

NANYANG TECHNOLOGICAL UNIVERSITY**SEMESTER 1 EXAMINATION 2022-2023****MA2024 – ENGINEERING MATERIALS AND MANUFACTURING PROCESSES**

November/December 2022

Time Allowed: 2½ hours

Seat No.:

--	--	--	--

Matriculation No.:

--	--	--	--	--	--	--	--	--

INSTRUCTIONS

1. This question and answer booklet contains **SIX (6) questions** and comprises **TWELVE (12) pages**.
2. **COMPULSORY** to 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. One double-sided A4-size reference sheet with texts handwritten or typed on the A4 paper (no sticky notes/post-it notes on the reference sheet) is allowed.

For examiners:

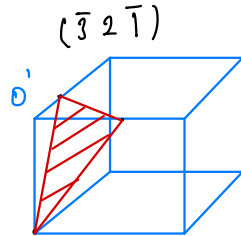
Questions	1 (17)	2 (13)	3 (20)	4 (14)	5 (18)	6 (18)	Total (100)
Marks							

Q1. (17 marks)

/17

(a) Draw within a unit cell the following:

(i) $(\bar{3} \ 2 \ \bar{1})$ Plane

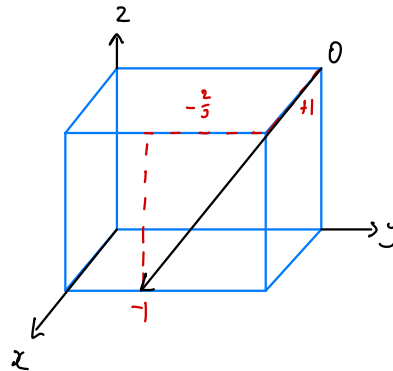
Solution:


$$\text{Reciprocal: } \begin{matrix} \bar{3} & 2 & \bar{1} \\ \hline \frac{1}{3} & \frac{1}{2} & 1 \end{matrix}$$

(3 marks)

(ii) $[3 \ \bar{2} \ \bar{3}]$ Vector

$$= [1 \ \frac{2}{3} \ \bar{1}]$$

Solution:


(3 marks)

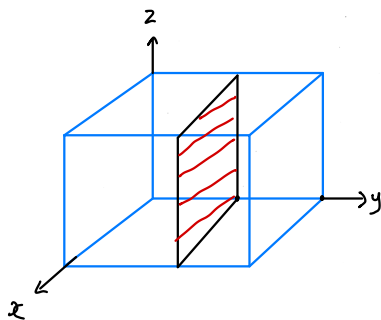
(b) Calculate the planar density of $(0 \ \bar{2} \ 0)$ for iron (atomic radius = 0.124 nm).

Solution:

$$\infty \ \frac{1}{2} \ \infty$$

(4 marks)

$$r = 0.124 \text{ nm}$$



Note: Question 1 continues on page 3.

- (c) Determine number of atoms present in 10 grams of gold bar. The lattice parameter of gold is 0.4065 nm. Density of gold is 19.30 g/cm³. Avagadro's number, N_A is 6.023×10^{23} atoms/mol. $\rightarrow 0.4065 \times 10^{-9} \text{ m}$ /mol?

(4 marks)

Solution:

$$= 0.4065 \times 10^{-9} \text{ cm}$$

FCC: $n = 4$

$$\rho = \frac{\text{mass}}{V} = \frac{10}{14.30}$$

$$\text{Vol of one unit cell} = a^3$$

$$= (0.4065 \times 10^{-9})^3$$

$$\frac{19.30 \text{ g}}{\text{cm}^3} \times \frac{1 \text{ kg}}{1000 \text{ g}} \times \frac{1 \text{ cm}^3}{10^{-6} \text{ m}^3}$$

 $\therefore$ Number of atoms in 10 grams of gold

$$= 4 \times \frac{1}{1930000}$$

$$\frac{10 \times 10^{-3}}{19.30} = \frac{1}{1930000} = 3.085 \times 10^{22} \text{ atoms}$$

$$\frac{10 \times 10^{-3}}{19.30} = \frac{1}{1930000}$$

- (d) Estimate the number of vacancies in the 10 grams of gold at room temperature (27 °C). The activation energy for vacancy formation in gold is 1.01 eV/atom. Boltzmann's constant = 8.62×10^{-5} eV/atom-K.

