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

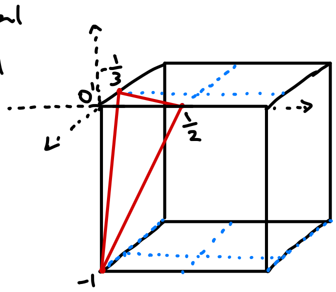
(a) Draw within a unit cell the following:

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

↳ reciprocal $-\frac{1}{3}, \frac{1}{2}, -1$

(3 marks)

Solution:

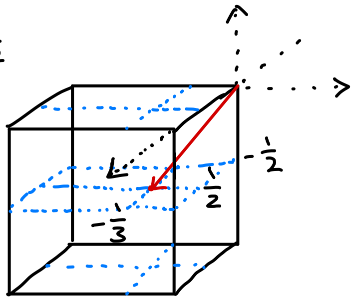


(ii) $[3\,\bar{2}\,\bar{3}]$ Direction

↳ $\div 6$ $\frac{1}{2}, -\frac{1}{3}, -\frac{1}{2}$

(3 marks)

Solution:



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

(4 marks)

Solution:

BCC

$a = \frac{4r}{\sqrt{3}}$

$(0\,\bar{2}\,0)$

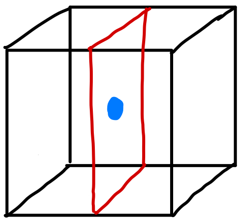
↳ $0, -\frac{1}{2}, 0$

$$PD = \frac{\text{No. of atoms}}{\text{Area of plane}}$$

$$= \frac{1}{\left(\frac{4r}{\sqrt{3}}\right)^2} = \frac{3}{16r^2}$$

$$= \frac{3}{16(0.124)^2}$$

$$= 12.19\,nm^{-2}$$



$n = 1$

$Area = a^2$

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/cm^3. Avagadro's number, N_A is 6.023 x 10^{23} atoms/mol.

FCC

a ρ

(4 marks)

Solution:

Vol of one unit cell = $(0.4065\times10^{-7})^3$ cm^3

Vol. of gold bar = $\frac{10}{19.3}$ cm^3

Number of unit cell = $\left(\frac{10}{19.3}\right) \div (0.4065\times10^{-7})^3$

$= 7.71367\times10^{21}$

n in FCC = 4

No. of atoms in gold bar = $4 \times 7.71367\times10^{21}$

$= 3.085\times10^{22}$ atoms

(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.

300K

Q_v

K

(3 marks)

Solution:

$$\frac{n}{N} = e^{-\frac{Q_v}{KT}}$$

$$\frac{g}{\cancel{cm^3}} \times \frac{\cancel{atom}}{mol} \times \cancel{cm^3} \times \frac{1}{\cancel{atom}}$$

$$N = \frac{\rho \times N_A}{A_W}$$

$$A_W = \frac{19.3\times(0.4065\times10^{-7})^3 \times 6.023\times10^{23}}{4}$$

$$= 195.205 \text{ g/mol}$$

$$N = \frac{19.3\times6.023\times10^{23}}{195.205}$$

$$\frac{\cancel{g}}{cm^3} \times \frac{atom}{\cancel{mol}} \times \frac{\cancel{mol}}{\cancel{g}}$$

$$= 5.955\times10^{22} \text{ atom/cm}^3$$

$$n = (5.955\times10^{22})\, e^{-\frac{1.01}{8.62\times10^{-5}\times300}}$$

$$= 6.5\times10^{5} \text{ vacancies/cm}^3$$

$$= 6.5\times10^{11} \text{ vacancies/m}^3$$

Q2. (13 marks)

/13

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

complete solubility

(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

H-R:

Solution:

1. Atomic size factor: atomic radii diff < ±15%
2. Crystal structure: same type
3. Electronegativity: similar
4. Valency: similar

∴ Cu & Ni

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

(3 marks)

