMASCO is experiencing high carbon and sulfur impurities levels in its ferrochrome alloy. Design a problem-solving approach to address this issue using your engineering skills and tools in physical metallurgy. In your design discuss the potential sources of carbon and sulfur contamination and propose suitable techniques for their removal or reduction. Consider factors such as alloy composition, processing parameters, and thermodynamic considerations. Finally, evaluate the potential impact of impurity reduction on the mechanical and chemical properties of the ferrochrome alloy, highlighting the significance of your proposed solution for ZIMASCO's production efficiency and product quality. [10]

b) Could you give instances of two catastrophic engineering disasters and explain why they happened, considering the influence of environmental factors and service conditions on the connection between material qualities and structure? [5]

c) In the field of physical metallurgy, demonstrate a comprehensive understanding of the two stages involved in the formation of particles of a new phase. Provide an in-depth analysis of each stage, including the underlying mechanisms, thermodynamic considerations, and microstructural changes. In your analysis present practical examples and highlight the significance of comprehending these stages in the context of physical metallurgy, particularly for materials design, processing, and performance optimization. [5]

Question 2:

a) Explain Fick's first and second laws of diffusion [5]

b) A carburizing process is done to a 0.15% C steel by introducing 1.1% C at the surface at 900°C where the iron is FCC. Calculate the carbon content at 0.6mm and 1.5mm beneath the surface after 50 min. *The pre-exponential factor (Do) is equal to* $1.2\times10^{-10} m^2/s$*, while the Activation energy (Q) is 170 kJ/mol and the Gas constant (R) is 8.31 J/mol-K.* [10].

c) A sheet of BCC iron 2 mm thick was exposed to a carburizing gas atmosphere on one side and a decarburizing atmosphere on the other side at 675ºC. After having reached a steady state, the iron was quickly cooled to room temperature. The carbon concentrations at the two surfaces of the sheet were determined to be 0.015 and 0.0068 wt%. Compute the diffusion coefficient if the diffusion flux is 7.36×10^{-9} kg/m^2-s *(Pro tip: Convert the weight percent concentrations to kilograms of carbon per cubic meter of iron.)* [5]

Question 3:

a) A steel component used in a high-temperature application has exhibited premature failure due to excessive grain growth. As a metallurgical engineer, propose a problem-solving approach to mitigate this issue. Discuss the factors contributing to grain growth and the mechanisms involved. Outline the steps in developing a heat treatment process to control grain growth and improve the component's mechanical properties. [8]

b) Superimpose the stress-strain curves of brittle and ductile materials. Explain the difference in elastic and plastic properties that are obtained from the stress-strain curves. [4]

c) A metal alloy is being developed for use in a new generation of aircraft engines. The alloy must have a high yield strength at high temperatures, good ductility, and good fatigue resistance. Edge and screw dislocations play an important role in the mechanical properties of metals. Discuss how edge and screw dislocations can affect a metal alloy's yield strength, ductility, and fatigue resistance. Suggest specific alloying elements and heat treatment processes that could be used to create a metal alloy with the desired properties. [8]

Question 4:

a) As a metallurgist, it is your responsibility to determine which type of cast iron is best for a particular usage, such as producing heavy-duty gears for industrial machinery's transmission systems. White cast iron and nodular cast iron are the two options that are being considered. Compare the composition, heat treatment, microstructure, and mechanical properties of white and nodular cast irons. Provide a well-reasoned recommendation for the best-cast iron material based on this information, taking into account the transmission system's limitations and the required performance requirements for the specific gear application. [5]

b) Using the isothermal transformation diagram for an iron–carbon alloy of eutectoid composition (Figure 4), specify the nature of the final microstructure (in terms of micro constituents present and approximate percentages) of a small specimen that has been subjected to the following time–temperature treatments. In each case assume that the specimen begins at 760^{o}C (1400^{o}F) and that it has been held at this temperature long enough to have achieved a complete and homogeneous austenitic structure.

(i) Rapidly cool to 350°C (660°F), hold for 10^4s, and quench to room temperature. [2]

(ii) Rapidly cool to 250°C (480°F), hold for 100s, and quench to room temperature. [3]

(iii) Rapidly cool to 650°C (1200°F), hold for 20s rapidly cool to 400°C (750°F), hold for 10^3s, and quench to room temperature. [5]