(3 marks)

Solution:

$$\text{from c) } N = 3.085 \times 10^{22}$$

$$\text{mass} = 10 \text{ g}$$

$$T = 27 + 273 = 300 \text{ K}$$

$$Q_v = 1.01 \text{ eV/atom}$$

$$K = 8.62 \times 10^{-5} \text{ eV/atom-K}$$

$$n = N \exp\left(-\frac{Q_v}{KT}\right) = 3.08 \times 10^{22} e^{\left(-\frac{1.01}{8.62 \times 10^{-5} \times 300}\right)}$$

$$= 3.08 \times 10^{22} e$$

$$= 336160.4292 \text{ vacancies?}$$

Q2. (13 marks)

/13

(a) Based on the data given below, WHICH TWO element combination will form an isomorphous phase diagram and WHY?

(4 marks)

Element	Atomic Radius (nm)	Crystal Structure	Electronegativity	Valence
Copper (Cu)	0.1278	FCC	1.9	+2
Cobalt (Co)	0.1253	HCP	1.8	+2
Iron (Fe)	0.1241	BCC	1.8	+2
Aluminium (Al)	0.1431	FCC	1.5	+3
Nickel (Ni)	0.1246	FCC	1.8	+2

Solution:

• Hume Rothery rules for complete solid solution
 ↳ same type: FCC: Cu, Al, Ni
 similar electronegativity,
 similar valence

∴ Copper and Nickel

(b) Label the different phase fields that are on the equilibrium phase diagram for the Cu-Ag binary system displayed below.

(3 marks)

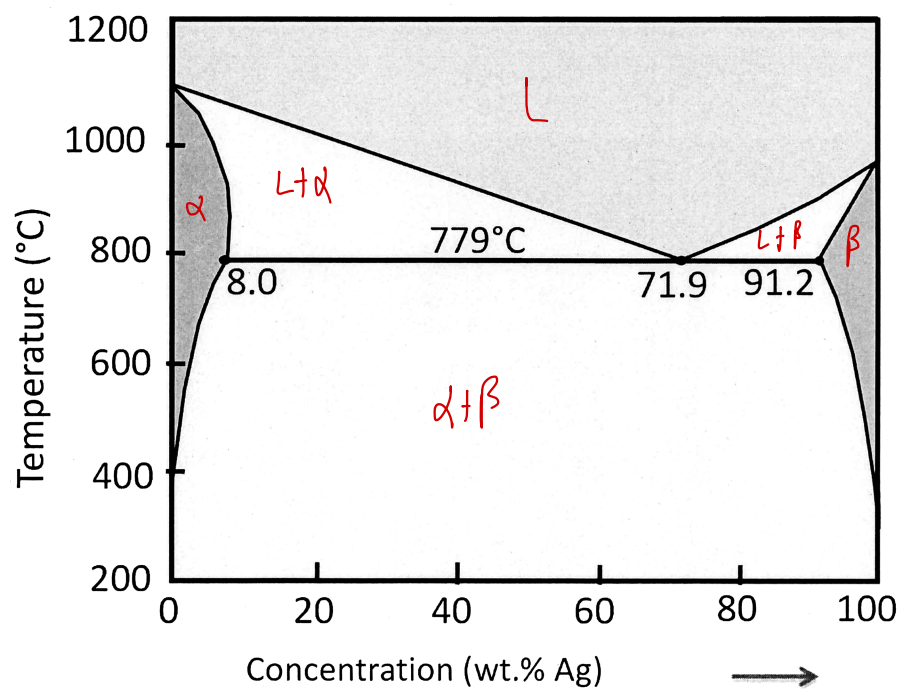
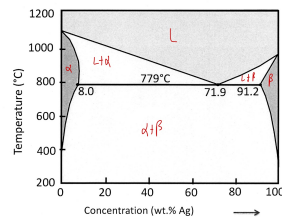


Figure 1

Note: Question 2 continues on page 5.

