**GWANDA STATE UNIVERSITY**

**FACULTY OF ENGINEERING AND THE ENVIRONMENT**

**DEPARTMENT OF METALLURGICAL ENGINEERING**

**EMG/EMN 1204 ENGINEERING MATERIALS**

**Part 1 Second Semester Final Examination Paper**

**April 2025**

This examination paper consists of 8 printed pages

**Time Allowed:** **3 hours**

**Total Marks:** **100**

**Examiner's Name:** **Mr P. Chamboko**

**INSTRUCTIONS**

1. Answer **Question 1** and any other four questions.
2. Each question carries 20 marks
3. Use of calculators is permissible

**Additional requirements**

Graph paper (on request)

**MARK ALLOCATION**

| | |
|---|---|
| Questions 1 to 6 | 20 Marks |
| Part Marks | As shown in each part question |
| Total Attainable | 100 Marks |

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

**Question 1:**

(a) Define the following phases that exist in the Fe – $Fe_3C$ phase diagram. (i) austenite (ii) α ferrite (iii) cementite (iv) δ ferrite. **[4 marks]**

(b) Thin pieces of 0.3mm hot rolled strips of 1080 steel are heat treated in the following ways. Use the IT diagram of Figure Q1(a) and other knowledge to determine the microstructure of the steel samples after each heat treatment.

(i) Heat 1 h at 800°C; water quench

(ii) Heat 1 h at 800°C; water quench; reheat 1h at 350°C. What is the name of this heat treatment?

(iii) Heat 1h at 800°C; quench in salt molten bath at 700°C and hold 2h; water quench.

(iv) Heat 1h at 800°C; quench in salt molten bath at 260°C and hold 1 min; air cool. What is the name of this heat treatment?

(v) Heat 1h at 800°C; quench in salt molten bath at 350°C and hold 1 min; air cool. What is the name of this heat treatment?

(vi) Heat 1h at 800°C; water quench; reheat at 700°C. **[9 marks]**

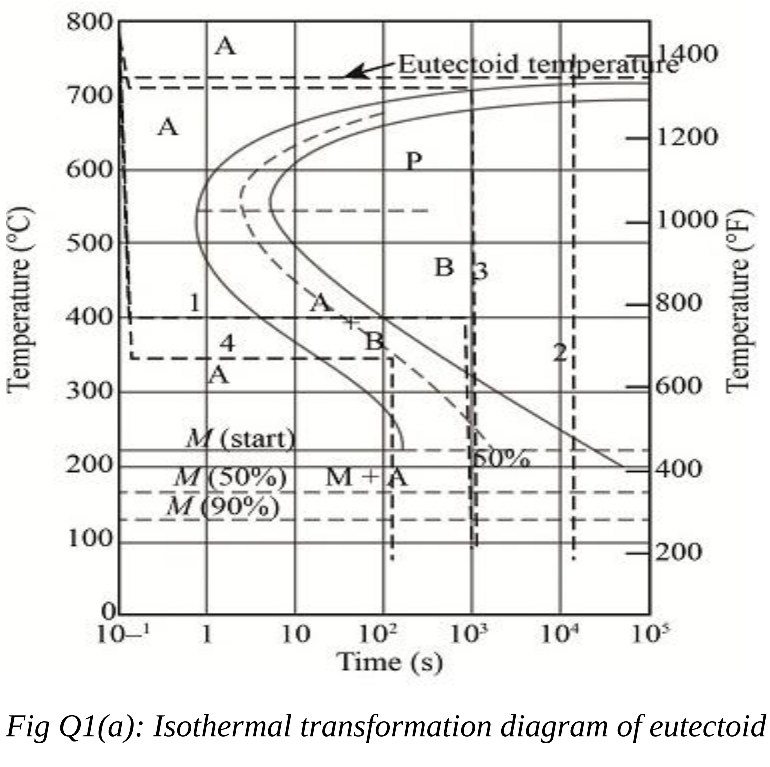


*Fig Q1(a): Isothermal transformation diagram of eutectoid steel.*

(c) The hardenability curves for five different steel alloys, all having 0.40 wt% C, yet differing amounts of other alloying elements, are shown in Figure Q1(b). Explain the effect of alloying compositions on the hardenability and microstructure of steels. **[7 marks]**

