NAMIBIA UNIVERSITY
OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING AND SPATIAL SCIENCES

DEPARTMENT OF MECHANICAL, MINING AND PROCESS ENGINEERING

QUALIFICATION: BACHELOR OF ENGINEERING IN METALLURGY	
QUALIFICATION CODE: 08BMET	LEVEL: 8
COURSE CODE: MMY820S	COURSE NAME: MECHANICAL METALLURGY
SESSION: June 2023	PAPER: THEORY
DURATION: 3 HOURS	MARKS: 100

FIRST OPPORTUNITY QUESTION PAPER	
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MODERATOR:	Prof Josias Van der Merwe

INSTRUCTIONS

1. Answer all questions.
2. Read all the questions carefully before answering.
3. Marks for each questions are indicated at the end of each question.
4. Please ensure that your writing is legible, neat and presentable.

PERMISSIBLE MATERIALS

1. Examination paper.

THIS QUESTION PAPER CONSISTS OF 6 PAGES (Including this front page)

Question 1 [25 marks]

(a) Table Q1 shows typical data for strength of copper alloys: pure copper, bronze (a solid solution of tin or beryllium in copper) and brass (a solid solution of zinc in copper). Rank the strengthening mechanisms (as indicated in the table) in order of effectiveness.

[2]

Table Q1. Strength of a selection of copper alloys.

Alloy	Process route	Main strengthening mechanism	Yield strength (MPa)
Pure Cu	Cast	None	35
Bronze: Cu + 10% Sn	Cast	Solid solution strengthening	200
Brass: Cu + 30% Zn	Cast	Solid solution strengthening	90
Brass: Cu + 30% Zn	Cold-rolled	Solid solution strengthening + dislocation strengthening	400
Bronze: Cu + 2% Be	Heat treated	Precipitation strengthening	1000

(b) The yield strength σ_y of plain carbon steel is dependent on the grain size d, and the relation can be described by the equation:

$$\sigma_y = \sigma_o + k\sqrt{\frac{1}{d}}$$

where σ_o and k are material constants. The yield strength of a plain carbon steel is 622 MPa for a grain size of 180 μm and 663 MPa for a grain size of 22 μm.

(i) Calculate the yield strength of the steel for a grain size of 11μm. [10]

(ii) Explain briefly the physical significance of the σ_o constant. [1]

(iii) What methods can you recommend to ensure grain refinement of a plain carbon steel?

[2]

(c) The critical strength бc of a plain carbon steel equals 900 MPa. Ultrasonic non-destructive inspection of an axle made of this steel has revealed a microcrack 50μm long (2a = 50μm). Is it safe to operate such an axel? Estimate with the aid of Griffith's criterion:

$$\sigma_c = \sqrt{\frac{2E\gamma_s}{\pi a}}$$

where σ_c is the critical stress required for propagation of the brittle crack;

γ_s is the energy of the new surface area per unit of area;

E is Young's modulus

a is a half-length of a critical crack that will propagate spontaneously;

π = 3,14;

if the following parameters apply:

	σ_c, MPa	Υ_s, J/m^2	E, GPa
Iron	900	1,2	205

[10]

Question 2 [25 marks]

(a) Figure Q2-1 reveals stress-strain curves for a selection of engineering alloys. Use the diagrams to find:

(i) The metal with the lowest yield strength. [1]
(ii) The metal with the highest tensile strength [1]
(iii) The metal with the lowest ductility [1]

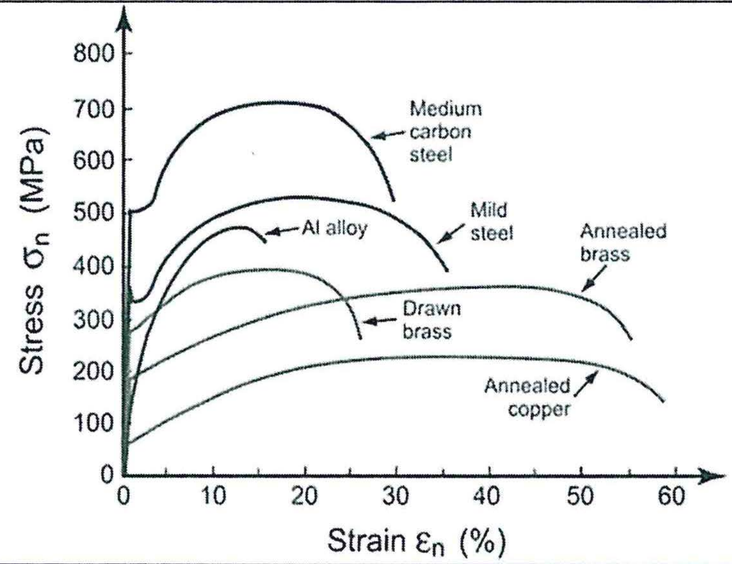

Figure Q2-1. Stress-strain curves for a selection of engineering alloys.

(b) Figure Q2-2 shows an S-N curve for AISI 4340 steel after heat treatment.

