NANYANG TECHNOLOGICAL UNIVERSITY

SEMESTER 2 EXAMINATION 2022-2023

MA2024 – ENGINEERING MATERIALS AND MANUFACTURING PROCESSES

April/May 2023 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. 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** (15)	**2** (20)	**3** (15)	**4** (16)	**5** (18)	**6** (16)	**Total** (100)
Marks							

Q1. (15 marks)

/15

Crystallinity of solids

(a) Draw the following plane and direction in cubic unit cells.

(6 marks)

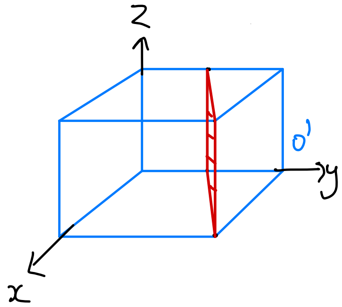
	x	y	z
	1	$\bar{2}$	0
Reciprocal	1	$\frac{\bar{1}}{2}$	∞

(i) $(1\bar{2}0)$ plane

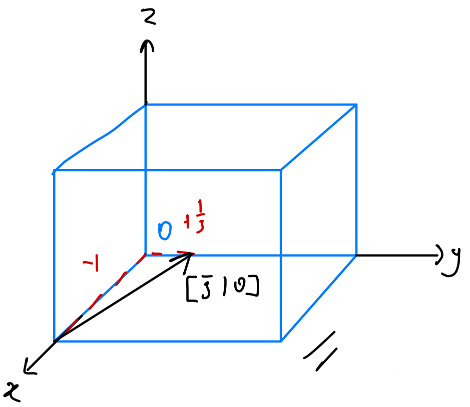
(ii) $[\bar{3}10]$ = $[\bar{1}\ \frac{1}{3}\ 0]$

Solution:

i)



ii)



(b) Calculate the planar density of (110) plane in tungsten, which is BCC structure with atomic radius of 0.210 nm.

(3 marks)

Solution:

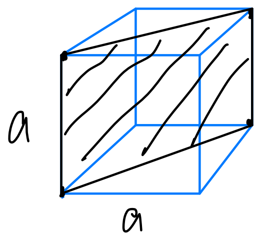
$a = \frac{4r}{\sqrt{3}}$

$r = 0.210\,nm$

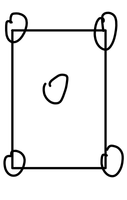
$$P.D\ BCC\ (110) = \frac{2}{a^2\sqrt{2}}$$

$$= \frac{2}{\left(\frac{4r}{\sqrt{3}}\right)^2\sqrt{2}} = \frac{2}{\left(\frac{4\times 0.210}{\sqrt{3}}\right)^2\sqrt{2}}$$

$$= 6.01\,nm^{-1}$$



Note: Question 1 continues on page 3.



$\frac{1}{4}(4)+1 = 2$ atoms

area $= a^2\sqrt{2}$

(c) Calculate the atomic packing factor of an FCC unit cell.

(3 marks)

Solution:

FCC: $n = 4$

$a = 2\sqrt{2}r$

$$APF\ (FCC) = \frac{V_s}{V_c} = \frac{n \times \frac{4}{3}\pi r^3}{a^3}$$

$$= \frac{4 \times \frac{4}{3}\pi r^3}{(2\sqrt{2}r)^3}$$

$$= \frac{4 \times \frac{4}{3}\pi \cancel{r^3}}{2^3 \times (\sqrt{2})^3 \cancel{r^3}}$$

$$= 0.74$$

$$\simeq 74\%$$

(d) Calculate the theoretical density of copper. Copper is FCC structure, with atomic radius of 0.128 nm and atomic weight of 63.546 g/mol. Avogadro's number is 6.023 x 10^{23} atoms/mol.

