Materials PhD Qualifying Exam
Information Sheet and Instructions

Objective

The student should demonstrate understanding of the Exam Topics as defined in the accompanying Outcomes (see below). In addition to the skills defined in the Exam Outcomes, understanding includes the ability to: 1) identify the correct fundamental facts, concepts, and principles applicable to a given engineering problem, and 2) apply these to solve engineering problems using appropriate assumptions and connections.

Most undergraduate texts contain problems ranging from simple questions intended to reinforce the understanding of a basic fact and principle to more advanced problems requiring a synthesis of the facts and principles and their applications to various engineering applications. Note that the purpose of the exam is to demonstrate what you know and are able to do, not your ability to recite other's knowledge. Consequently, you should make sure to clearly demonstrate your knowledge, rather than simply quoting the open-book, open-note resources available to you.

Students should feel prepared for the qualifier when they can identify and apply relevant principles to formulate a solution to real world engineering problems in materials science. Typically, a student should have the equivalent of undergraduate materials science (e.g., ME EN 250 at BYU) in order to have the background to study for the exam. This exam is meant to assess the PhD Program Outcomes of subject mastery and independent learning.

Exam Topics and Learning Outcomes

- This exam will have 3 problems, each problem will include subject matter from at least one of the following materials topic areas: (1) structure and properties, (2) failure modes, and (3) transformation and diffusion (further details on these topics are given below).
- All 3 problems are weighted equally and you will be required to answer 2 of the 3 problems.
- A score of 70% or higher is considered a passing grade.
- This exam is open book and open notes – with the exception of solution manuals, which are not allowed. *Note: Text, figures, and equations knowingly copied from any source should receive proper attribution; failure to do so is considered plagiarism and grounds for failure of the exam. Attribution can be skipped for equations, figures, and text which you recall without looking at the book.*
- Calculators are required; however, cell phones and other electronic devices are not permitted in the exam room.

- The exam has a time limit of 2.0 hours.
- All work should be in neat engineering style with assumptions clearly stated.
- Note that partial credit may be awarded, but only in cases where assumptions and solution approach are clearly explained by the examinee in writing as part of the examinee's response.

Exam Topics and Learning Outcomes

The topics for the exam focus on three general areas:

(1) structure and properties
(2) failure modes
(3) transformation and diffusion.

Together with the Exam Topics, specific Outcomes are listed. These Outcomes are intended to clarify the scope of the topics and what the committee expects of the students.

Additionally, for each of the topics, several example concepts are given (in bullets). These examples, however, are **NOT** intended to be an exhaustive list. These topics are presented in Callister's Materials Science and Engineering (7th, 8th, or 9th Edition), chapters 1-17.

All classes of materials (metals, polymers, ceramics and composites) may be covered in each topic. In most cases the emphasis is on one or more connection(s) between structure, processing, properties, and performance, including the ability to use this information to select an appropriate material for a given situation.

1. Structure and Properties

Outcome: Be able to describe the functional behaviors of the primary classes of materials (metals, ceramics, polymers, composites) and predict material properties based on structure and defects, including modeling the stress-strain diagram and describing the mechanisms for altering it for the various classes of materials.

Examples:
- Relationships between structure and material properties for each of the primary classes of materials (metals, polymers, ceramics and composites)
- Nature of various types of atomic bonding and their influence on material properties
- The influence of imperfections and other features of material microstructure on properties
- Microstructural and macro-scale behavior during various degrees of applied stress for each of the different classes of materials
- etc.

2.   Failure Modes

Outcome: Be able to describe the various forms of degradation and failure processes for each basic class of materials.

Examples:

- Fatigue, fracture, creep, corrosion as they affect the different classes of materials
- Other modes of failure and degradation that are most relevant for each of the different classes of materials
- Basic relationships between structure (Topic 1) and failure modes
- etc.

3.   Transformation and Diffusion

Outcome: Understand and be able to use phase diagrams (e.g. to classify reactions, identify phases, amounts and concentrations, etc.). Be able to describe the kinetics of diffusion and phase transformations, including the processes of nucleation and growth as they affect transformation products.

Examples:

- An understanding of diffusion driven processes, transformations, precipitation, grain growth, etc.
- Fick's laws of diffusion
- Isothermal and continuous cooling transformation diagrams
- Phase diagrams
- Processing of polymers and ceramics and the resulting influence on structure and properties
- etc.

Representative courses at BYU: MeEn 250: Science of Engineering Materials
Representative texts: Callister, *Materials Science and Engineering: An Introduction*

Additional Intermediate Courses that provide a helpful review of some of the MeEn 250 topics but include additional topics that are not covered in the exam include: MeEn 452

Structure and Properties

Problem 1: Basic Mechanical Testing/Behavior (S/P)

A standard cylindrical tensile test specimen is pulled to failure in a displacement controlled servohydraulic testing machine. The specimen has an initial diameter of 2 cm and an initial gauge length (L_o) of 10 cm. The testing machine has been calibrated to report applied load and increases in distance between the specimen grips. Testing notes are below:

Standard tensile test specimen

0 N, 0 mm: Test start
35 kN, 0.075 mm
70 kN, 0.15 mm
95 kN, 10 mm
100 kN, 15 mm
99 kN, 17 mm
98 kN, 20 mm: Fracture
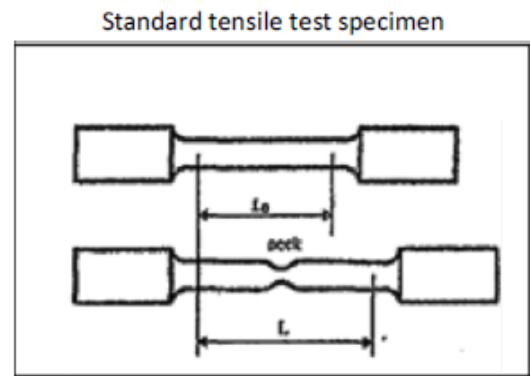
A. (15 pts). Compute the engineering stress and engineering strain values for each indicated testing sample point. Graph (approximately) the engineering stress-strain diagram for the material (specify units)

B. (10 pts). Based on the given data, could you plot the true stress-true strain diagram? What assumptions would it require?

C. (5 pts). What is the elastic modulus of the material?

D. (5 pts). What is toughness of the material?

E. (5 pts). What is the Maximum Tensile Strength of the material?

F. (10 pts). Describe how you would modify the test to obtain Poisson's ratio for the material.

G. (5 pts). If a **3 cm diameter** cylindrical test specimen of the same material with an **initial gauge length of 20 cm** is pulled with **50 kN of force**, what elongation will it experience?

H. (15 pts). If a **3 cm diameter** cylindrical test specimen of the same material with an **initial gauge length of 20 cm** is pulled with **210 kN** of force, what elongation will it experience? Will it fracture?

I. (15 pts). If the test specimen material is a low-carbon steel, describe **three** different ways to obtain a stiffer, less ductile response.

J. (15 pts). If the test specimen material is a semi-crystalline polymer, describe *three* different ways to obtain a stiffer, less ductile response.

Problem 2: (S/P)

Ultra high molecular weight polyethylene (UHMWPE) is a semicrystalline polymer with very long chain length (more than a kilometer long) and a glass transition temperature of -125°C. A graph depicting the true stress-true strain behavior of a standard cylindrical tensile test specimen of UHMWPE at room temperature (25°C) at three different strain rates is given below. The cylindrical tensile test specimen had a gauge region initial length of 10 mm and a gauge region initial diameter of 8 mm.

