NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 1 EXAMINATION 2023-2024

MA2024 – ENGINEERING MATERIALS AND MANUFACTURING PROCESSES

November/December 2023 Time Allowed: 2½ hours

Seat No.:

Matriculation No.:

INSTRUCTIONS

1. This question and answer booklet contains **SIX (6) questions** and comprises **FIFTEEN (15)** 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** (18)	**2** (16)	**3** (16)	**4** (25)	**5** (9)	**6** (16)	**Total** (100)
Marks							

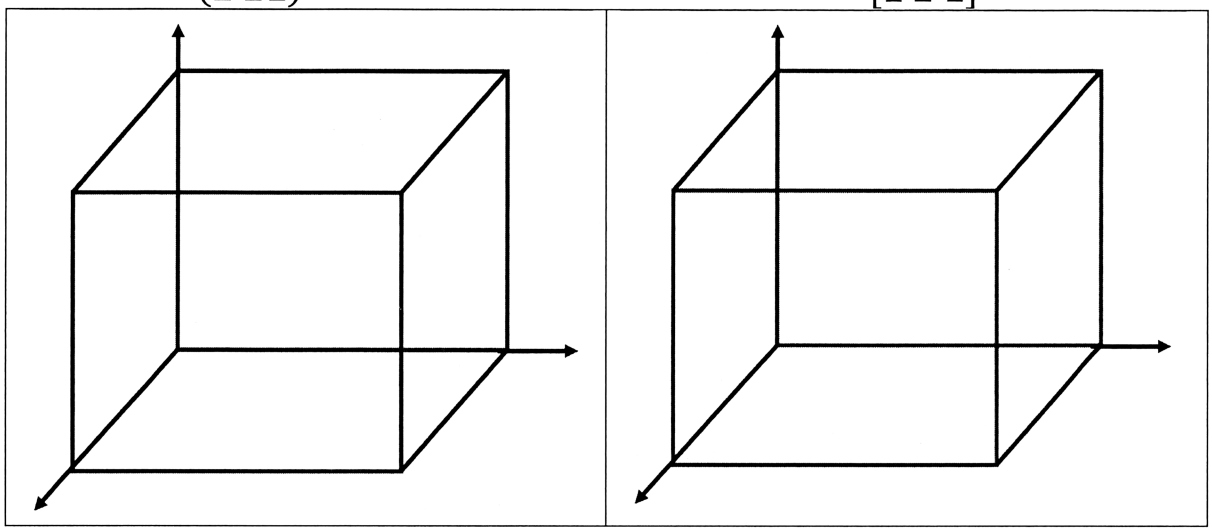
Q1. (18 marks)

/18

(a) Draw the following within the given unit cells:

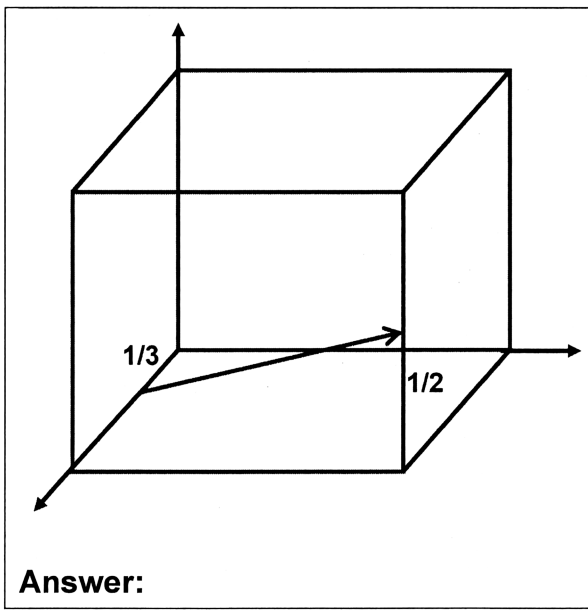
(4 marks)