(3 marks)

Solution:

√?

$$\text{Vol of unit cell} = \frac{4 \times \frac{4}{3}\pi (0.128 \times 10^{-9})^3}{0.74} = 4.743 \times 10^{-29} m^3$$

$$\text{mass of one copper atom} = \frac{63.546}{6.023 \times 10^{23}} \times 10^{-3} = 1.055 \times 10^{-25} kg$$

$$\rho = \frac{4 \times \text{mass}}{\text{Vol}} = 8889.8 kg/m^3$$

3

Q2.(20 marks)

/20

(a) Refer to the phase Cu-Ag phase diagram in Figure 1. The composition of a Cu-50%-Ag alloy was cooled from 1000ºC to room temperature.

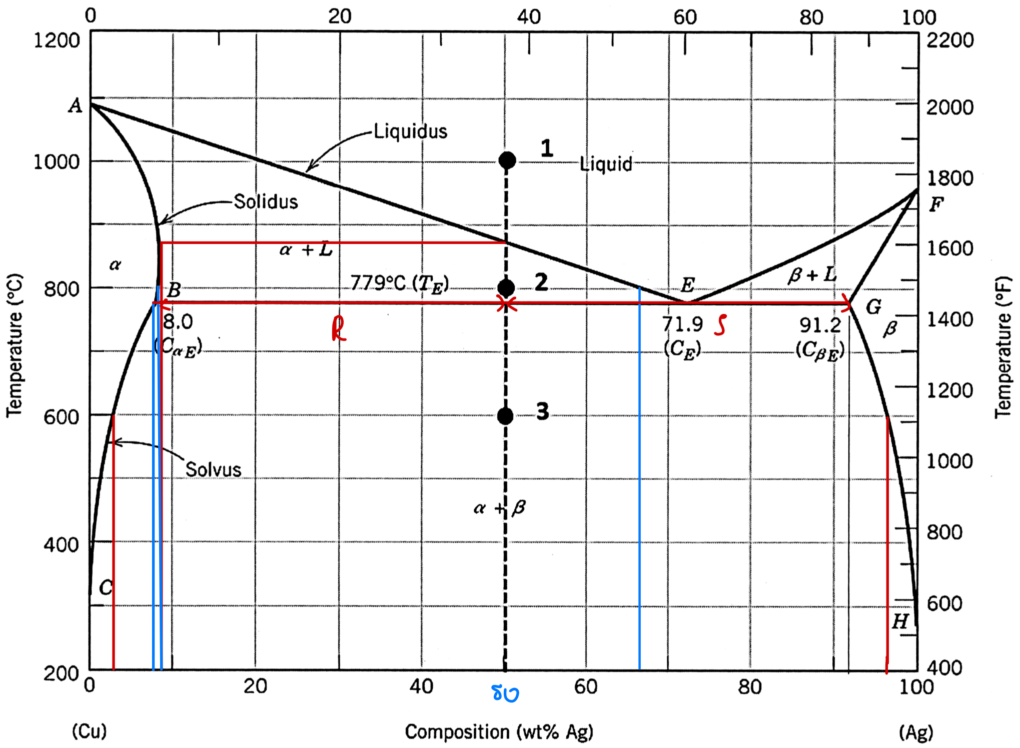
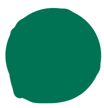


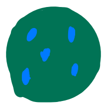
Figure 1

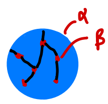
(i) Draw the microstructures of the alloy at point 1 (1000 ºC), 2 (800 ºC), and 3 (600 ºC).

(5 Marks)

Solution:

1000°C
Pt 1:  Liquid

800°C
Pt 2: α+L  α (8 wt% Ag)
L (66 wt% Ag)

600°C
Pt 3: 

α (3 wt% Ag)
β (96 wt% Ag)

Note: Question 2 continues on page 5.

(ii) Find the composition of the first formed solid phase. Also, find the composition of the last remaining liquid phase.

(5 Marks)

Solution:

First formed solid phase: α (8 wt % Ag)

Last remaining L Phase: L (71.9 wt% Ag)

(iii) Determine the mass fraction of primary α, eutectic α, and eutectic β at 600ºC.