UHMWPE (GUR 1050)
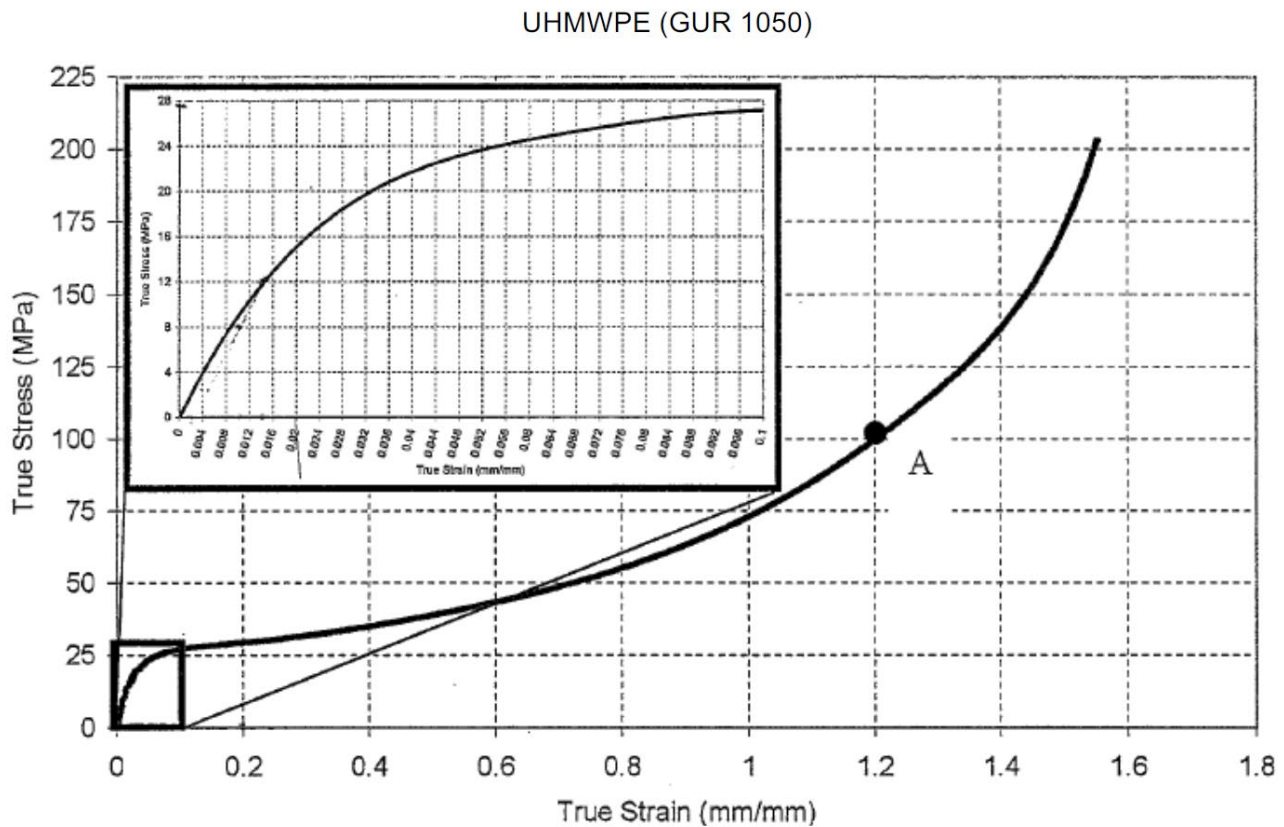
A. Determine:
   a. What is the initial elastic modulus (0.2% offset) of the material?
   b. What is the tensile strength of the material?
   c. What is the resilience of the material?

B. Explain the microstructural response (mechanisms of deformation) of UHMWPE in the following regions:
   a. True strain from 0-0.02
   b. True strain from 0.1-0.2

   c. True strain from 1.0-failure
C. Sterilization of UHMWPE medical implants is often done through gamma irradiation. Gamma irradiation induces crosslinks between the polymer strands, but leaves free radicals in the material. How do you anticipate that this process affects:
   a. The strength of UHMWPE?
   b. The ductility of UHMWPE?
   c. The recyclability of UHMWPE?
   d. The oxidation resistance (resistance to covalent bond rupture) of UHMWPE?
   e. What changes would you anticipate in the material response if the test was repeated at 37°C instead of room temperature?
   f. An UHMWPE total knee replacement is exposed to an oxygen rich environment. The initial oxygen content in the 0.0001 wt%, whereas the surface concentration in the oxygen rich environment is 0.5 wt% oxygen. The diffusion coefficient is 12.6 x 10^{-11} m^2/s. What is the oxygen content at a point 0.5 mm below the surface after being exposed to this environment for one hour? Assume that the dimensions of the component are sufficiently large to be approximated as semi-infinite.

Problem 3: (S/P)

A certain aerospace company is aiming to increase the volume percentage of composites in a new aircraft to 90%. One component under review is the landing gear. It has determined that one of the struts is to be constructed from a 0°/90° mix unidirectional ply to form a rectangular beam. The beam undergoes high compressive and bending forces during each landing cycle.

A. (40 pts). You have conducted an initial search for potential unidirectional prepreg (fiber preimpregnated with resin to form the individual plies) materials. Discuss the following material characteristics, and their relative merits in the context of your design problem. Be specific as to why these characteristics are present, and be sure to discuss such issues as cost, weight, strength, failure modes, repair-ability, environmental durability, etc., where appropriate.
- Fiber type (carbon vs. glass)
- Thermoplastic vs. thermoset resin for the matrix
- Fiber diameter (from nano to ~100 μm diameter)

B. (30 pts). The lead engineer decides to go with a unidirectional glass epoxy thermosetting prepreg for the individual plies based on the fact that his brother is president of the company that makes this product. The isotropic modulae, E_g and E_m of the glass and cured epoxy, respectively, are E_g=70 GPa, E_m=2 GPa. The volume fraction of the fiber is v_f=0.6 and of resin v_m=0.4.

Determine the modulus of a ply in the longitudinal and transverse directions from first principles by considering a representative region of the composite as shown in Figure 1 and assuming either a constant strain ($\varepsilon_m = \varepsilon_g$) or constant stress ($\sigma_m = \sigma_g$) condition (as appropriate) in each direction; show all your work.

Figure 1

Matrix (E_m)

V_m

Transverse direction (E_T)

1

V_f

Fiber (E_g)

1

Longitudinal direction (E_L) ⟶
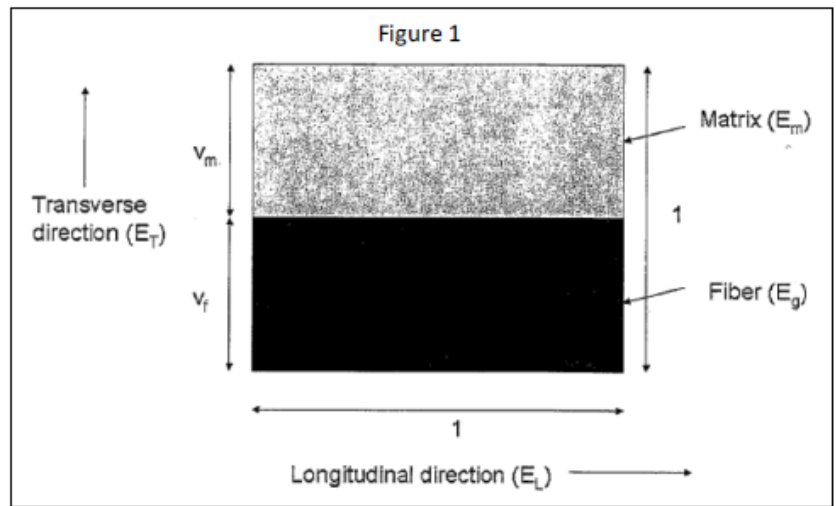
C. (15 pts). You wish to design structural health monitoring into the strut by passing light through one region of fibers, and monitoring the quality of the pattern emitted at the far end of the strut. Discuss what aspects of the atomic structure of the glass fibers enable or prohibit such an approach (include a discussion of any defects or impurities that may be present).

