# NANYANG TECHNOLOGICAL UNIVERSITY

## SEMESTER 2 EXAMINATION 2023-2024

## MA2024 - ENGINEERING MATERIALS AND MANUFACTURING PROCESSES

April/May 2024 Time Allowed: 2½ hours

Seat No.:

| | | | |
|---|---|---|---|
| | | | |

Matriculation No.:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

## INSTRUCTIONS

1. This question and answer booklet contains **SIX (6) questions** and comprises **FOURTEEN (14)** pages.
2. Answer **ALL** questions.
3. Marks for each question are as indicated.
4. All your answers should be contained in this answer booklet and within the space provided after the question.
5. This is a **RESTRICTED-OPEN BOOK** examination. You are allowed to bring into the examination hall **one double-sided A4-size reference sheet with texts handwritten or typed on the A4 paper or one restricted material as instructed by the examiner(s) without any attachments (e.g. sticky notes, post-it notes, gluing or stapling of additional papers)**.

For examiners:

| Questions | **1** (20) | **2** (15) | **3** (15) | **4** (15) | **5** (17) | **6** (18) | **Total** (100) |
|---|---|---|---|---|---|---|---|
| Marks | | | | | | | |

Q1 Crystallographic structure, defects. (20 marks)

/20

(a) Find the Miller Indices for the two shaded planes A and B. Use the correct bracket for the planes.

(4 marks)

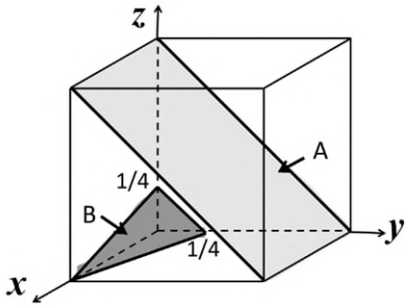


Figure 1

(b) Draw the 3 slip directions on the FCC $(\bar{1}\ \bar{1}\ 1)$ plane directly in Figure 2. Also, write down the Miller Indices for the 3 slip directions. Use the correct brackets for the slip directions.

(3 marks)

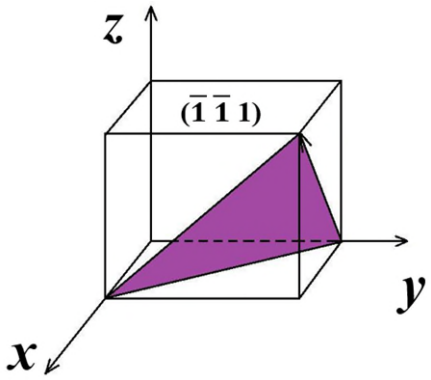


Figure 2

(c) Draw the location of an "octahedral interstitial site" in an FCC unit cell. Specify the point coordinate of that octahedral interstitial site you draw. An empty unit cell is given in Figure 3 to draw and write your answer.

(3 marks)

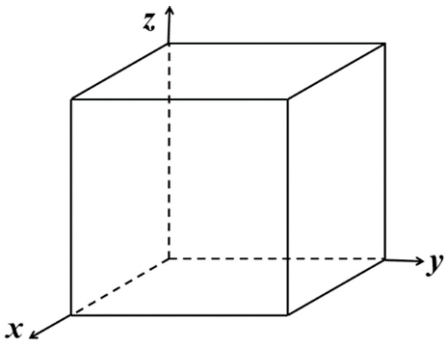


Figure 3

Note: Question 1 continues on page 3

(d) Find the linear densities along [110] and [111] directions for a BCC unit cell, if the atomic radius of the element is 0.141nm.

(4 marks)

(e) A cubic hypothetical alloy has an atomic radius of 0.133 nm, a density of 13.42 g/cm$^3$, and an atomic weight of 107.6 g/mol. Determine whether it is an FCC, BCC, or Simple Cubic crystalline structure.

(6 marks)

Q2 Mechanical properties, Dislocations, and Strengthening Mechanism (15 marks)

/15

(a) Figure 4 shows the engineering stress-strain curves for iron at three different temperatures:(1) -200 °C, (2) -100 °C, and (3) 25 °C.
Rank how the following properties vary at these three temperatures in Table 1. (For example, 1 > 3 > 2)

(4 marks)