(10 Marks)

Solution:

$$W_{\text{Primary }\alpha} = \frac{71.90-50}{71.90-8} = 0.3427$$

$$W_\alpha = \frac{S}{S+R} = \frac{91.2-50}{91.2-8} = 0.495$$

$$W_\beta = 1-0.495$$
$$= 0.5047$$

$$\text{eutectic } \alpha = W_\alpha - W_{\text{pri }\alpha}$$
$$= 0.495 - 0.3427$$
$$= 0.1523$$

$$\text{eutectic } \beta = W_\beta - W_{\text{pri }\alpha}$$
$$= 0.1621 \ ?$$

Q3. (15 Marks)

/15

Mechanical Properties of metals.

(a) Figure 2 shows the stress-strain curve of 3 different engineering materials. Fill in the ranks in the table 1 of the following properties among the three materials.

(5 Marks)

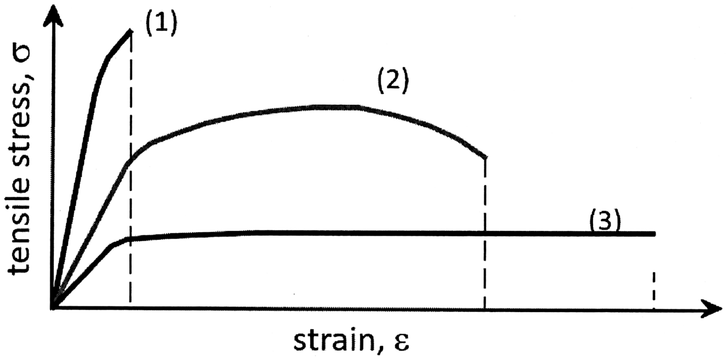


Figure 2

Solution: $\sigma = E\varepsilon$ $E = \frac{\sigma}{\varepsilon}$

Table 1

Property	Rank				
Young's modulus	1	>	2	>	3
Yield strength	1	>	2	>	3
Tensile strength		>		>	
Ductility	3	>	2	>	1
Toughness	2	>	3	>	1

(b) Explain the following statement in your own words regarding the strength of a metal. "A perfect material, namely a perfectly pure crystal without defects in structure is perfectly useless."

(5 Marks)

Solution:

Note: Question 3 continues on page 7.

(c) Using Figure 3 and Hall-Patch Relation, estimate the yield strength of the material if it is nanostructured with a grain size of 50 nm.

(5 Marks)

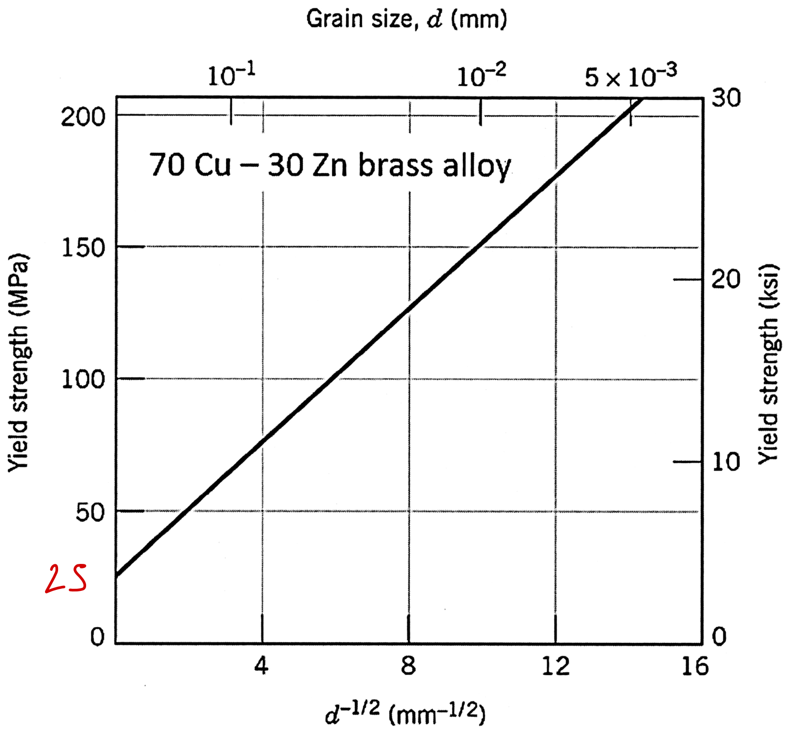


Figure 3

Solution:

5×10^{-3} mm

$\sigma_0 \rightarrow 25$ MPa

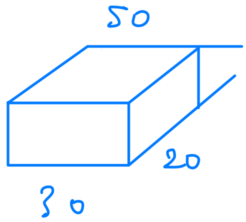
$$\sigma_y = \sigma_0 + K D^{-0.5}$$

$$\frac{y_2 - y_1}{x_2 - x_1}$$

$$K = \text{gradient} = \frac{(200 - 25)}{(5 \times 10^{-3} - 0)}$$

$=$

Q4. (16 marks)



/16

This question relates to metal casting.

(a) A rectangular piece of dimensions 30×50×20 cm^3 is fabricated using sand casting and has a solidification time of 20 min. We add a cylindrical riser of diameter 5 cm and length 8 cm for this rectangular piece. What is the total solidification time of the riser?

The total solidification time T is given by the Chvorinov's rule: $T = C_m \left(\frac{V}{A}\right)^2$, where C_m is the mold constant, and V and A the volume and area of the cast, respectively.

(3 marks)

Solution: 1) Find C_m

Rectangle : $20\,\text{min} = C_m \left(\frac{30\times 50\times 20}{(2\times 30\times 50)+(2\times 30\times 20)+(2\times 50\times 20)} \right)^2$

$C_m = 0.85422$ min/cm^2

Cylindrical: $TST = C_m \left(\frac{L\frac{\pi}{4}D^2}{\pi D L + \frac{\pi}{2}D^2} \right)^2 = 0.775\,\text{min}$

d
L = 8cm
d = 5cm

(b) Is this a suitable riser? Justify your answer.

(1 mark)

Solution:

Not suitable as riser takes a much shorter time to solidfy than the casting

(c) We now want to modify the riser's geometry so that its solidification time is of 30 min. We decide to keep a cylindrical riser of length at 8 cm but to vary its diameter. What should be the new riser diameter to have a solidification time of 30 min?

(2 marks)

Solution: $30 = 0.85422 \left(\frac{8\frac{\pi}{4}D^2}{8\pi D + \frac{\pi}{2}D^2} \right)^2$

$5.92429 = \frac{4\pi D^2}{8\pi D + \frac{\pi}{2}D^2}$

$148.94\cancel{D} + 9.3088 D^{\cancel{2}} = 4\pi D^{\cancel{2}}$

$9.3088 D - 4\pi D = -148.94$ $D = 45.7\,\text{cm}$

Note: Question 4 continues on page 9.

(d) Is this a suitable riser? Justify your answer.

(1 mark)

Solution:

Suitable as riser Solidify longer than casting

(e) Finally, we decide to make a riser with a ratio D/L = 1. What would in this case be the dimensions of the riser to have a solidification time of 30 min?

(2 marks)

Solution:

$$30 = 0.85422\left(\frac{L\frac{\pi}{4}D^2}{\pi DL+\frac{\pi}{2}D^2}\right)^2 \qquad \frac{D}{L}=1 \qquad D=L$$

$$5.92619257 = \frac{\frac{\pi}{4}D^{\cancel{3}}}{\frac{3\pi}{2}\cancel{D^2}} \qquad D = 35.6\text{cm} = L \text{ //}$$

(f) If the dimensions of the cast part were $30\times50\times20$ mm^3 instead of $30\times50\times20$ cm^3 but with the same casting time, what would be the dimensions of the riser with a ratio D/L = 1?

(2 marks)

Solution: Cast: Rectangle

(g) Would sand casting be a suitable method for fabricating this piece of dimensions $30\times50\times20$ mm^3? What other method can you propose and explain why.

(2 marks)

Solution:

Note: Question 4 continues on page 10.

(h) After sand casting, the piece has a rough surface. Using a stylus apparatus, the vertical deviations are measured and reported in the below table 2. Based on this data, what is the surface roughness Ra of the piece?