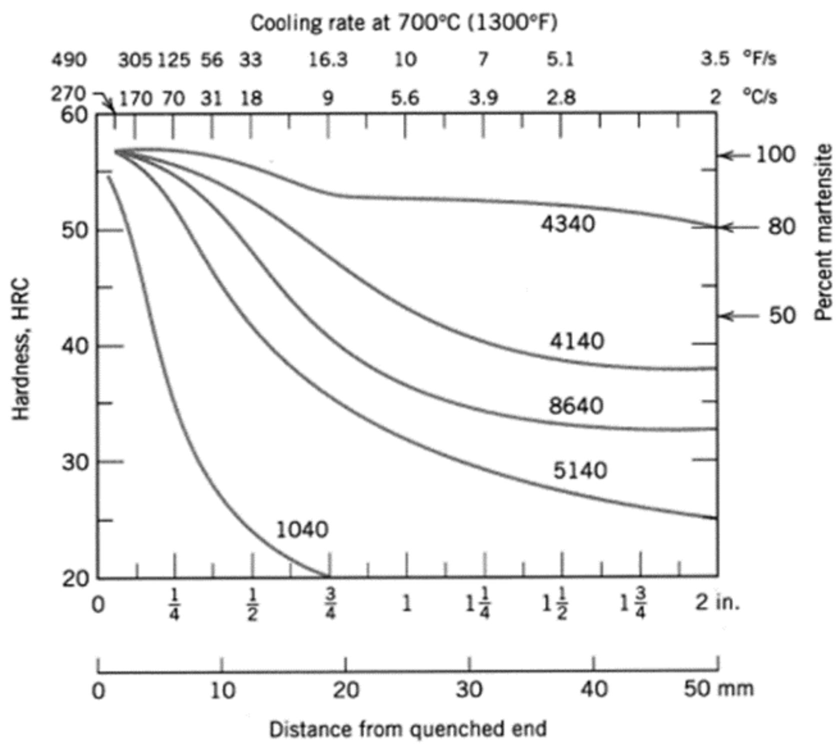


*Fig Q1(b): Hardenability curves for five different steel alloys, each containing 0.4wt%. Approximate alloy compositions (wt%) are as follows: 4340 – 1.85 Ni, 0.80 Cr, and 0.25Mo; 4140 – 1.0 Cr, and 0.20 Mo, 8640 – 0. 55Ni, 0.50 Cr, and 0.20 Mo; 5140 – 0.85 Cr; and 1040 is an unalloyed steel.*

**Question 2:**

(a) The provided load-elongation data is for a metallic rod with a small notch at its midsection. How would the presence of the notch likely affect the values of

| | **Load (kN)** | **Elongation (mm)** |
|---|---|---|
| Start | 0 | 0.0 |
| | 10 | 0.010 |

| | | |
|---|---|---|
| | 20 | 0.020 |
| Yield | 25 | 0.025 |
| | 30 | 11.2 |
| Maximum load | 38 | 18.7 |
| | 18 | 24.5 |

(i) Engineering ultimate tensile strength (UTS)? **[2 marks]**

(ii) Engineering strain at the yield point? **[2 marks]**

(iii) Engineering Fracture Stress? **[2 marks]**

(b) Estimate Young's Modulus (E) for the metallic rod using the data provided. Discuss the limitations of your estimation and how the presence of the notch might affect the actual value of E. **[2 marks]**

(c) An 850kg force is applied to a 0.15 cm diameter nickel wire at room temperature. The yield strength of nickel at room temperature is 45 kPa and the tensile strength is 55 kPa. However, nickel exhibits significant strain rate sensitivity, meaning its strength increases at higher strain rates.

(i) Determine whether the wire will plastically deform and considering the strain rate sensitivity of nickel, under what loading conditions (slow loading vs. rapid loading) would necking be more likely to occur? Briefly explain your reasoning. **[2 marks]**

(d) A high-strength steel is being considered for the construction of a critical component in an offshore oil-drilling platform operating in cold arctic waters. Brittle fracture is a major concern due to the low service temperatures.

(i) What mechanical testing method would you recommend for evaluating the steel's susceptibility to brittle fracture at low temperatures? Briefly explain your rationale. **[2 marks]**

(e) High-rise buildings in coastal areas are often constructed with a combination of steel and reinforced concrete. When establishing the allowable tensile stress for these materials during design, what factors, beyond the material itself, should be considered? Briefly explain the rationale for each factor. **[2 marks]**

(f) A Gwanda State University student claims that a finer grain size in a metallic alloy will always result in a stronger material. A rival student argues that while finer grains can improve strength, there might be a point of diminishing returns or even negative consequences.