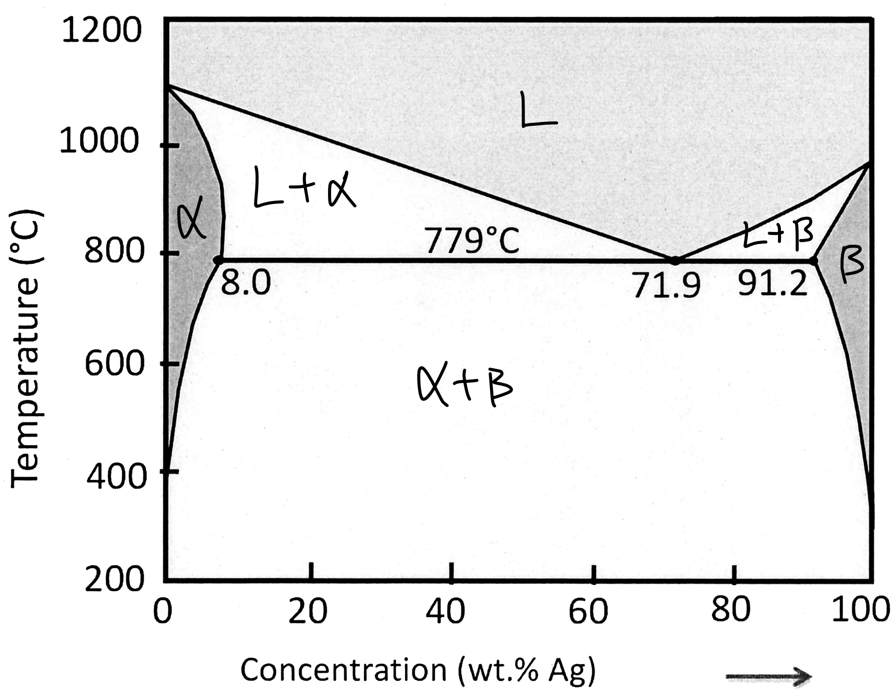


Figure 1

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: Eutectic reaction:

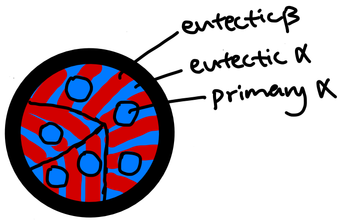
$$L(71.9) \xrightarrow{\text{cooling}} \alpha(8.0) + \beta(91.2)$$

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

$\alpha + \beta < C_e$

(3 marks)

Solution:



Q3. (20 marks)

/20

l E d

(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?

F

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

$= \frac{1}{2}\sigma\left(\frac{\sigma}{E}\right)$

(5 marks)

Solution:

$$\sigma = \frac{2000}{\pi\left(\frac{0.002^2}{4}\right)}$$

$$U_r = \frac{1}{2}\frac{\sigma^2}{200\times10^9} = 1013211\text{J}$$

(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:

σ (MPa)	ε	$\sigma_T = \sigma(1+\varepsilon)$	$\varepsilon_T = \ln(1+\varepsilon)$
800	0.1	880	0.0953
1000	0.2	1200	0.1823

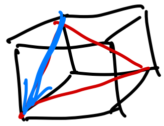
$$\sigma_T = K(\varepsilon_T)^n$$

$$\ln\sigma_T = \ln K + n\ln\varepsilon_T$$

n: gradient of $\ln\sigma_T$ & $\ln\varepsilon_T$

$$n = \frac{\ln 1200 - \ln 880}{\ln 0.1823 - \ln 0.0953} = 0.478$$

Note: Question 3 continues on page 6.



σ_y

(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.