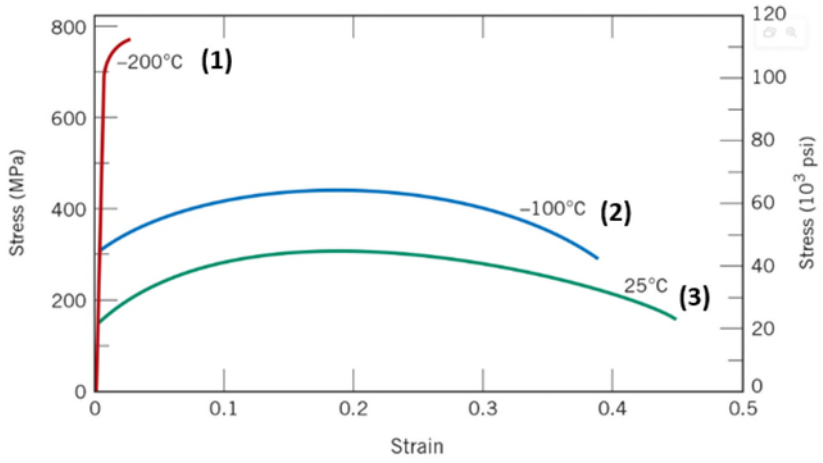


Figure 4: Engineering stress-strain curves for iron at three temperatures.

Table 1

| Property | Rank | |
|---|---|---|
| Yield strength | > | > |
| Tensile strength | > | > |
| Ductility | > | > |
| Toughness | > | > |

(b) A cylindrical rod of copper with Youngs modulus of E=110GPa and a yield strength of 240MPa is subjected to a load of 6660N. If the length of the rod is 400mm, find the diameter of the rod to allow an elongation of 0.5mm.

(3 marks)

Note: Question 2 continues on page 5.

(c) A cold-worked brass material was annealed at 650°C. The average grain diameters measured at 30 minutes and 90 minutes of annealing times were $3.9\times10^{-2}$ mm and $6.6\times10^{-2}$ mm, respectively. Use the empirical relation of grain growth dependence with time, $d^n - d_0^n = Kt$, answer the following questions. Assuming n=2.

(i) Find the grain diameter at t=0 minute.

(1 mark)

(ii) Find the grain diameter at t=150 minutes.

(1 mark)

(iii) Among the brass materials annealed for 30, 90, and 150 minutes, which one do you expect to have the highest yield strength? Briefly explain your answer.

(2 marks)

(iv) Among the brass materials annealed for 30, 90, and 150 minutes, which one do you expect to have the highest ductility? Briefly explain your answer.

(2 marks)

(v) If we increase the annealing temperature to 750°C, how do the yield strength and ductility for the brass materials annealed with the same duration of time change? Briefly explain your answer.

(2 marks)

Q3 Phase Diagrams (15 marks)

