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

SECOND OPPORTUNITY QUESTION PAPER	
EXAMINER(S)	Prof. Sofya Mitropolskaya
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 5 PAGES (Including this front page)

Question 1 [25 marks]

(a) A low carbon mild steel at ASTM grain size of N1 (d=0,25 mm) has revealed rather poor yield strength. Is it possible to triple the yield strength of the steel due to grain refinement to ASTM grain size of N8 (d=0,022 mm)? With the aid of the Hall-Petch equation:

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

where σ_o and k are material constants, d is the grain size;
estimate the yield strength growth of this steel as a result of such grain refinement. Note that for mild steel the lattice resistance stress σ_o is small and can be neglected.

[15]

Initial grain size (mm)	Grain size after refinement (mm)
0,25	0,022

(b) With the aid of Griffith's analysis of the critical stress:

$$\sigma_{max} = \sigma_a (1 + 2a/b),$$

estimate the stress concentration σ_{max} in the vicinity of an elongated non-metallic inclusion (Figure Q1). You may consider non-metallic inclusions as potential cracks. Assume the tensile stress σa is applied in vertical direction and equals 50 MPa.

[10]

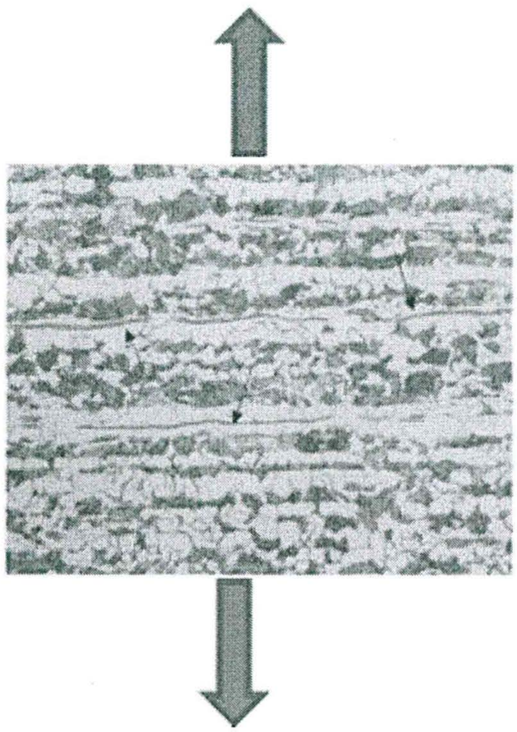

Figure Q1. Elongated non-metallic inclusions: length ***a***=20 μm, width ***b***=1 μm

Question 2 [25 marks.

(a) You are asked to select a material for the teeth of a digger truck (Figure Q2-1). To do so you need to prioritize the materials properties that matter. List the key material properties required for the teeth of a digger truck. [6]

Figure Q2-1. A digger truck.

(b) Figure Q2-2 features stress-strain diagrams for a medium carbon steel, a mild steel, an Al alloy, brass (a solid solution of zinc in copper), and copper.

(i) Roughly estimate the yield strength (or if appropriate a 0.2% proof stress) of each alloy.[3]

(ii) Roughly indicate the tensile strength of each alloy. Fill in the table provided. [3]

(iii) Which technological methods are available for strength increase of a mild steel by grain refinement? [3]

	Medium carbon steel	Mild steel	Al alloy	Annealed brass	Drown brass	Annealed copper
Yield strength, MPa						
Tensile strength, MPa						

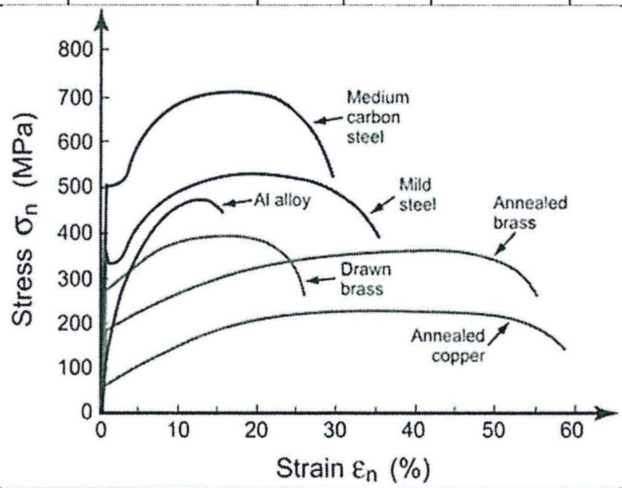

Figure Q2-2. Stress-strain curves for a selection of engineering alloys.