D. (15 pts). If the refractive index of the glass is 1.5, determine the maximum index of refraction of the epoxy matrix to ensure that the light is carried along the fibers if the angle the light makes with the internal wall of the fiber is $10°$

(see figure; recall Snell's law $n_1 \sin\theta_1 = n_2 \sin\theta_2$).

$10°$
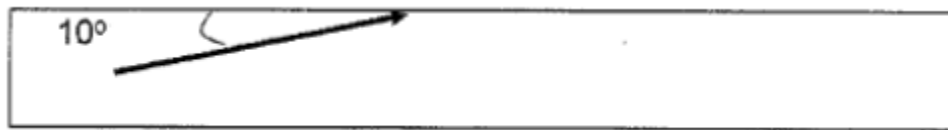
Problem 4: (S/P)

Three different hardening mechanisms are commonly found in aluminum alloys: (1) precipitation hardening, (2) work hardening, and (3) dispersion hardening.

A. (40 pts). For each of these hardening mechanisms, explain the microscopic mechanisms that produce increased hardness.

B. (30 pts). For each of these mechanisms, explain how the addition of alloying elements facilitates the increased hardness.

C. (30pts). For each of these mechanisms, explain how an alloy is annealed and the microscopic mechanism causing the decrease in hardness.

Problem 5: (S/P)

Sketch an engineering stress-strain curve for a ductile metal.

A. (30 pts). On the plot indicate the yield strength, tensile strength, Young's modulus, elastic and plastic strain to failure.
B. (70 pts). Describe in detail the phenomenon occurring in a metal at the atomic, micro and macro scales with regards to atomic bonding and motion as it is pulled in tension to create this engineering stress-strain curve.

Problem 6: (S/P)

There are five primary methods of strengthening metals. Please use any drawings that may help you describe the various methods.

A. (30 pts). Name four of the five methods of strengthening a metal or metal alloy.

B. (70 pts). Explain the fundamental principles with respect to atomic bonding, lattice movement or dislocation glide for two of these mechanisms.

Failure Modes

Problem 7: Toughness, strengthening, materials selection (F/M)

A rotor forging for the low temperature section of an aerospace turbine engine is made of 2024-T6 (Al-4.5% Cu alloy fully hardened at 130°C). This section of the rotor is a 10 cm diameter forging. The mechanical properties of the alloy are shown in the table below. The rotor forging is designed for service at 50% of the yield stress. Prior to service, the rotor forging is inspected and proof tested. During inspection, a 0.4 cm deep semicircular surface flaw is found.

    A. (20 pts). If the proof test were to be performed at 80% of the yield strength, would you approve the proof testing?

$$\text{Assume K} = \left(\frac{2}{\pi}\right)\sigma\sqrt{\pi a}$$

    B. (20 pts). With an in service design safety factor requirement of two (2), would you recommend this rotor forging for service with a crack of this size (0.4 cm deep)?

    C. (40 pts). After proof testing, the rotor is finished machined, during which the flaw is removed, and the rotor is put into service. In service this rotor experiences temperatures near 120°C. After 1000 of service the rotor was taken out of service and proof tested again. Although it did not fail by fracture, the aluminum alloy rotor yielded. You were asked to do the post failure metallurgical analysis. What metallurgical phenomenon occurred that could have caused this? Explain what occurred at the atomic and microscopic levels. Please use appropriate drawings and diagrams to help illustrate or support your hypothesis.

    D. (20 pts). From the table of materials below, can you select a more suitable material for this particular aerospace application? Please justify your answer.

Material	K_{IC}		σ_{ys}	
	MPa$\sqrt{m}$	ksi$\sqrt{in.}$	MPa	ksi
2014-T651	24.2	22	455	66
2024-T3	~44.	~40	345	50
2024-T851	26.4	24	455	66
7075-T651	24.2	22	495	72
7178-T651	23.1	21	570	83
7178-T7651	33.	30	490	71
Ti-6A1-4V	115.4	105	910	132
Ti-6A1-4V	55.	50	1035	150
4340	98.9	90	860	125
4340	60.4	55	1515	220
4335+V	72.5	66	1340	194
17-7PH	76.9	70	1435	208
15-7Mo	49.5	45	1415	205
H-11	38.5	35	1790	260
H-11	27.5	25	2070	300
350 Maraging	55.	50	1550	225
350 Maraging	38.5	35	2240	325
52100	~14.3	~13	2070	300

Problem 8: (F/M)

A truck mounted steel tank is used to transport liquid ammonia. The tank consisted of a cylindrical shell 6000mm long, with two hemispherical caps welded on to each end with a circumferential weld (submerged arc). The thickness of the shell and caps is 7 mm. The full penetration weld bead is approximately 9mm in thickness. Adjacent to this weld, and extending ~3 mm into the base metal is a heat affected zone (HAZ). In order to contain the liquid ammonia the pressure in the tank had to be equal to the saturation pressure, the pressure at which a mixture of liquid and vapor is at equilibrium. This saturation pressure increases rapidly with temperature: at 20°C the absolute pressure is 0.84 MPa; at 50°C it is 2.00 MPa. The maximum operating pressure was 2.07 MPa. This allows the tank to be used safely to 50°C, well above the maximum pressure expected in a hot climate.

While liquid was being unloaded from the tank, a fast fracture occurred in one of the circumferential weld, and the cap was blown off the end of the shell. In order to decant the liquid (to pour liquid off from one tank to another), the space above the liquid had been pressurized with ammonia gas using a compressor. The normal operating pressure of the compressor was 1.83 MPa; the maximum pressure (set by a safety valve) was 2.07 MPa.

The initial crack was intergranular and penetrated the inner wall of the tank 2.5 mm from the inside wall within the HAZ. This defect went some way around the circumference of the vessel. It is well known that steels are susceptible to intergranular stress corrosion cracking in environments containing ammonia. The final fast fracture occurred by transgranular cleavage. The tank was made from high strength low alloy (HSLA) steel with a yield strength of 712 MPa, and a fracture toughness of 80 Mpa$\sqrt{m}$. It is known that the welding process can alter the structure of the steel in the HAZ to give much higher yield strength (940 MPa), but a much lower fracture toughness (39 $MPA\sqrt{m}$).

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A. (40 pts). Assuming the circumferential stress in the wall of the tank to be well approximated by the formula $\sigma = pr/t$, where p is pressure, r is the tank radius, and t is the wall thickness, and that the longitudinal stress is ½ this amount, calculate the critical stress for fast fracture.

You may assume that the appropriate formula for fast fracture is $Y\sigma\sqrt{\pi a} = K_C$. Use the attached chart to determine the correct value for Y.