(i) What is the endurance limit for this steel? [3]
(ii) If cycled for 100 cycles at an amplitude of 1200 MPa, will it fail? [2]
(iii) If cycled for 100 000 cycles at the amplitude of 1000 MPa, will it fail?[2]

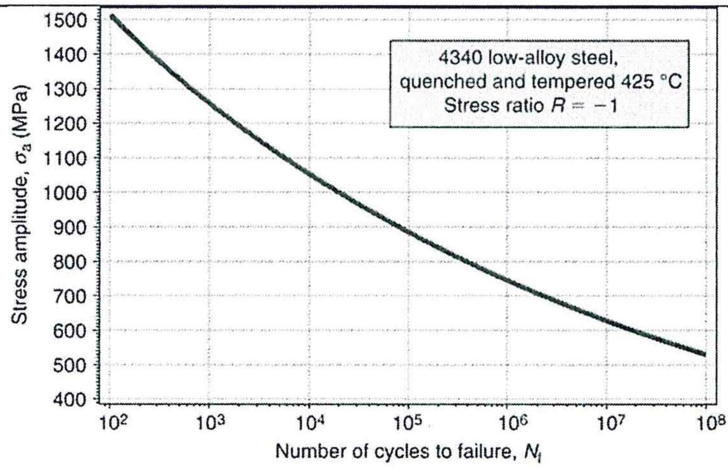

Figure Q2-2. Fatigue behaviour of low-alloy steel 4340.

(c) A newly developed vaccine against COVID-19 is to be transported and stored under extremely low temperature (minus 70 ^{0}C). The vaccine will be administered with the aid of refrigerating containers. Fig. Q2-3 features the Charpy impact energy of three candidate steel grades (A, B, and C) in a wide temperature range, from +80^{0}C to -80^{0}C.

(i) Which steel grade should be selected for the refrigerating containers manufacturing (the operating temperature is as low as minus 70 ^{0}C): steel A or steel B or steel C? Briefly provide reasons.

[10]

(ii) Speculate upon the type of steel suitable to meet the target (lattice type, alloying system).

[5]

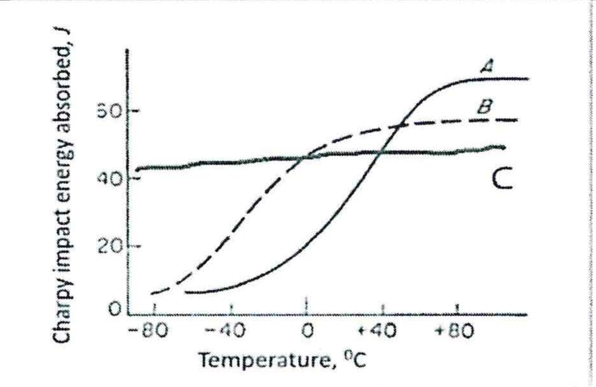

Figure Q2-3. Charpy impact energy as a function of temperature for candidate steel grades A, B, and C

Question 3 [50 marks]

In April 1912, the Royal Mail Ship (RMS) Titanic struck an iceberg and sank off Newfoundland in less than 3 hours with a loss of over 1,500 people. It was only in 2015 when a piece of the Titanic hull steel was recovered and Charpy impact tests as well as chemical analysis, fracture surface and microstructure examination were carried out on test specimens machined from the sample. A modern hull steel of AISI1018 grade was also examined for comparison. It is obvious that Titanic was seriously damaged due to collision with the iceberg. However, why did the ship sink so quickly after the collision? Being a failure investigator, you should consider all the data provided and answer the following questions:

(i) Did the Titanic hull steel become brittle at the ice water temperature? What evidence can you provide with the aid of Figure Q3-1 and Figure Q3-2? Point out and label the regions of your concern.

[15]

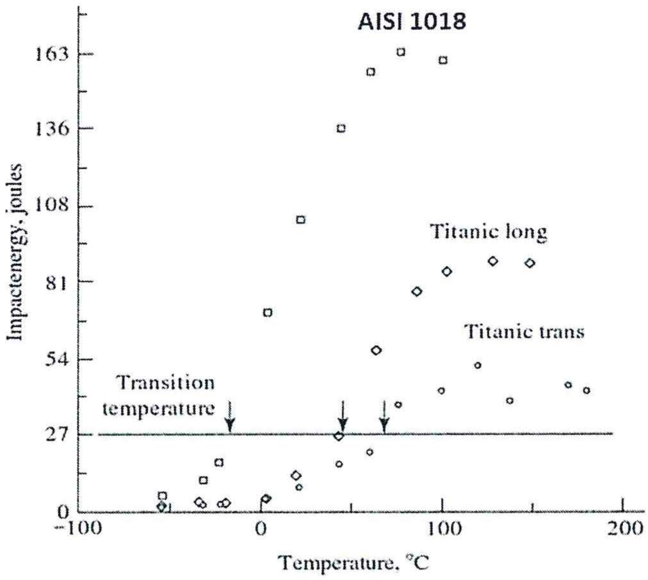

Figure Q3-1. Charpy impact energy versus temperature for specimens taken longitudinal and transverse to the rolling direction of the Titanic 's hull steel. Results for a modern steel AISI 1018 are shown for comparison.