- (c) Write down the reaction that occurs when an alloy with 71.9 wt.% Ag composition is slowly cooled from 780 to 778 °C. What is the name of this reaction?

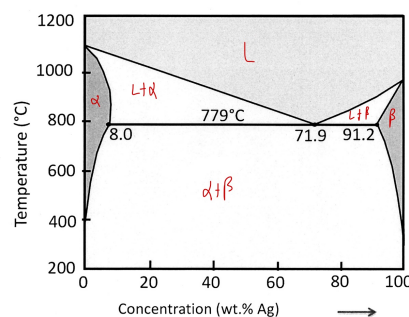
(3 marks)

Solution:

$L \rightarrow \alpha + \beta$
 $\therefore$ Eutectic reaction

- (d) Draw a schematic diagram of the microstructure (with different phases labelled) of the alloy with 60 wt.% Cu.

(3 marks)

Solution:

Phase is Ag, having Cu

Q3. (20 marks)

/20

- (a) A 20 mm long steel wire (Young's modulus = 200 GPa) with 2 mm diameter was stretched by applying a force of 2 kN. What is the elastic strain energy stored in the wire?

(5 marks)

Solution:

$$L = 20 \text{ mm}$$

$$E = 200 \times 10^3 \text{ MPa}$$

$$d = 2 \text{ mm}$$

$$F = 2000 \text{ N}$$

$$U_r = \frac{1}{2} \sigma \epsilon$$

$$\sigma = \frac{F}{A} = \frac{2000}{\frac{\pi}{4} (2)^2} = 636.62 \text{ MPa}$$

$$\therefore U_r = \frac{\sigma^2}{2E} = \frac{636.62^2}{2 \times 200 \times 10^3} = 1.01 \text{ J}$$

- (b) In the plastic deformation regime of a ductile metal that is being tensile tested, application of the engineering stresses of 800 and 1000 MPa result in engineering strains of 0.1 and 0.2, respectively. Compute the work hardening exponent of the metal.

(5 marks)

Solution:

	ϵ	σ	ϵ_1	σ_1	$\sigma_1 = 800 (1 + 0.1)$
A	0.1	800	0.0953	880	= 880

$$\epsilon_{TA} = \ln(1 + 0.1)$$

$$= 0.0953$$

	ϵ	σ	ϵ_2	σ_2	$\sigma_2 = 1000 (1 + 0.2)$
B	0.2	1000	0.18232	1200	= 1200

$$\epsilon_{TB} = \ln(1 + 0.2)$$

$$= 0.18232$$

$$\therefore n = \frac{\log(1200) - \log(880)}{\log(0.18232) - \log(0.0953)}$$

$$= 0.48$$

Note: Question 3 continues on page 6.

- (c) The tensile yield strength of a single crystal of gold is 50 MPa. If the critical resolved shear stress for gold on (111) plane, which is oriented at angle of 30° to the tensile axis, is 21.65 MPa, calculate the angle that the $[10\bar{1}]$ direction, along which slip occurs, makes with the loading axis.

(5 marks)

Solution:

$$\sigma_y = 50 \text{ MPa}$$

$$\tau_R = \sigma \cos \lambda \cos \phi$$

$$21.65 \text{ MPa} = 50 \cos(30^\circ) \cos(\phi)$$

$$\phi = 60^\circ$$

- (d) The yield strengths of a steel with the grain sizes of $3.24 \mu\text{m}$ and $400 \mu\text{m}$ are 1 GPa and 636 MPa, respectively. What would be the yield strength of the same steel if the grain size of the steel was reduced to 810 nm ?