B. (30 pts). Explain why you think the tank fractured, including consideration of environmental, microstructural, and geometrical variables.

C. (30 pts). Using the attached Ashby chart for fracture toughness versus yield strength, identify two materials other than HSLA steels that could be considered for pressurized tanks for transport of liquid ammonia. Justify your choices in terms of yield strength, fracture troughness, and environmental considerations. Show any calculations you perform.

Problem 9: (F/M)

Wind tunnels are powered by banks of large air-filled pressure vessels. Each time the tunnels are used the pressure vessels are slowly charged by compressors, and then quickly discharged through the tunnel. This problem is about designing and checking pressure vessels of this type to make sure they are safe. You are asked to consider two principal kinds of failure mechanism: plastic collapse and fast fracture.

Stress State: You may assume that the hoop (circumferential) stress in the wall of the vessel is given, in terms of the pressure p, by the expression $\sigma = pr/t$ where r is the radius of the cylindrical tank, and t is the wall thickness. You may also assume that the longitudinal stress is half the value of the hoop stress, and that the radial stress (through thickness) is negligible.

A. (25 pts). Derive an expression for yield limited design (design against plastic collapse) assuming that the material has tensile yield strength σ_y. (You may assume that a Mises yield criterion is operative:

$$2\sigma_y^2 = (\sigma_{11} - \sigma_{22})^2 + (\sigma_{33} - \sigma_{22})^2 + (\sigma_{11} - \sigma_{33})^2 + 6(\sigma_{12}^2 + \sigma_{13}^2 + \sigma_{23}^2)$$

B. (25 pts). Derive an expression for fast fracture, assuming that cracks could form that have their normal parallel to the circumferential direction. (You may assume the following form of the fracture condition where

$$K_{1c} = Y\sigma\sqrt{\pi a_3}$$

C. (25 pts). Plot the expressions obtained in parts a) and b) in a schematic with crack size a on the x-axis and stress $\sigma=pr/t$ on the y-axis. Show the region where the fracture condition would dominate the performance of the vessel, and conversely, the region where the yield condition would predominate.

D. If the safe design criterion selected by the design team is the tank must "leak before fracture" and not reach a stress of greater than 0.8 of yield, then describe how you would determine the maximum pressure that a tank of radius 20 cm and a wall thickness 2 mm can receive without violating the safe design conditions. What additional information, if any, would be required to solve this problem?

(1) Failure Modes Problem:
(Points awarded as noted for each part)

Japan Airlines Flight 123 crashed in August 1985 due to a failure of the rear bulkhead, which caused loss of hydraulic controls and a large portion of the tail. The cause of the failure was attributed to an improperly executed repair on the rear bulkhead. The flawed repair reduced the fatigue resistance by 70%. Consider the following example problem as an analogy for the failure of Flight 123.

Consider a 6 m diameter cylindirical pressure vessel with spherical caps as an analog for the airplane cabin. The pressure vessel is made of Aluminum 2024-T3 (E = 72.4 GPa, v = 0.33, K_{IC} = 44 MPa√m, σ_Y = 345 MPa, σ_{TS} = 485 MPa, % elongation = 18, T_m = 502 °C). The air pressure at sea level is 100 kPa. When the aircraft ascends to 30,000 feet, the inside cabin pressure is maintained at sea level air pressure, while the air pressure outside the plane is reduced to ¼ of the pressure at sea level. For all your answers below, use a safety factor of 2 and assume vessel is a single body.

A. **(30 pts)** Determine the minimum thickness required for the pressure vessel to ensure that the design does not yield.

B. **(25 pts)** Determine the critical flaw size that would cause fracture of the vessel. Assume mode I loading and a crack geometry factor of Y=1.

C. **(10 pts)** How can one ensure that the plane would leak air rather than catastrophically breaking? Does the design of this airplane need to be changed at all?

D. **(25 pts)** Considering that the cabin is pressurized and depressurized on every flight, use the provided S-N curve to determine how many flights the plane can make prior to fatigue failure.
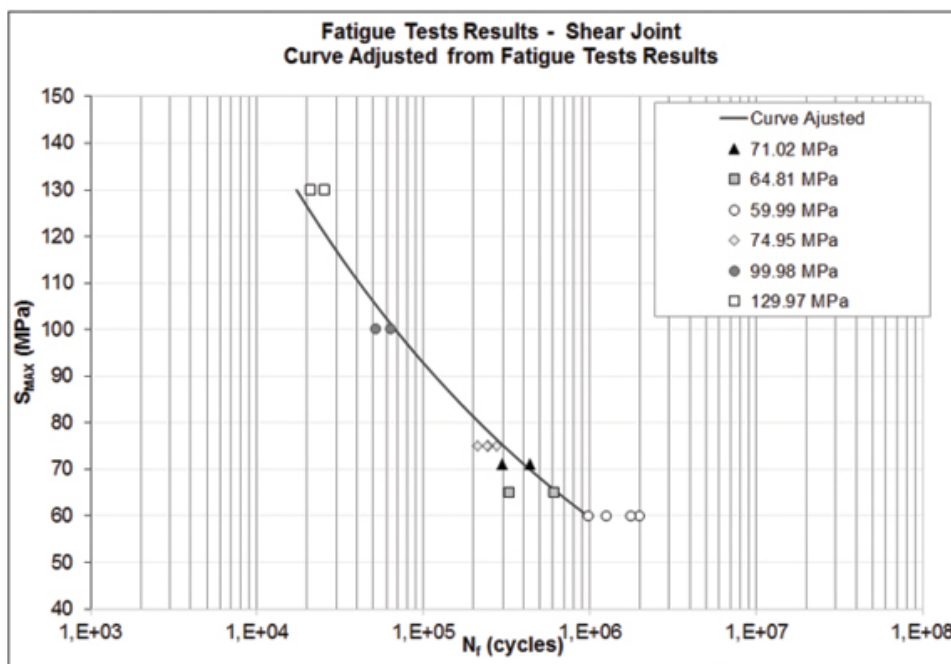

Figure 6   Application 2 (shear joint analysis) - S-N curve with original data

(10 pts) Considering that the plane will operate in temperatures in the range of (-70,40)°C, are there any other failure, deformation, or degredation modes to be considered? (Hint: discuss other items you can think of and reasons why they would or would not be a factor.)

Transformation and Diffusion

Problem 10: Phase Transformations (T/D)