/15

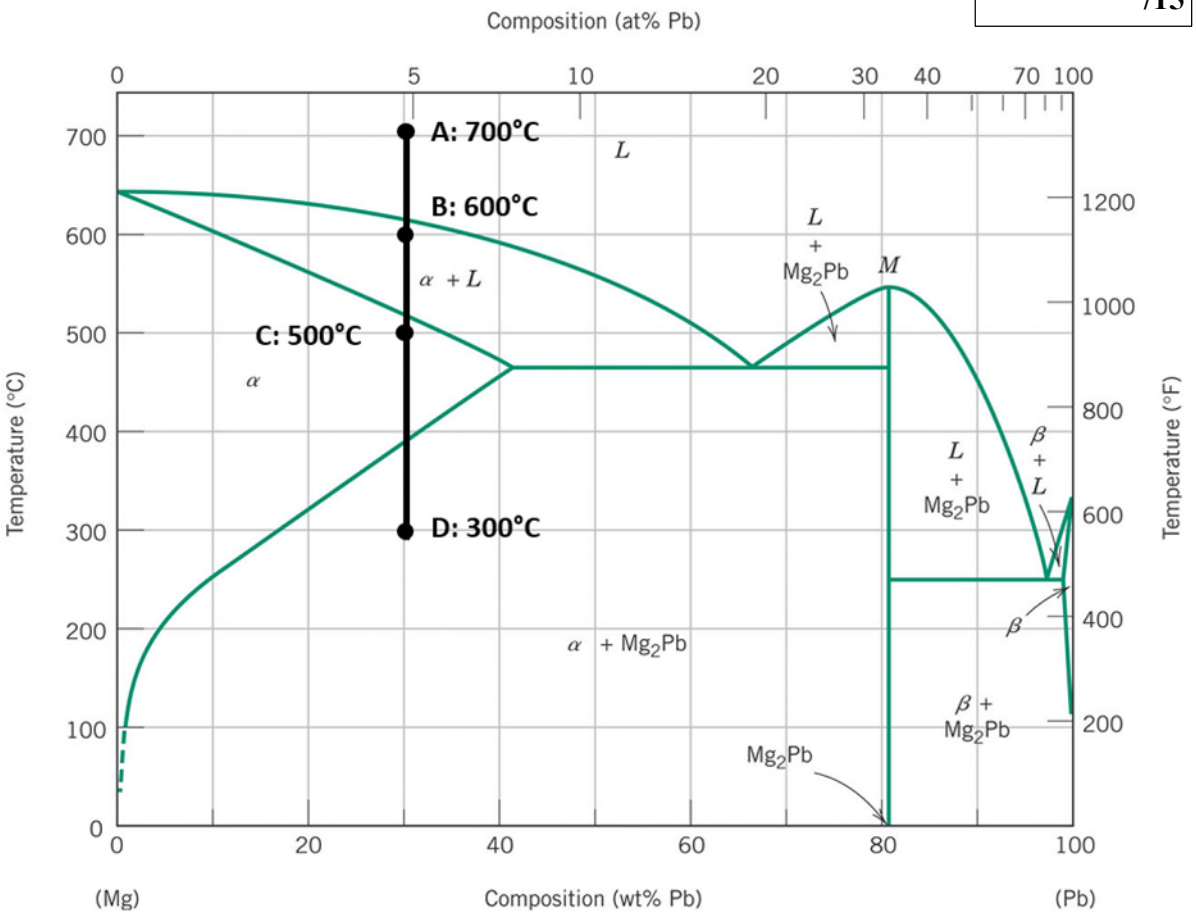


Figure 5: Mg-Pb phase diagram.

Based on the Mg-Pb phase diagram in Figure 5, find the following information.

(a) The melting point of pure Mg.

(2 marks)

(b) The melting point of pure Pb.

(2 marks)

Note: Question 3 continues on page 7.

(c) The two Eutectic temperatures and the corresponding Eutectic compositions.

(2 marks)

| Eutectic Temperature | Corresponding Eutectic Composition |
|---|---|
| °C | |
| °C | |

(d) Draw the microstructure evolution at point A, B, C, and D (as marked in Figure 5) for the Pb-Mg alloy with 30wt%-Pb cooling from 700 to 300 °C.

(4 marks)

(e) Find the composition of α phase and liquid phase at 600°C for the Pb-Mg alloy with 30wt%-Pb.

(2 marks)

(f) Find the mass fraction of α phase and $Mg_2Pb$ intermetallic compound at 300°C for the Pb-Mg alloy with 30wt%-Pb.

(3 marks)

Q4 Metal Casting and Polymer Forming (15 marks)

/15

(a) A manufacturer is producing metallic faucets made of brass to place in private bathrooms. The fabrication method for making these faucets is sandcasting. How is the typical surface finish of parts made by sandcasting and what implication this will have for the manufacturer?

(1 mark)

(b) The faucet is assimilated to a tube. The cavity of the mold is a tube of 15 cm length, 3 cm outer diameter, and 0.3 cm thickness. Given a mold constant of 75 min/cm$^2$, what is the total solidification time? Use n=2 in the Chvorinov's rule.

(2 marks)

(c) Given that brass has a solidification shrinkage of 2.5%, what will be the actual diameter of the final faucet?

(1 mark)

(d) A profilometer is used on the side of the final faucet produced. The profilometer records the following surface deviation values (in micrometres) across the length.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 235 | 500 | 150 | -10 | 0 | -54 | -20 | 67 | 38 | 150 |

What is the surface roughness, Ra, of the faucet?

(1 mark)

Note: Question 4 continues on page 9.

(e) The manufacturer wants to improve their production rate of the brass faucets and decides to design a sandcasting mold able to produce 2 faucets at the same time. How would the mold look like and what would be the new casting time? You can make a schematic to help you describe the new mold design.

(2 marks)

(f) The manufacturer thinks that producing 2 faucets at the same time is still a too slow production rate. They now decide to produce 50 faucets at the same time. What metal manufacturing method would be the best to achieve 50 faucets at the same time? Briefly describe the method. You may make some schematics to help you explaining.

(2 marks)

(g) Brass is a metal alloy made of 60% copper, 30% zinc and 10% of other metals. Draw the grain microstructure after solidification of the cross-section of the diameter of the faucet.

(1 mark)

(h) Among the 10% of other metals present in brass, 3% is made of lead that is used to increase the machinability of the faucet. What could be the issue in using lead in brass for faucet application?

(1 mark)

Note: Question 4 continues on page 10.