$(\bar{2}\,21)$ $[1\,\bar{2}\,\bar{1}]$

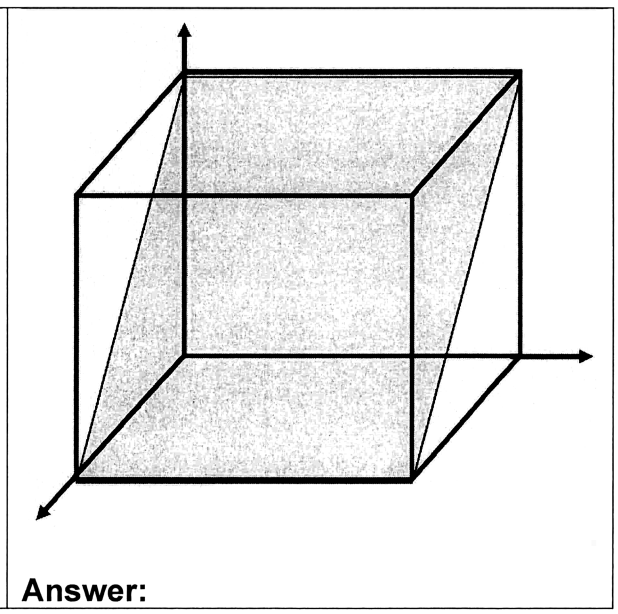


(b) Identify the Miller indices for the direction and plane shown below:

(4 marks)



Answer:



Answer:

Note: Question 1 continues on page 3.

(c) Calculate the planar density of (101) for iron at room temperature (atomic radius = 0.126 nm).

(5 marks)

(d) The vacancy concentration in a 10 grams of gold bar at room temperature (27 °C) is 1.1 x 10^{-17}. Estimate the activation energy for vacancy formation in gold. (The lattice parameter of gold is 0.4065 nm. Density of gold is 19.30 g/cm^3. Avagadro's number, N_A is 6.023 x 10^{23} atoms/mol. Boltzmann's constant = 8.62×10^{-5} eV/atom-K.)

(5 marks)

Q2. (16 marks)