This question pertains to plain carbon steel with carbon content equal to 0.5 wt%C. The diagram to the right is a portion of the Fe-C equilibrium phase diagram. The diagram to the left is the isothermal transformation diagram.
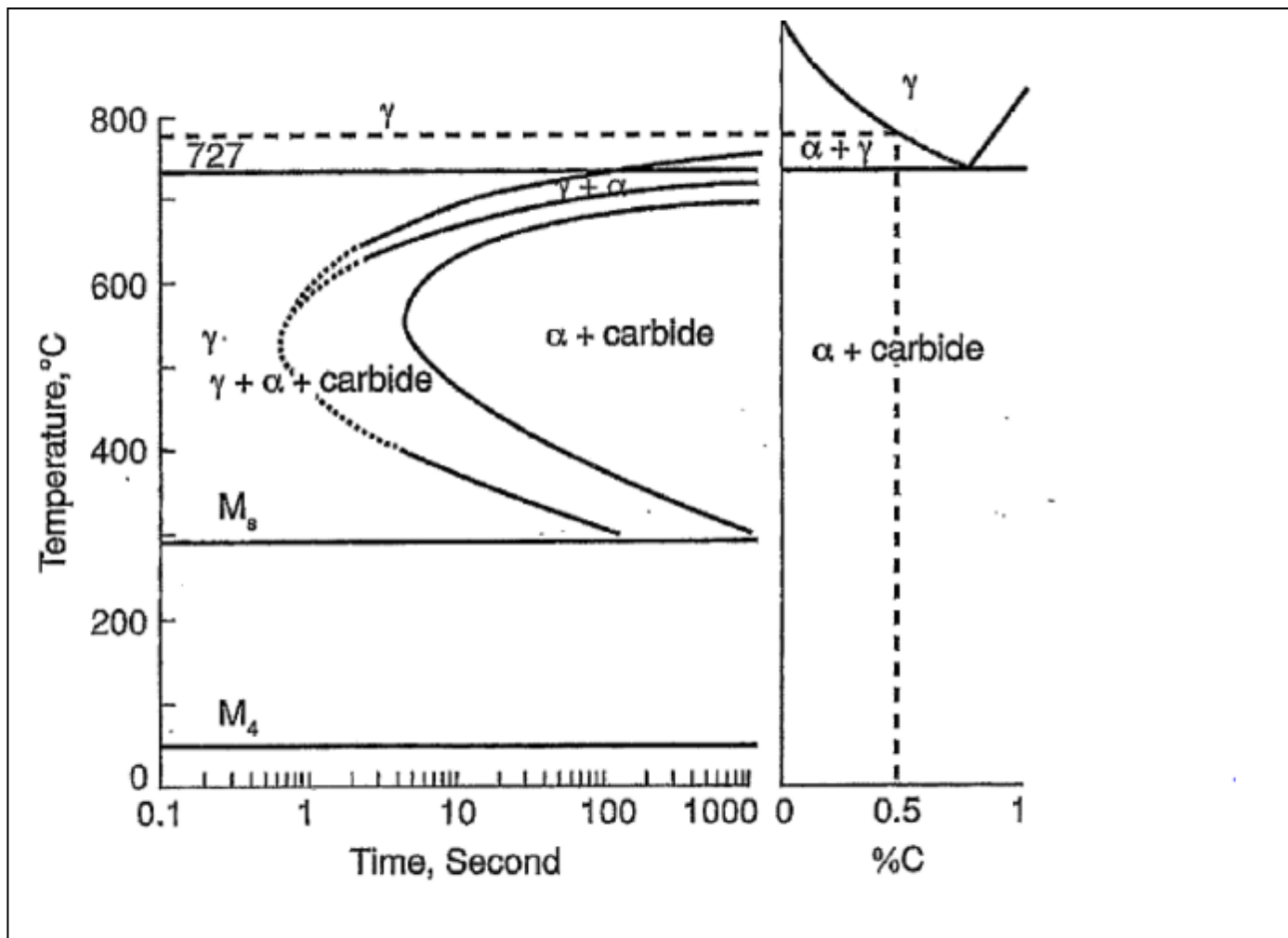
A. (15 pts). Assuming equilibrium at each temperature in question, sketch several grains of the microstructure of this material at 800, 728, 725, and 200°C. Label each phase in your sketches and distinguish between "primary" and "secondary" phases. (Note that phase morphology is important in your sketches).

B. (15 pts). For each microstructure in part a), determine the equilibrium wt% of the phases present at each temperature. Please distinguish between "primary" and "secondary" phases in your calculations.

C. (10 pts). For transformations at the eutectoid temperature, at what approximate time do you expect to see ferrite appearing in the microstructure?

D. (10 pts). Explain the physical basis for the "knee" (also known as the "nose" or the "C") in the isothermal transformation diagram.

E. (10 pts). Consider the isothermal transformations of this alloy at 500 and 600°C. After complete transformation at these temperatures, which do you expect to have the highest yield strength? What is the physical explanation for this?

F. (10pts). For the same isothermal transformations described in part (e), which microstructure do you expect to have the highest ductility? What is the physical explanation for this?

G. (10 pts). Estimate the cooling rate required to transform this material completely into martensite.

Distance from quenched end, D_{qe} (Jominy distance)
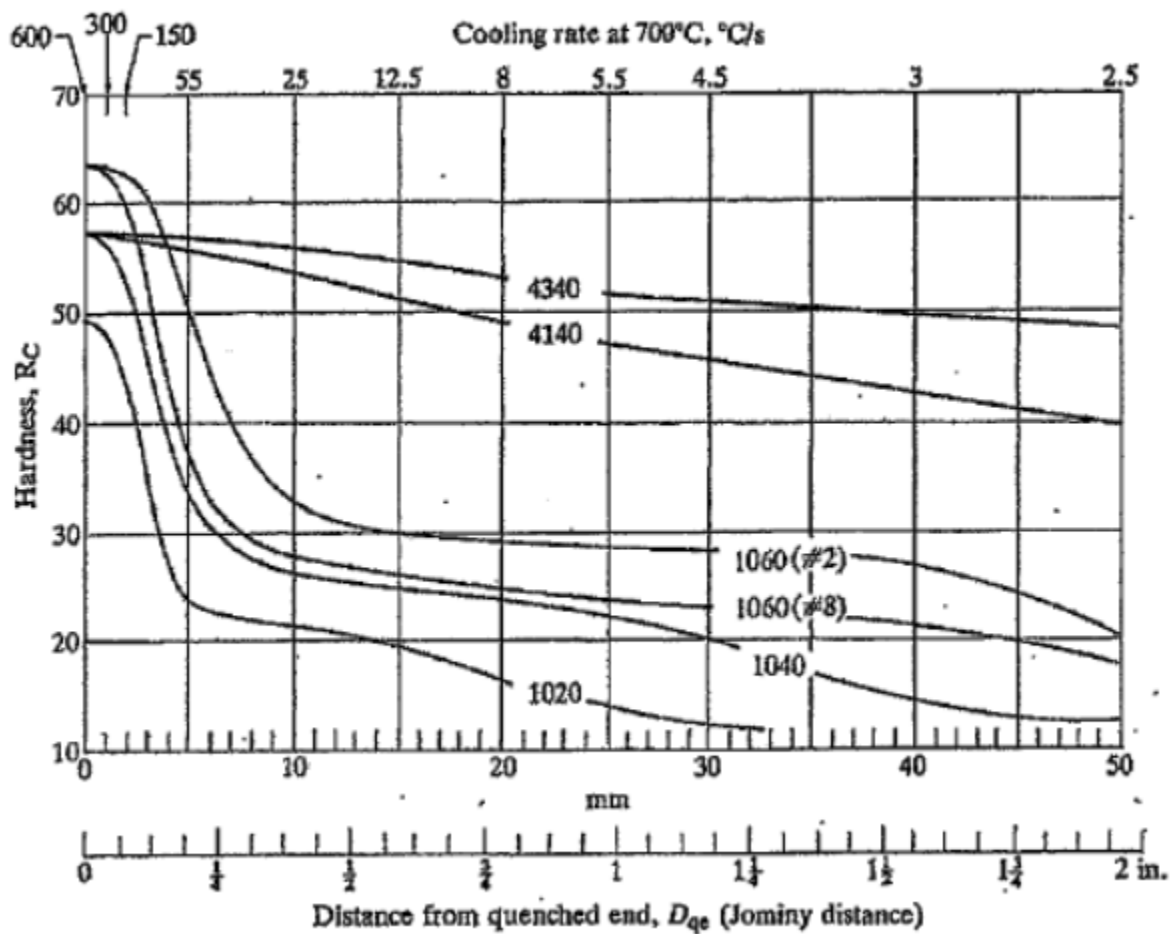
H. (10 pts). Based upon the Jominy end quench data given above, and your estimate for the cooling rate obtained in part g), what thickness of material do you expect to fully transform into martensite if the material is subjected to quenching in agitated water?