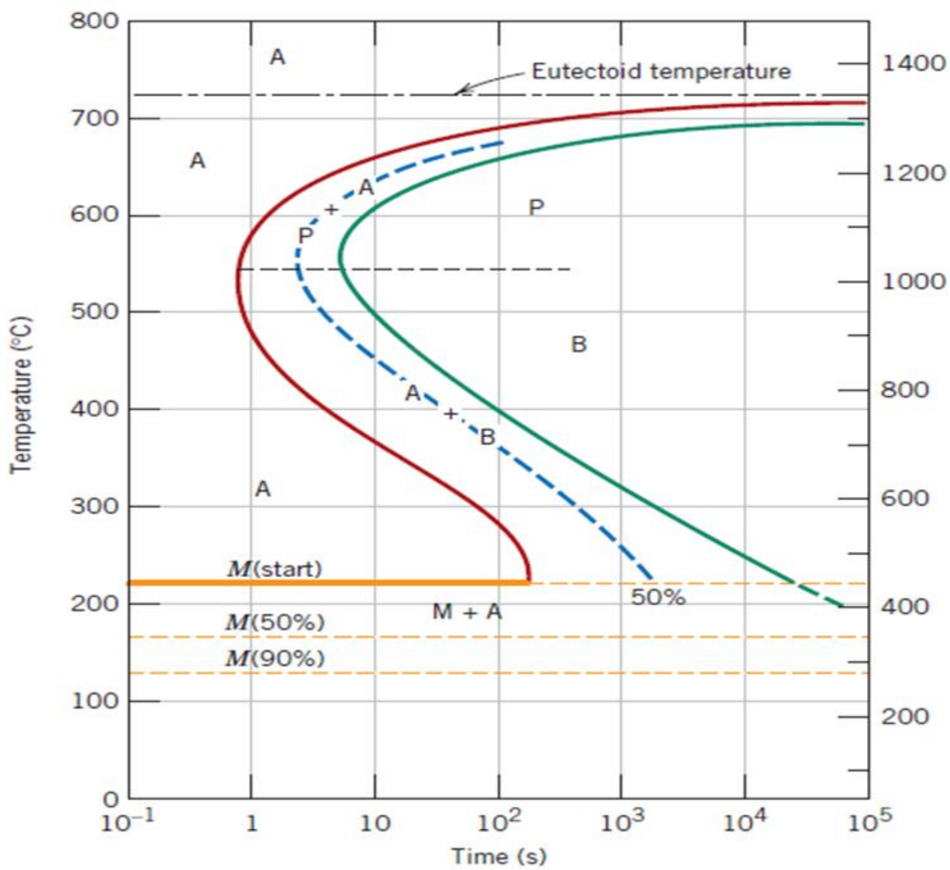

Fig 4: The complete isothermal transformation diagram for an iron–carbon alloy of eutectoid composition: A, austenite; B, bainite; M, martensite; P, pearlite.

c. You are a materials engineer responsible for optimizing heat treatment processes in a manufacturing company. In a recent project, you are evaluating the heat treatment requirements for a specific steel grade: case-carburized aluminum-killed steel. Your task is to explain why core refining heat treatment may not be necessary for this type of steel. Apply your engineering knowledge and problem-solving skills to provide a comprehensive answer. [5]

Question 5:

a) Explain how the grain size in an aluminum plate with a bullet hole will vary outward if the plate is annealed. Discuss the impact of annealing on grain structure and provide a problem-solving approach to analyze the grain size distribution. Consider factors such as initial grain structure, annealing temperature, and duration. Utilize your metallurgical engineering skills to predict the grain size variation and discuss its implications for the mechanical properties of the aluminum plate. [10]

b) In the field of materials engineering, consider an industrial application that involves periodic annealing between cold working operations. Provide a comprehensive analysis of the reasons for implementing periodic annealing and its significance in this application [5].

c) A nitriding heat treatment of a BCC steel normally requires 1h 45 min at 680^{o}C. What temperature would be required to reduce the heat treatment to 1h? [5].

Question 6:

a) A copper alloy used in electrical connectors is experiencing corrosion-related failures in a harsh environment. Apply your engineering skills to develop a problem-solving strategy. Identify the key factors influencing the corrosion behavior of the alloy, such as alloy composition, microstructure, and exposure conditions. Propose appropriate surface treatment methods, coatings, or alloy modifications to enhance corrosion resistance. Discuss the advantages and limitations of your proposed solution, considering factors such as cost, manufacturability, and long-term performance. [6]

b) A titanium alloy used in aerospace applications is susceptible to hydrogen embrittlement, leading to reduced mechanical properties and premature failure. Apply your understanding of physical metallurgy to address this issue. Discuss the mechanisms of hydrogen embrittlement in titanium alloys and the factors influencing susceptibility. [6]

c) Consider a single crystal of BCC iron oriented such that tensile stress is applied along a [010] direction.

i. Compute the resolved shear stress along a (110) plane and in a [111] direction when a tensile stress of 52 MPa (7500 psi) is applied. [4]

ii. If slip occurs on a (110) plane and in a [111] direction, and the critical resolved shear stress is 30 MPa (4350 psi), calculate the magnitude of the applied tensile stress necessary to initiate yielding. [4]

END OF EXAMINATION