τ_{CRSS}

(5 marks)

Solution:

$$\tau_{CRSS} = \sigma_y \cos\lambda \cos\phi$$

$$21.65 = 50 \cos 30^\circ \cos\phi$$

$$\phi = 60^\circ$$

(d) The yield strengths of a steel with the grain sizes of 3.24 μm and 400 μm 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:

$$\sigma_y = \sigma_o + kD^{-0.5}$$

$$10^9 = \sigma_o + k(3.24 \times 10^{-6})^{-0.5} \rightarrow \sigma = 10^9 - k(\ldots$$

$$636 \times 10^6 = \sigma_o + k(400 \times 10^{-6})^{-0.5}$$

$$636 \times 10^6 = 10^9 + k((400 \times 10^{-6})^{-0.5} - (3.24 \times 10^{-6})^{-0.5})$$

$$k = 720\,000 \qquad \sigma_o = 600\text{MPa}$$

$$\sigma_y = (600 \times 10^6) + 720\,000(810 \times 10^{-9})^{-0.5}$$

$$= 1.4\text{GPa}$$

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:

- Additive manu. is a manu process that increases weight of the part.
- 3D printing is an example of this process as it adds weight/material to a part
- Surface welding.

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

(3 marks)

Solution: Tolerance: allowable deviation from the value that can be tolerated for a part

Low tolerance → more expensive process

High tolerance → cheaper, less ideal functioning

(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)

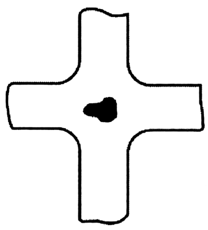


Figure 2

Shrinkage Cavity

- Maintain uniform cross section in casting

or

- Redesign system with appropriate riser that can fill molten metal in gaps

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 tells how much metal needed to fill mold and how long to solidify. $V = \frac{4}{3}\pi r^3$ $A = 4\pi r^2$

$T_{TS} = C_m \left(\frac{V}{A}\right)^2$ $\frac{V}{A} = \frac{\cancel{\frac{4}{3}}\cancel{\pi} r^{\cancel{3}}}{\cancel{4\pi r^2}} = \frac{r}{3}$

$\left(\frac{V}{A}\right)^2 = \text{constant} = \frac{r^2}{9}$

diameter double $\rightarrow r \times 4 = \frac{(4r)^2}{9} = 16 \times \frac{r}{9}$

$\%\ \text{increase} = \frac{16-1}{1} \times 100 = 1500\%$

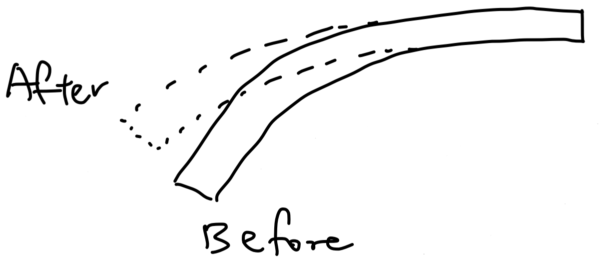
Q5. This question relates to ***metal forming*** and ***metal machining***. (**18 marks**)

/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:



- Due to elastic recovery when load is removed
- Bottoming: high compressive pressure causes plastic deform. & reduces thickness @ bend area

(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: · Longitudinal tensile stress when blank pulled into cavity (high blankholder force)
· Reduce blankholder force

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:

Punching: Sheet metal is part, slug is scrap
Blanking: Sheet metal is scrap, blank is part

$$F = STL = (380\times10^6)(0.0012)(\pi(0.08))$$
$$= 114605.3\,N$$

(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.

0.2C

(6 marks)

Solution:

$$VT^{0.5} = C$$
$$VT = \text{constant} = C^2$$
$$(0.2C)^2 = 0.04C^2$$
$$\frac{VT}{0.04} = 25VT$$
$$\% = \frac{25-1}{1}\times100 = 2400\% \quad V \text{ const.}$$

V↑, T↑ as lesser heat dissipation time

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)