I. (10 pts). Why do the higher alloy materials, like 4140 and 4340 steel have higher hardenability than plain carbon steels like 1050? What is the physical reason? What does the term "hardenability" mean?
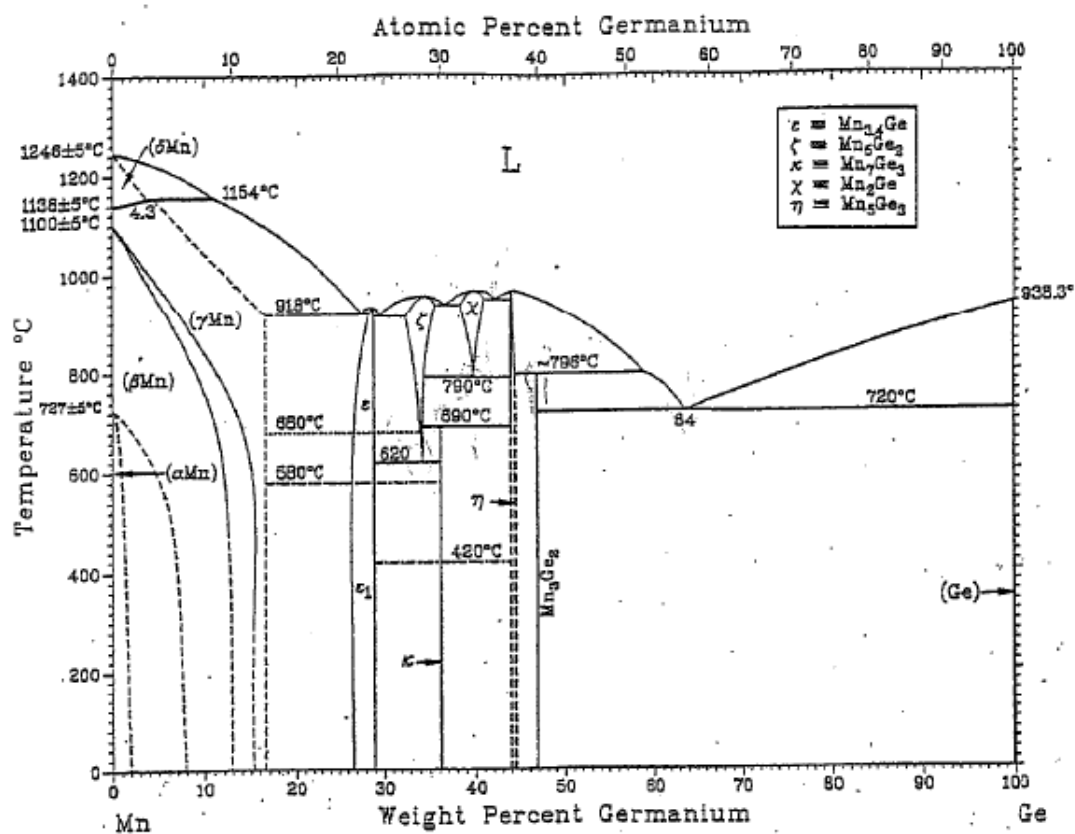
Problem 11 (T/D)

The figures on the next page show a portion of the Germanium-Manganese binary phase diagram, as reported in ***ASM Handbook, Volume 3: Alloy Phase Diagrams***. The dotted horizontal line at 680°C represents an ordered transition between ϵ and ϵ_1. For purposes of this question, consider ϵ and ϵ_1 to be the same phase. The dashed horizontal lines at 580°C and 420°C represent magnetic transformations; they do not represent phase boundaries. The other dashed lines represent phase boundaries where the location is known only approximately or is inferred from limited experimentation.

A. (10 pts). List all phases identified in the diagram.

B. (10 pts). Use the Gibbs Phase Rule to determine the number of degrees of freedom when three phases are present.

C. (10 pts). Identify the temperature, phases present, and composition of each of the phases at all three-phase (or invariant) points on this phase diagram.

D. (10 pts). Identify the points in part c) that are eutectic points, eutectoid points, peritectic points, and peritectoid points. You may, but are not required to, identify monotectic points.

E. (10 pts). Identify all intermediate phases and intermediate compounds found in the phase diagram. Describe the difference between an intermediate phase and an intermediate compound.

F. (20 pts). Sketch approximate cooling curves (temperature vs. time) that would result if Ge-Mn alloys of the following composition were cooled from liquid until solidification is complete. Explain the differences between the cooling curves:

    a. 29.4 weight percent Ge
    b. 31.5 weight percent Ge
    c. 33 weight percent Ge
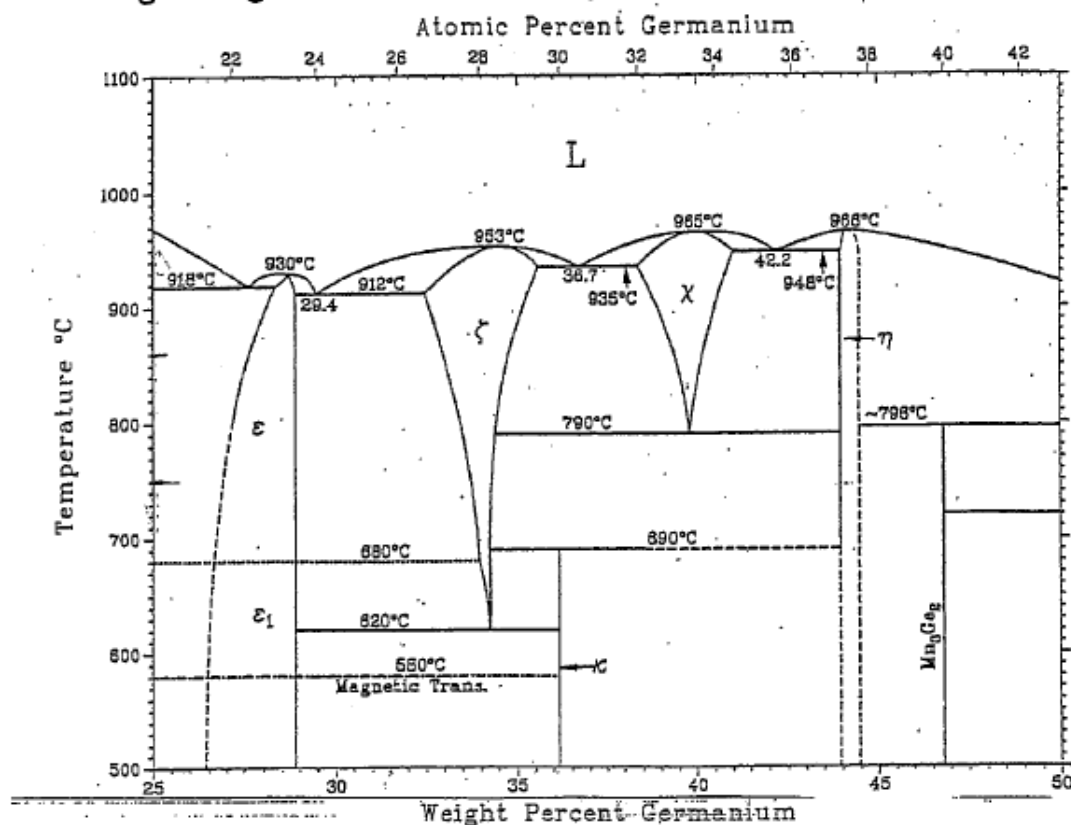
Suppose an alloy of Germanium and Manganese containing 36 weight percent Germanium were cooled very slowly from 1000°C:

G. (15 pts). Describe the phases that would be present, the approximate mass fraction of the phases, and the expected morphology of the phases at 850°C.