(i) To first experiment the design of the brass faucet, the manufacturer decides to make a prototype in plastic. A thermoplastic is used. The manufacturer intends to use the sandcasting mold made for the metal casting, and to pour the molten thermoplastic inside instead. How is the viscosity of the polymer melt in comparison to the viscosity of the liquid metal? What will be the consequence on the casting process?

(2 marks)

(j) Draw the typical rheological curve of a thermoplastic melt (viscosity as a function of shear rate). How is this type of behaviour called?

(2 marks)

Q5 (17 marks)

/**17**

A lathe is used to machine an aluminium workpiece from an original 100mm diameter to a final 90mm diameter having a 500mm length. The one-pass operation is performed at a rotational speed of 1100 rev/min with a feed of 0.06cm/rev. The specific machining energy for aluminium is 0.8 J/mm$^3$. The lathe has a mechanical efficiency of 85%.

Determine the following:

(a) Power required to perform the operation.

(4 marks)

Note: Question 5 continues on page 11.

(b) The cutting force of the operation.

(3 marks)

(c) If the tool can be used to machine 10 workpieces only, what is the expected life of the tool?

(3 marks)

(d) Of the machining conditions relating to cutting speed, feed rate and depth of cut, which one has the greatest effect on tool wear? State your reason for your choice.

(4 marks)

(e) Briefly highlight the likely chip type formed, the hazard it may pose and suggest a remedial action to overcome them.

(3 marks)

Q6 (18 marks)

/**18**

(a)(i) Fillet welds are commonly used to weld corner joint, lap joint and tee joint. By means of a diagram, sketch where fillet welds are commonly employed on lap and tee joints.

(4 marks)

(ii) An inside fillet corner joint that is used to join 2 medium carbon steel plates at $90^{o}$ with each other. Each plate has a thickness of 5.0mm. The cross section of the weld is assumed to be a right-angle isosceles triangle with a leg length of 5 mm. The velocity of the weld head is 7 mm/sec. Assume the heat transfer factor is 0.8 and melting factor is 0.65. Determine the rate of heat generation required at the welding source to accomplish the weld. The melting temperature of medium carbon steel is assumed to be 1700 K with a K constant value of $3.33 \times 10^{-6}$.

(5 marks)

(iii) Briefly describe a welding process that is typically used to perform such welds.
(3 marks)

(b) Figure 6 shows the starting blank and resulting sheet metal part of a bending operation performed on a 5mm thick cold rolled sheet metal. The starting blank is 138mm long and 30mm wide. The sheet is bent along the 30mm direction. The bend radius, R must not be greater than 12mm. Determine the following:

(i) Part bend allowance
(1 mark)

(ii) Part bend radius
(5 marks)

Note: Figure 6 appears on page 14.

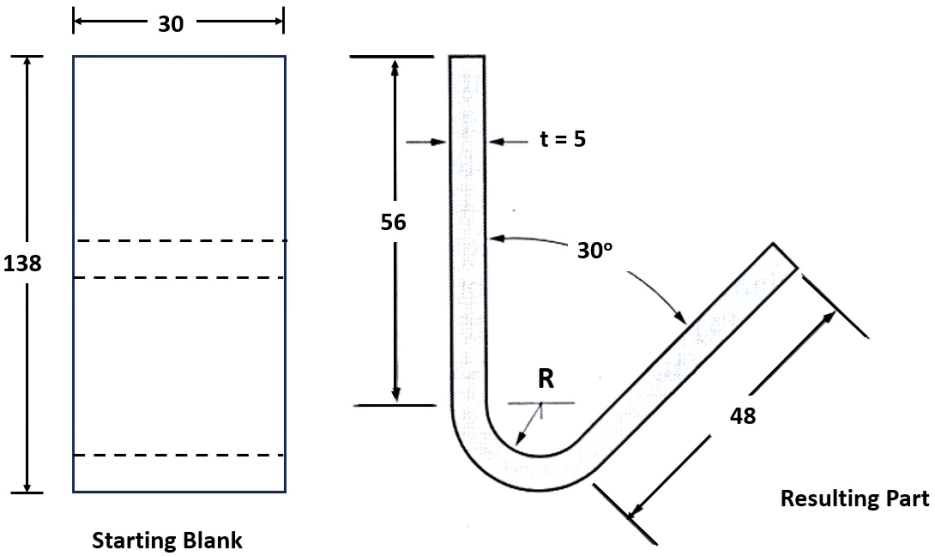


Figure 6: Sheet Metal Blank and Part

END OF PAPER