(5 marks)

Solution:

$$\sigma_y = \sigma_0 + K D^{-0.5}$$

$$\sigma_y = 1 \times 10^3 \text{ MPa}$$

$$D(\text{grain size}) = 3.24 \times 10^{-6} \text{ mm}$$

$$1 \times 10^3 \text{ MPa} = \sigma_0 + K (3.24 \times 10^{-6})^{-0.5} \quad \text{--- ①}$$

$$636 \text{ MPa} = \sigma_0 + K (400 \times 10^{-6})^{-0.5} \quad \text{--- ②}$$

$$\text{①} - \text{②} \quad 364 \text{ MPa} = K (15.987)$$

$$K = 22.767$$

$$K (53.974167)$$

$$364 \text{ } 000 \text{ } 000$$

$$K =$$

Q4. This question relates to *overview of manufacturing* and *metal casting*. (14 marks)

/14

- (a) What is the definition of additive manufacturing? Is it the same as 3D printing? Give your reasons and give an example of additive manufacturing process.

(4 marks)

Solution:

- (b) What is tolerance? How does tolerance affect functioning of a product and manufacturing cost of the product?

(3 marks)

Solution:

- (c) A defect is found in a metal part produced by casting, as shown in Figure 2. What is the name of the defect? Suggest a method to avoid the defect.

(3 marks)

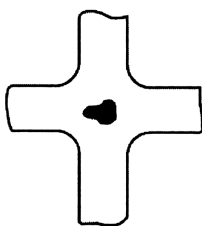


Figure 2

Solution:

Note: Question 4 continues on page 8.

- (d) What is the definition of total solidification time (TST)? A spherical part of magnesium alloy is produced by casting. If its diameter is doubled, what is the percentage increase of TST? You may assume the exponent n in Chvorinov's rule to be 2.

(4 marks)

Solution:

$$TST = C_M \left(\frac{Vol}{A} \right)^n = \frac{C_M \left(\frac{\frac{4\pi}{3} (1)^3}{4\pi (1)^2} \right)^2}{C_M \left(\frac{\frac{4\pi}{3} (2)^3}{4\pi (2)^2} \right)^2} \times 100$$

Q5. This question relates to *metal forming* and *metal machining*. (18 marks)

/18

- (a) Springback occurs during metal bending process. Make a simple drawing to illustrate the phenomenon. What causes springback? Suggest a method to minimize or eliminate springback.

(4 marks)

Solution:

- (b) Tearing is a common defect in deep drawing process. What is the cause for the defect. Suggest a method to avoid the defect.

(3 marks)

Solution:

Note: Question 5 continues on page 9.

- (c) What is the difference between punching and blanking? A punch die is designed to punch a circular hole of 8 cm in diameter from a 1.2 mm thick steel sheet. If the steel has a shear strength of 380 MPa, determine the force required to perform the punch operation.

(5 marks)

Solution:

$$t = 1.2 \text{ mm}$$

$$F = S \tau L = 380 \times 1.2 \times 80 \pi$$

$$= 114608.3 \text{ N}$$

- (d) If n is 0.5 in the Taylor equation for tool life:

$$V T^n = C$$

where V is cutting speed in m/min and T is tool life in min, what is the percentage increase in tool life if the cutting speed is reduced by 80%? How does the change in cutting speed influence the temperature in cutting? Give your reasons.

(6 marks)

Solution:

$$V_1 T_1^{0.5} = V_2 T_2^{0.5}$$

$$V_2 = 0.2 V_1$$

$$V_1 T_1^{0.5} = 0.2 V_1 T_2^{0.5}$$

$$5 T_1^{0.5} = T_2^{0.5}$$

$$5 = \left(\frac{T_2}{T_1} \right)^{0.5}$$

$$25 T_1 = T_2$$

$$\frac{T_2 - T_1}{T_1} \times 100\%$$

$$= \frac{25 - 1}{1} \times 100$$

$$= 2400\%$$

Q6. This question relates to *metal joining*, *engineering polymers*, and *polymer forming*.
(18 marks)

/18

- (a) What is the name of the welding process shown in Figure 3? Which type of shielding gas can be used in the welding process? Give your reasons. What is the role played by the filler wire in the welding process?