H. (15 pts). Describe how the microstructure from part g) would change when the temperature dropped to 750°C.

Ge-Mn

L

ε = Mn₃.₄Ge
ζ = Mn₅Ge₂
κ = Mn₇Ge₃
χ = Mn₂Ge
η = Mn₅Ge₈

Legend (as shown):
- ε = Mn₃.₄Ge
- ζ = Mn₅Ge₂
- κ = Mn₇Ge₃
- χ = Mn₂Ge
- η = Mn₅Ge₈

Temperature °C

1400
1248±5°C   (δMn)
1200   1154°C
1138±5°C 4.3
1100±5°C
1000   918°C
             (γMn)   ζ   χ   935.3°
800 (βMn)   ~796°C
727±5°C   ε   790°C   720°C
             650°C   890°C   64
600   (αMn) 580°C 620
                              η →
400   420°C
                  ε₁   Mn₃Ge₂   (Ge)→
200   κ →
0
  0   10   20   30   40   50   60   70   80   90   100

Weight Percent Germanium

Mn   Ge

Enlarged region of the Mn-Ge system

L

1100
1000
          918°C   930°C   953°C   965°C   966°C
900   29.4 912°C   36.7   χ   42.2   948°C
          ε   ζ   935°C   η
800   790°C   ~796°C
700   650°C   690°C
      ε₁   620°C
600   550°C   κ   Mn₃Ge₂
          Magnetic Trans.
500
  25   30   35   40   45   50

Weight Percent Germanium

Problem 12 (T/D)

Suppose you have been given some 0.60wt% C steel bar stock. The heat treatment condition of the steel is unknown. The Fe-C phase diagram and the isothermal transformation (TTT) diagram for this iron carbon alloy are shown on the next page. Please answer the following questions regarding this alloy:

A. (10pts). All isothermal transformation (TTT or precipitation) diagrams are similar in shape, sometimes referred to as a C-shape curve. What are the two competing mechanisms which contribute to this shape?

B. (20 pts). Describe the simplest heat treatment to convert the following microstructures to the other:

    a. Martensite to coarse pearlite
    b. Pearlite to bainite
    c. Tempered martensite to bainite
    d. Bainite to martensite

C. (20 pts). Considering the final microstructures in part b) please list these in order of decreasing toughness and describe why you rank them in this order.

D. (20 pts). If this 0.60wt%C alloy were slow cooled from 1200°C, please draw and describe what the room temperature microstructure would consist of.

E. (30 pts). A 0.5" diameter rod of the same material is constrained between two water cooled copper jaws that are two inches apart. Now suppose that the bar stock was resistively heated by passing current between the copper jaws. Sufficient current was applied such that the peak temperature in the steel bar stock reached 800°C. The bar was held at 800°C for 10 seconds then current was shut off.

    a. Draw the temperature profile in the steel bar stock at the end of the 10 seconds.
    b. Draw the room temperature hardness profile as a function of distance across the steel bar stock between the copper jaws.
    c. Describe the room temperature microstructure across the same region. Assume that the microstructure of the steel bar stock was initially fully martensitic.

pdated: 8/31/2022
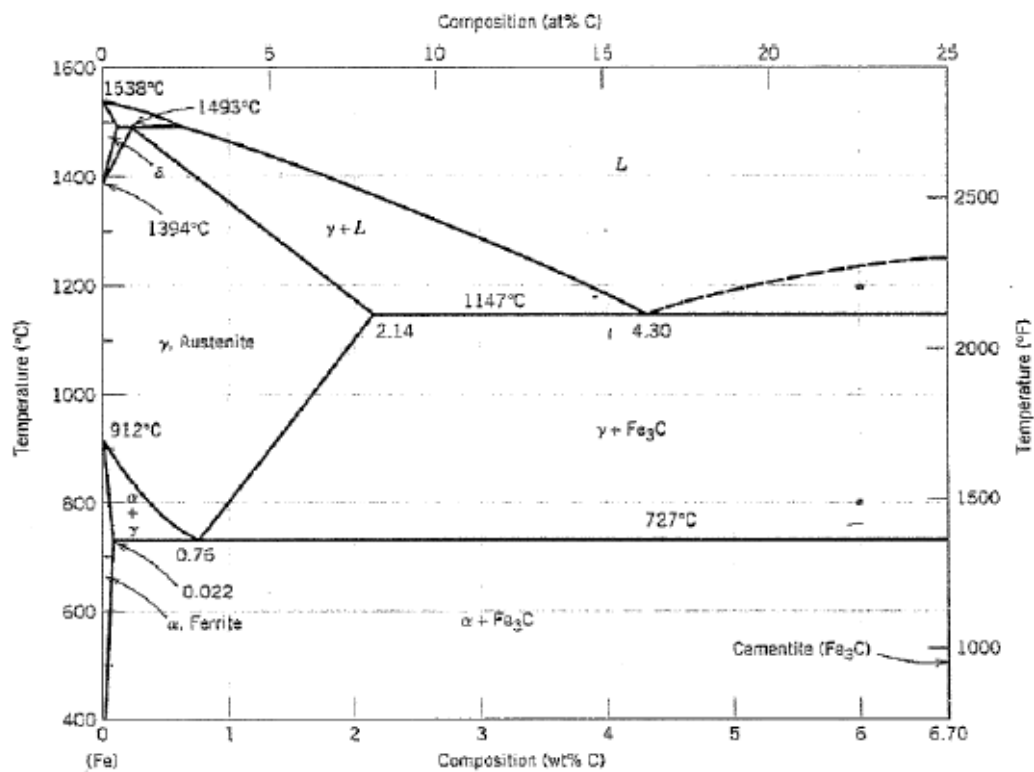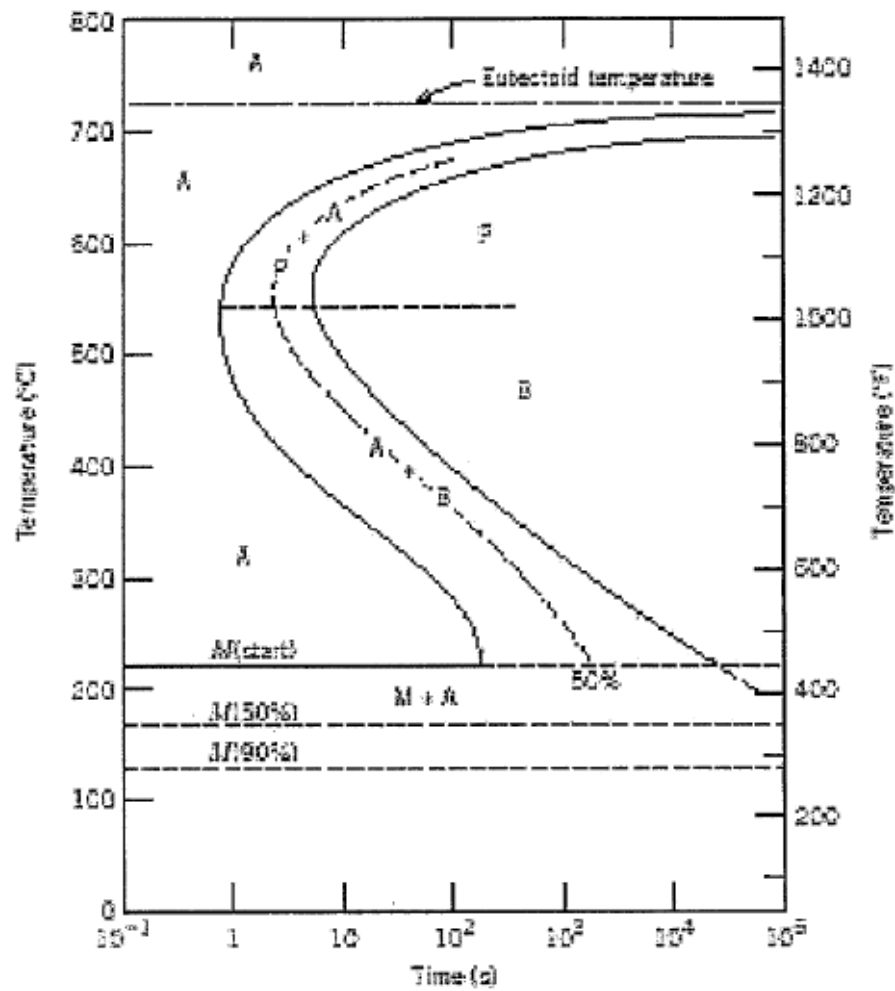
Problem 13 (T/D)