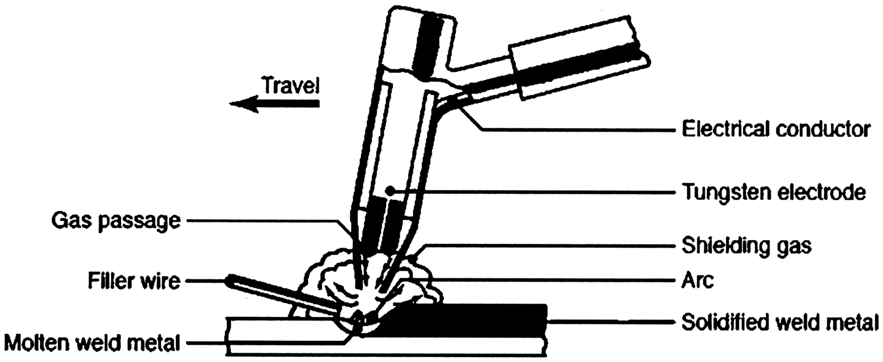


Figure 3

Solution:

Gas Tungsten Arc Welding

- Argon: to protect operation from surr. air as metals are chemically reactive to air at high temp. which can degrade mechanical properties of joint.

Filler metal added to facilitate process, provide bulk & added strength to welded joint.

Note: Question 6 continues on page 11.

A

WVR (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, $E = 24$ V, welding current, $I = 160$ A, heat transfer efficiency, $f_1 = 0.7$, melting efficiency, $f_2 = 0.55$, welding speed, $v = 120$ mm/min, and unit melting energy of the steel = 9.8 J/mm^3.

U_m

(5 marks)

Solution: $HR = EI = 24 \times 160 = 3840\,W$

$$A_w = \frac{f_1 f_2 HR}{U_m v} = \frac{(0.7)(0.55)(3840)}{(9.8)(120)}$$

$$= 1.257\,mm$$

$$WVR = 1.257 \times 120$$

$$= 150.84\,mm^3/min$$

(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)

- Temp. @ which polymer transition between brittle glass and rubber.
- Molecular size & reptation (?)

Note: Question 6 continues on page 12.

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

(5 marks)

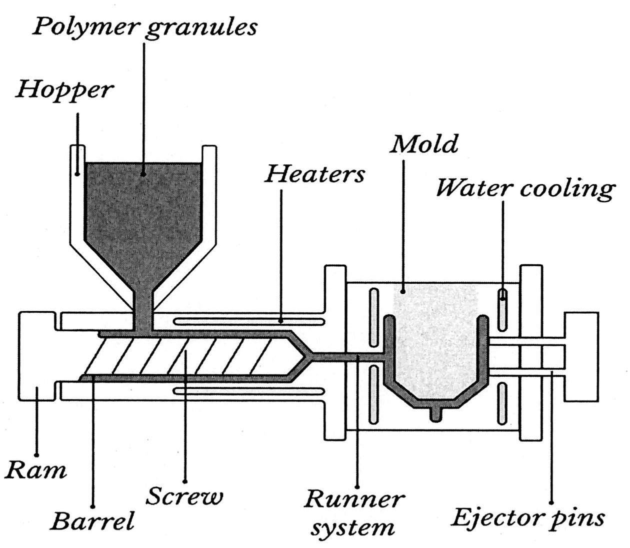


Figure 4

Solution: Injection Molding

3. Injection Molding: used to make all sorts of small, large, complicated pieces. Polymer is heated to a highly plastic state & forced to flow under high pressure into a mold cavity where it solidifies & the molding is then removed from the cavity. Produces discrete components almost always to net shape. Typical cycle time about 10-30s. Mold may contain multiple cavities so multiple parts can be produced in each cycle. Complex & intricate shapes are possible. Shape limitations - capability to fabricate a mold whose cavity is the same geometry as the part and shape must allow for part removal from the mod. Part size from 5g (lego) up to 25kg (automobile bumpers). Economical only for large quantities due to high cost of mold. Identify by small dot (where it was injected), 2 parts of the mold (line), ejection pins (dots)

Process: Mold is closed. Polymer melt is injected into the cavity. The screw is retracted. The mold opens & the part is ejected.

The runners distribute the polymer melt from the sprue to the cavities. They should be wide enough to ensure the correct amount of melt fills the cavities. Cooling takes place along the runner walls.

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.