(i) Explain the concept of grain boundaries and their role in influencing the strength of a metal. **[4 marks]**

(ii) Discuss the merits of the claims made by each student. Use the concept of dislocation movement and the Hall-Petch relationship (if familiar) to support your arguments. **[2 marks]**

**Question 3:**

(a) Cite three reasons why ferrous alloys are used so extensively. Cite three characteristics of ferrous alloys that limit their utilization. **[4 marks]**

(b) Based on microstructure, briefly explain why gray cast iron is brittle and weak under tension. **[4 marks]**

(c) Calculate the equilibrium vacancy concentration in copper at 800°C given that the formation energy 0.9 eV, atomic site density $8.47 \times 10^{22}$ $cm^3$, and Boltzmann constant (k) = $8.617 \times 10^{-5}$ eV/K **[4 marks]**

(d) What happens to these vacancies if we quickly cool this copper to room temperature? Explain briefly **[4 marks]**

(e) (i) Briefly describe sandwich panels.

(ii) Cite three reasons why fiberglass-reinforced composites are utilized extensively.

(iii) Cite three limitations of this type of composite. **[4 marks]**

**Question 4:**

(a) Define the term "ceramics" and state three of its properties **[5 marks]**

(b) Compute the atomic packing factor for the rock salt crystal with a radius ratio of 0.1414. Given that he rock salt (NaCl) crystal structure is face-centered cubic (FCC).

**[5 marks]**

(c) Calculate the density of NaCl from a knowledge of its crystal structure, the ionic radii of $Na^+$ and $Cl^-$ ions, and the atomic masses of Na and Cl. The ionic radius of $Na^+$ = 0.102nm and that of $Cl^-$ = 0.181nm. The atomic mass of Na = 22.99g/mol and Cl = 35.45g/mol.

**[5 marks]**

(d) (i) Draw the unit cell for $BaF_2$, which has the fluorite $CaF_2$ crystal structure, if the $Ba^{2+}$ ions occupy the FCC lattice.

(i) Which sites do the $F^-$ ions occupy?

(ii) What fraction of the octahedral interstitial sites are occupied in the $CaF_2$ structure?

**[5 marks]**

(e) State one application of the following ceramics.

(i) Silicon Nitride ($Si_3N_4$)

(ii) Boron Carbide ($B_4C$)

(iii) Tungsten Carbide (WC)

(iv) Aluminium oxide ($Al_2O_3$)

(v) Zirconium dioxide ($ZrO_2$) **[5 marks]**

**Question 5:**

(a) A batch of gears was rejected by the customer due to insufficient surface hardness. The gears are made of steel grade 1040, quenched and tempered. You prepare a cross-section and examine the hardness as a function of distance from the surface (see Table Q3). What is the reason for the heat treatment defect? Is it possible to rectify the problem? (Hint: plot the hardness as a function of distance). **[10 marks]**

Table Q3: Hardness distribution along the cross-section

| **Distance from the quenched end, mm** | **HRC** |
|---|---|
| 1.5 | 40 |
| 3 | 50 |
| 5 | 55 |
| 15 | 52 |
| 20 | 50 |

(b) The material is a copper alloy with 5% zinc added as a substitutional element. The component is a wire with a diameter of 2mm and a length of 100mm. The wire was cold-worked to increase strength and then annealed at 500°C.

(i) The vacancy formation energy in copper is 1.1eV, and the Boltzmann constant is $1.38 \times 10^{-23}$J/K. Calculate the equilibrium vacancy concentration at 500°C. Explain how these vacancies influence the wire's ductility after annealing.

**[5marks]**

(ii) Cold working increases the dislocation density from $10^{6}$cm$^{-2}$ to $10^{10}$cm$^{-2}$, but annealing reduces it to $10^{8}$cm$^{-2}$. Calculate the percentage reduction in dislocation density after annealing. Discuss how this reduction affects the wire's yield strength.

**[5 marks]**

**Question 6:**

(a) Explain the difference between vacancy diffusion and interstitial diffusion. Provide an example of a material system where each mechanism is dominant. How does the diffusing species' atomic radius influence the diffusion rate in each case? **[5 marks]**

(b) A hydrogen gas pipeline is made of a steel alloy. Hydrogen diffusion through the steel can lead to embrittlement and failure. If the hydrogen diffusion coefficient in the alloy is $3 \times 10^{-12}$ m²/s at room temperature, calculate the time it takes for hydrogen to penetrate 1 mm into the steel. How would you modify the alloy to reduce this penetration rate? **[5 marks]**

(c) In the design of a semiconductor device, the controlled diffusion of dopants is critical. Explain how steady-state and non-steady-state diffusion principles are applied in the fabrication process. What factors would you consider to minimize unwanted diffusion during high-temperature processing? **[5 marks]**

(d) A pressure vessel is designed to operate at high temperatures and pressures. Discuss the potential failure mechanisms (e.g., fracture, fatigue, creep) that could occur and propose design modifications to mitigate these risks. How would you select materials to ensure safe and reliable operation? **[5 marks]**

**END OF EXAMINATION**