The attached figure shows a portion of the Copper-Titanium binary phase diagram, as reported in ***ASM Handbook, Volume 3: Alloy Phase Diagrams.***

A. (10 pts). List all phases identified in the diagram.

B. (10 pts). Use the Gibbs Phase Rule to determine the number of degrees of freedom when three phases are present.

C. (10 pts). Identify the temperature, composition, and phases present at all three-phase (or invariant) points on this phase diagram.

D. (10 pts). Identify the points in part c) that are eutectic points, eutectoid points, peritectic points, and peritectoid points.

E. (10 pts). Identify all intermediate phases and intermediate compounds found in the phase diagram. Describe the difference between an intermediate phase and an intermediate compound.

F. (50 pts). Suppose two different allows of Copper and Titanium, one containing 53% Cu and the other containing 55% Cu by weight, were cooled very slowly from 1700°C to room temperature. Describe the phases that would be present, the approximate mass fraction of the phases, and the expected morphology of the phases at room temperature. Explain the differences in microstructure you would expect to see in the two alloys and the origin of difference.

Cu-Ti

Atomic Percent Copper

Ti · · · Weight Percent Copper · · · Cu
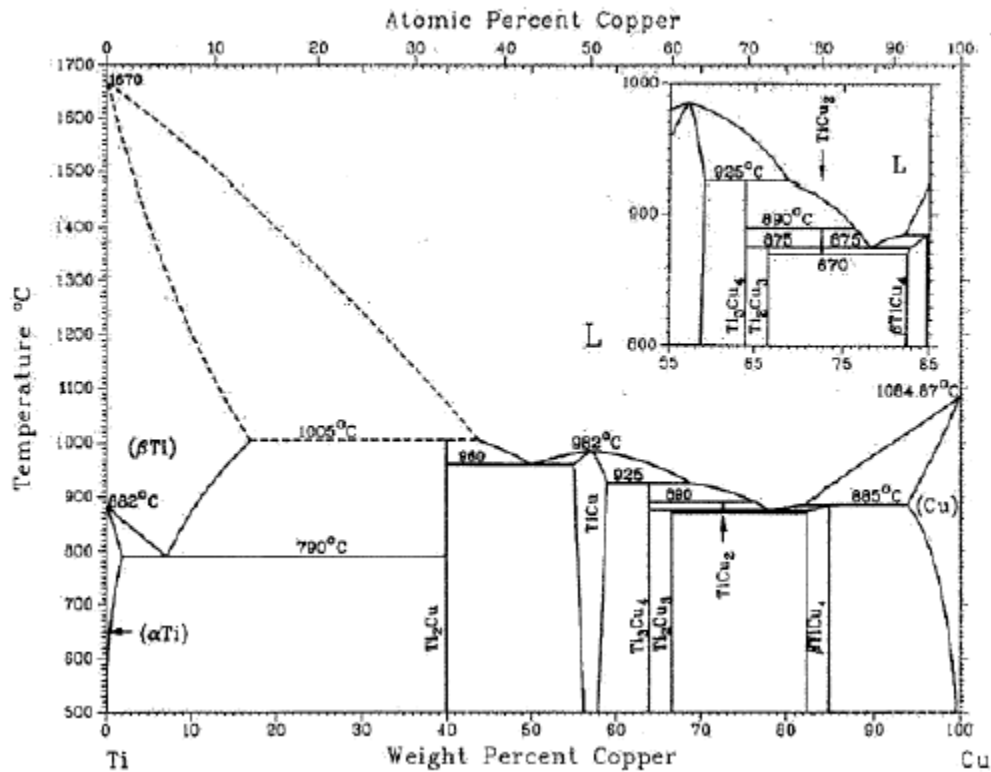
Problem 14 (T/D)

An air hardenable steel bar (50 mm diameter) is quench and tempered to a Rockwell hardness of 42. The approximate composition of the bar is given in Table 1 below. While in service, one end of the bar is accidentally subjected to an elevated temperature for a short time creating a temperature gradient along the length of the bar. The peak temperature at the high-temperature end is approximately 900°C. The peak temperature of the low-temperature end is approximately 150°C.

  A. (15 pts). Show the expected temperature profile along the bar when the end temperature is 900°C.

  B. (35 pts). Describe the expected microstructures for critical regions along the bar when the end temperature is 900°C.

  C. (60 pts). Describe the expected microstructures along the bar after the bar has cooled to room temperature.

Table 1. Nominal composition of Fe-Cr-Mo-V alloy

Steel	Cr	Ni	Mo	Mn	Si	C	V	W
Cr-Mo-V	2	0.2	1.0	0.5	0.3	0.6	1.0	-

Problem 15 (T/D)

The attached figure shows a portion of the Iron-Germanium binary phase diagram, as reported in ***ASM Handbook, Volume 3: Alloy Phase Diagrams***.

A. (10 pts). List all phases identified in the diagram.

B. (10 pts). Use the Gibbs Phase Rule to determine the number of degrees of freedom when three phases are present.

C. (20 pts). Identify the temperature, composition, and phases present at all three-phase (or invariant) points on this phase diagram.

D. (15 pts). Identify the points in part c) that are eutectic points, eutectoid points, peritectic points, and peritectoid points.

E. (10 pts). Identify all intermediate phases and intermediate compounds found in the phase diagram. Describe the difference between an intermediate phase and an intermediate compound.

F. (35 pts). Suppose an alloy of Iron and Germanium containing 31% Ge by weight were cooled very slowly from 1700ºC to room temperature. Describe the phases that would be present, the approximate mass fraction of the phases, and the expected morphology of the phases at room temperature. Explain the origins of the microstructure you would expect to see.