(ii) Compare and contrast the chemical composition of the Titanic's hull steel with that of a modern steel AISI1018 (Table Q3). What is wrong with the chemistry of Titanic's hull steel? Discuss possible disadvantages of the steelmaking processes responsible for the poor chemical analysis of the Titanic's hull steel.

[15]

Table Q3. The composition of the Titanic 's hull steel in weight % and the composition of a comparable modern steel. Results for a modern steel, AISI 1018, are shown for comparison.

Element	*Titanic*	AISI 1018
Carbon	0.21	0.18–0.23
Sulfur	0.065	0.05 max
Manganese	0.48	0.6–1.0
Phosphorus	0.027	0.04 max
Nitrogen	0.004	0.0026
Oxygen	0.013	—

(iii) Label the regions of your concern in the Titanic's hull steel micrograph (Figure Q3-3 a). What is wrong with this microstructure? How does it compare and contrast with the microstructure of modern 1018 steel (Figure Q3-3 b)? Note the magnification. Based upon the microstructural features, discuss the metallurgical defects leading to failure. [20]

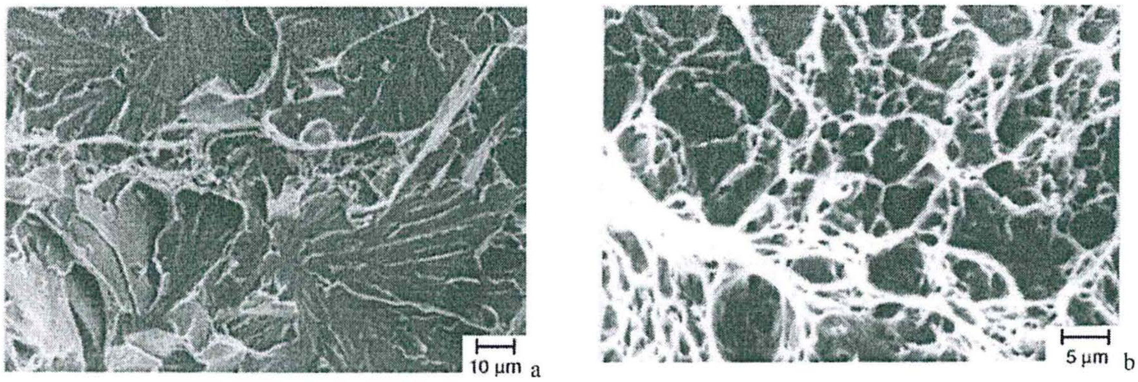

Figure Q3-2. The fracture surface (a) of the Titanic's hull steel and (b)the fracture surface of modern 1018 steel after Charpy impact test at 0^0C.

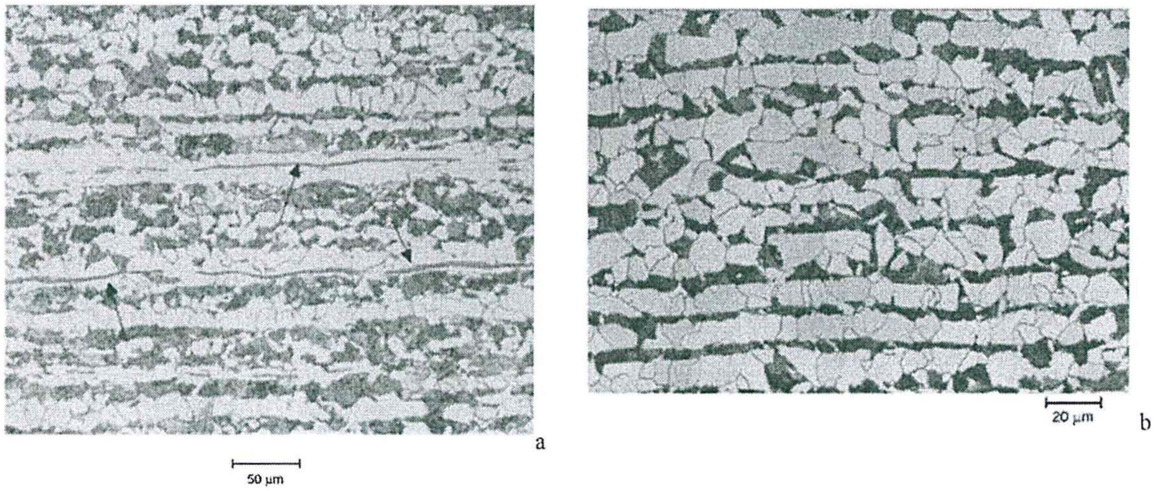

Figure Q3-3. The microstructure (a) of a longitudinal section of the Titanic's hull steel in comparison with that of modern 1018 steel (b). Polished sections, nital etched.

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