(2 marks)

Table 2: Vertical deviations measured using the stylus apparatus

Measurement number	Vertical deviation in μm
1	+100
2	+50
3	-10
4	+3
5	-80
6	-65
7	+46
8	-82
9	+4
10	+6

Solution:

(i) Considering the other process you proposed in question (g), do you expect this other process to produce a piece with a higher or lower surface roughness? If you had proposed several methods, please select only one.

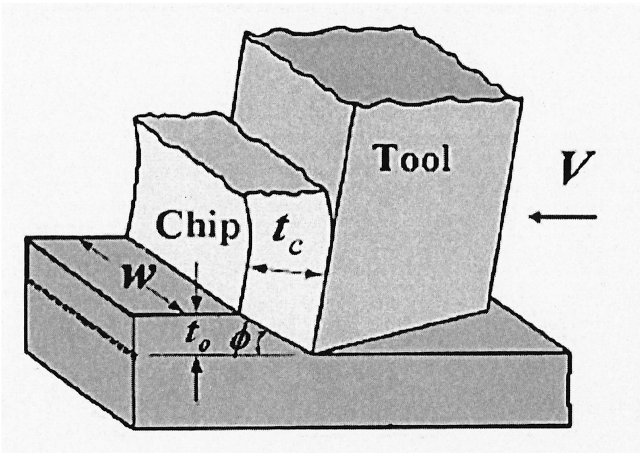
(1 mark)

Solution:

/18

Q5. (18 marks)

Figure 4 shows a 2-D orthogonal cutting (OC) process with the various cutting parameters.



Cutting Parameters
w = 10mm
t_o = 2mm
t_c = 3mm
ϕ = 10°

Figure 4 A schematic diagram of an orthogonal cutting process

Determine the following:

(a) What is a relief angle? What function does it serve? What happens when the relief angle is not properly controlled?

(4 marks)

Solution:

(b) Cutting ratio

(2 marks)

Solution:

Note: Question 5 continues on page 12.

(c) Rake angle

(3 marks)

Solution:

(d) Given the chip velocity is 10 m/min, determine the material removal rate.

(5 marks)

Solution: $\rightarrow V$

$\frac{10m}{min} \times \frac{1mm}{1\times10^{-3}m} \times \frac{1min}{60s}$

$= 166.67 mm/s$

$MRR = w t_0 V$

$= 10(2)(166.67) = 3333 mm^3/s$

(e) Cutting power required for the OC process on all these materials listed in Table 3.

(4 marks)

Table 3 Specific energy requirements of various materials

Material	Specific Energy Requirements, J/mm^3
Aluminium alloys	0.7
High temperature alloys	5.9
Nickel alloys	5.5
Stainless steels	4.1

Solution: Specific energy = $\frac{Power}{MRR}$

Al: Power = 3333×0.7

= 2333 W

Q6. (16 marks)

/16

(a) (i) Briefing discuss what is fusion and solid state welding in terms of the application of heat and pressure as well as filler.

(3 marks)

Solution:

(ii) Laser beam welding (LBW) and electron beam welding (EBW) are fusion welding processes having very high-power densities. Name two merits for the use of EBW over LBW.

(4 marks)

Solution:

(iii) A laser beam heat source is capable of transferring 3500J/sec to a metal part surface. 80% of the heat is concentrated in a circular area used to melt the metal. The minimum power density to melt the metal is given as $10 W/mm^2$. What is the maximum diameter where melting of the metal can occur?

(3 marks)

Solution:

$$PD = \frac{P}{A}$$

$$10 = \frac{3500 \times 0.8}{A}$$

$$A = 280\ mm^2 = \frac{\pi}{4} d^2$$

$$d = 18.88\ mm$$

(b) A desired deep drawing process is to be performed on a blank sheet metal. The drawn part is a cylindrical cup of 50mm height with inside diameter of 70mm. Determine the required starting blank size D_b and thickness of the sheet metal, t.

(6 marks)

Solution:

END OF PAPER