(4 marks)

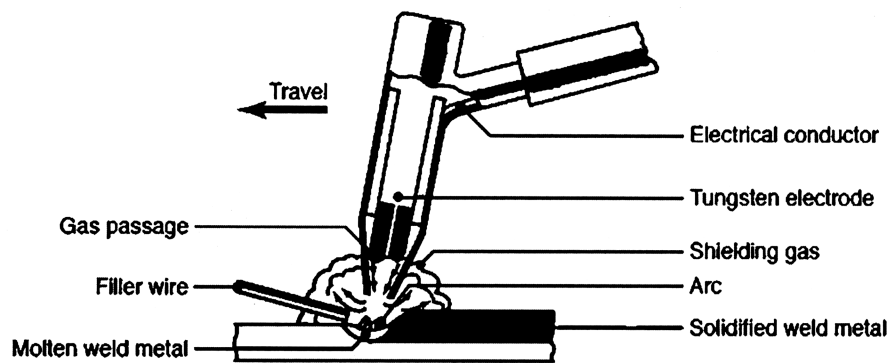


Figure 3

Solution:

Arc welding

Note: Question 6 continues on page 11.

- (b) An arc welding operation takes place on high strength low alloy steel plates. Calculate the welding volume rate and the cross-sectional area of the weld if the following can be assumed: welding voltage, $E = 24 \text{ V}$, welding current, $I = 160 \text{ A}$, heat transfer efficiency, $f_1 = 0.7$, melting efficiency, $f_2 = 0.55$, welding speed, $v = 120 \text{ mm/min}$, and unit melting energy of the steel $= 9.8 \text{ J/mm}^3$.

(5 marks)

Solution:

WVR? A?

$$f_1 = 0.7 \quad f_2 = 0.55$$

$$v = 120 \text{ mm/min}$$

$$u = 9.8 \text{ J/mm}^3$$

$$WVR = HRW / u$$

$$HRW = f_1 f_2 P$$

$$= 0.7 \times 0.55 \times 3840$$

$$= 1478.4$$

$$WVR = \frac{HRW}{u} = \frac{1478.4}{9.8}$$

$$= 150.86 \text{ mm}^3/\text{s}$$

$$V = \frac{f_1 f_2 P}{u \times A}$$

$$A = \frac{f_1 f_2 P}{u \cdot v} = \frac{0.7 \times 0.55 \times 3840}{9.8 \times 120} = 1.257 \text{ mm}^2$$

- (c) What does the term “glass-transition temperature” mean for a polymer? What are the two major structural factors affecting this material property?

(4 marks)

- (d) What is the name of the manufacturing process shown in Figure 4? Describe the full manufacturing cycle.

(5 marks)

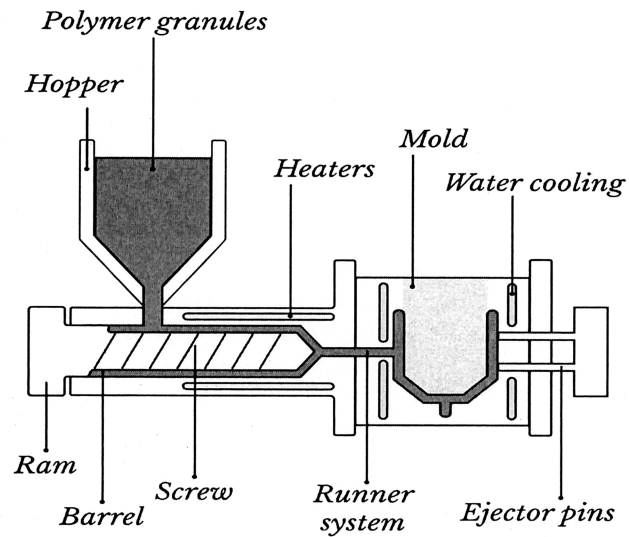


Figure 4

Solution:

END OF PAPER