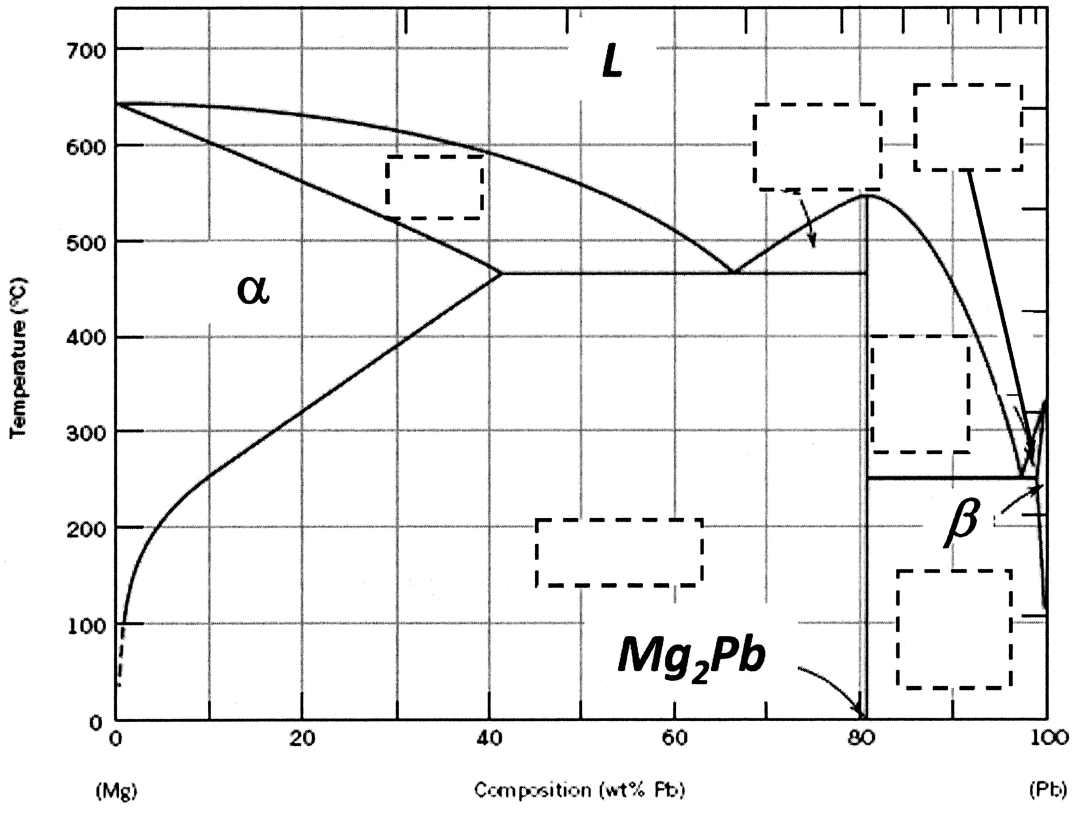
/16

(a) List all the Hume-Rothery rules that need to be satisfied for forming complete solid solutions.

(4 marks)

(b) The equilibrium phase diagram for the Mg-Pb binary system displayed below. Identify the phase(s) that (co-)exist in the phase fields highlighted with dashed boxes.

(6 marks)



Note: Question 2 continues on page 5.

(c) The alloy with the composition of 30 wt.% Pb is cooled from 700 °C to room temperature. Describe, using schematic diagrams, the different phases at 550, 450, and 250 °C in the alloy as it is cooled down. Estimate the weight fractions of the phases at these temperatures.

(6 marks)

Q3. (16 marks)

/16

(a) When a force of 100 N is applied, a metallic wire (10 cm in length and 2 mm in diameter) elongates by 31.83 microns. Estimate the Young's modulus (in GPa) of this metal.

(4 marks)

(b) The most favourably oriented slip plane in a silver single crystal is $(1\bar{1}\bar{1})$. Write down all the possible crystallographic directions along which slip can occur on this plane.

(3 marks)

Note: Question 3 continues on page 7.

(c) List at least THREE mechanisms that can be employed to strengthen a metallic alloy?
(3 marks)

(d) Write down the mechanisms, in sequence, that take place when a heavily cold worked metal is annealed at high temperatures.
(3 marks)

Note: Question 3 continues on page 8.

(e) What is the recrystallization temperature? On its basis, define 'hot working' and 'cold working' temperature regimes of metals.

(3 marks)

Q4. This question relates to metal casting and polymer forming. **/25**

(a) A thermoplastic polymer is casted into a mold that has the shape of a dental crown. To be able to cast this thermoplastic polymer into the mold, under which state should the polymer be? Can you explain how you would proceed with the casting in terms of processing parameters (temperature, pressure, time, …)

(2 marks)

Note: Question 4 continues on page 9.

(b) Using a thermosetting polymer instead, how would you proceed now?

(2 marks)

(c) Casting of polymers is ideal for producing a small number of pieces. What other process would you propose to use to produce a large number of identical pieces in a very short time?

(1 mark)

(d) Poly Lactic Acid (PLA) is a thermoplastic polymer with a glass transition temperature Tg of 60 °C and a melting temperature Tm of 160 °C. During the casting, PLA shrinks by a value S = 0.025. Given that the desired final dimension of the dental crown is 1 cm diameter, what should be the dimension of the mold diameter?

(2 marks)

Note: Question 4 continues on page 10.

(e) Would PLA be a suitable material for a dental crown? Give your reasons.

(1 mark)

(f) To compare with PLA, we now use a cobalt-chromium alloy (Co-Cr) and study its casting using the sand-casting method. Knowing that the viscosity of the molten Co-Cr alloy is 10 Pa.s, the density is 8768 $kg.m^{-3}$, the channels diameter is 2 mm, what should be the velocity of the fluid flow to have a laminar flow? You can give a range e.g. the velocity should be higher or lower than a certain value.

(3 marks)

(g) Given the velocities that induce laminar flow, what should the maximum height of the riser? The constant of gravity g is 9.81 $m.s^{-2}$. Please comment on that value.

(3 marks)

Note: Question 4 continues on page 11.

(h) In practice, the riser is a cylindrical shape of diameter 5 mm and 5 cm height. Given a mold constant of 30 $s.mm^{-2}$, what is the total solidification time for the riser?

(3 marks)

(i) What is the condition between the total solidification time for the riser and for the main cast?

(1 mark)

(j) Assuming the dental crown can be approximated by a cylinder of 1 cm height and 1 cm diameter, is the condition from question (i) satisfied?

(3 marks)

Note: Question 4 continues on page 12.

(k) After solidification of the alloy, how does the grain structure look like? Draw a schematic showing the grain structure in the casted crown.

(1 mark)

(l) Instead of sand-casting method, what other process would you use to produce a large number of metallic dental crown? Please explain the process steps. You can make schematics if that is helpful.

(3 marks)

Q5. This question relates to ***metal forming***.

/9

(a) Figure 1 shows a type of common defect in deep drawing process. What is the name of the defect? What is the cause for the defect. Suggest a method to avoid the defect.

(5 marks)

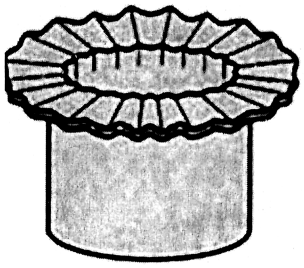


Figure 1

(b) A blanking die is designed to produce a circular blank of 10 cm in diameter from a 1.8 mm thick steel sheet. If the steel has an ultimate tensile strength of 540 MPa, determine the force required to perform the blanking operation.

(4 marks)

6. This question relates to ***metal machining*** and ***metal joining***.

/16

(a) In a metal cutting operation, width of cut w = 4.5 mm, undeformed chip thickness t_o = 0.12 mm, chip thickness t_c = 0.20 mm, chip velocity V_c = 150 m/min, rake angle α = 10°, cutting force F_c = 150 N, and thrust force F_t = 80 N, calculate the cutting velocity and the cutting power.

(4 marks)

(b) Which of the following two figures illustrates conventional milling? Explain why it is a more commonly used method of milling.

(4 marks)

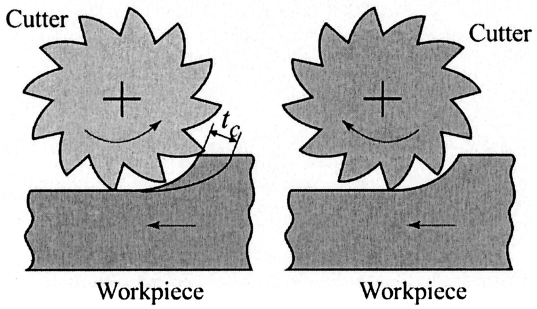


Figure 2(a)

Figure 2(b)

Note: Question 6 continues on page 15.

(c) What is the name of the welding process shown in Figure 3? Describe the welding process briefly. Is filler material used in the welding process?

(4 marks)

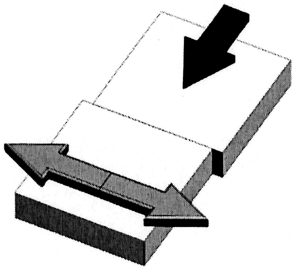


Figure 3

(d) An arc welding operation takes place on aluminium alloy plates. Calculate the welding speed if the following can be assumed: welding voltage, E = 22 V, welding current, I = 120 A, heat transfer efficiency, $f_1 = 0.6$, melting efficiency, $f_2 = 0.5$, cross-sectional area of weld, A = 12 mm^2, and unit melting energy of the aluminium alloy = 5.1 J/mm^3.

(4 marks)

END OF PAPER

MA2024 ENGINEERING MATERIALS & MANUFACTURING PROCESSES

Please read the following instructions carefully:

1. **Please do not turn over the question paper until you are told to do so. Disciplinary action may be taken against you if you do so.**

2. You are not allowed to leave the examination hall unless accompanied by an invigilator. You may raise your hand if you need to communicate with the invigilator.

3. Please write your Matriculation Number on the front of the answer book.

4. Please indicate clearly in the answer book (at the appropriate place) if you are continuing the answer to a question elsewhere in the book.