(c) The critical strength σ_c of zinc is as low as 2 MPa. Ultrasonic non-destructive inspection of a zinc plate has revealed a crack 1 mm long (2a = 1 mm). Is it safe to operate such a plate under Griffith's plain stress? 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 (Pa);
γ_s is the energy of the new surface area per unit of area;
E is Young's modulus (Pa)
a is a half-length of a critical crack that will propagate spontaneously; π = 3,14.

Make use of the following parameters:

	σ_c, MPa	Υ_s, J/m^2	E, GPa
Zinc	2	0,8	35

[10]

Question 3 [25 marks]

(a) Some bicycle forks are subjected to fatigue loading. Figure Q3-1 features the S–N diagram for the low-alloy steel used.

(i) What is the 'fatigue limit' of the material? Estimate the fatigue limit of this steel. [5]

(ii) The loading cycle due to road roughness is assumed to have a stress amplitude σ_a of 1200 MPa. How many loading cycles will the forks withstand before failing [5]

(iii) Components that are susceptible to fatigue are sometimes surface treated by 'shot peening'. Explain how the process works, and why it is beneficial to fatigue life. [5]

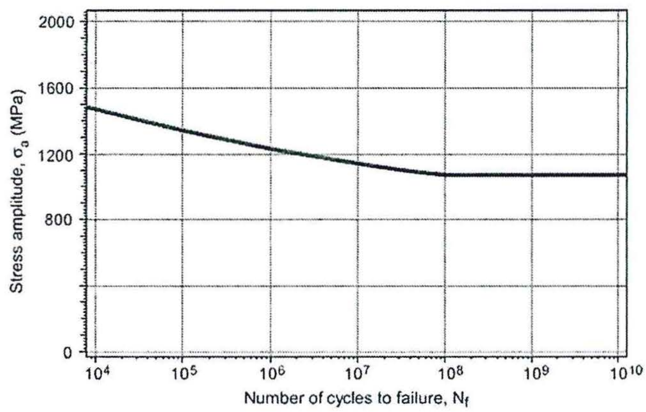

Figure Q3-1. Fatigue behaviour of low-alloy steel.

(b) Why does a low carbon mild steel become brittle in the heat-affected zone next to a weld joint? No mechanical stress was applied [5]

(c) Engineering creep is observed when a metal part is subjected to constant load at elevated temperature. Is creep a typical problem in Africa? [5]

Question 4 [25 marks]

A premature failure of lifting-fork arm was reported to a lift-truck manufacture (Figure Q4-1). The failure occurred in the elbow region of the lifting-fork arm. Lifting-fork arms are normally made of alloyed steel EN25 (0,3 %C; 2,5 %Ni; 0,6 % Cr; and 0,5 % Mo) by forging followed by heat treatment (quenching from 850 ^{0}C into oil and tempering under 600 ^{0}C for 1 hour). This treatment produces tempered martensite with the hardness of HV600. A group of failure investigators identified the chemical composition of the failed fork arm (see Table Q4) and examined the fracture surface (see Figure Q4-2). The microstructural examination of the failed arm revealed coarse bainite (Figure Q4-3). Vickers hardness measurement revealed the hardness of HV440.

(i) Which metallurgical defect is responsible for the failure? [9]

(ii) Briefly comment on the most likely failure mode. [8]

(iii) What should be done to prevent the same failure in future? [8]

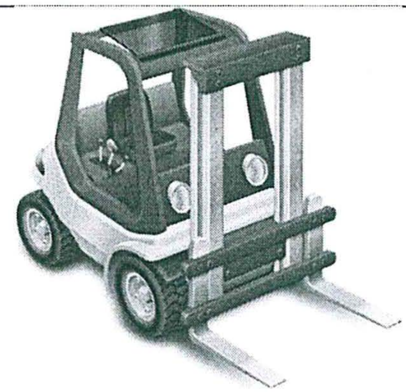

Figure 4-1. A lift truck with lifting-fork arms.

Table Q4. Lifting-fork arm steel chemical composition, as revealed.

C	Si	Mn	Ni	Cr	Mo	S	P
0.30	0.25	0.60	2.50	0.60	0.50	0.025	0.025

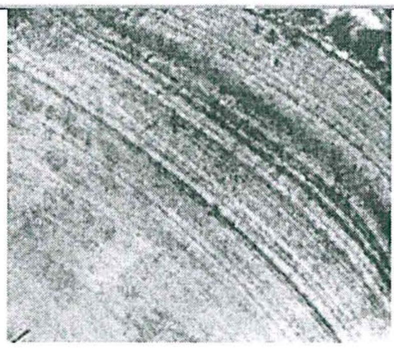

Figure 4-2. The fracture surface observed. X100

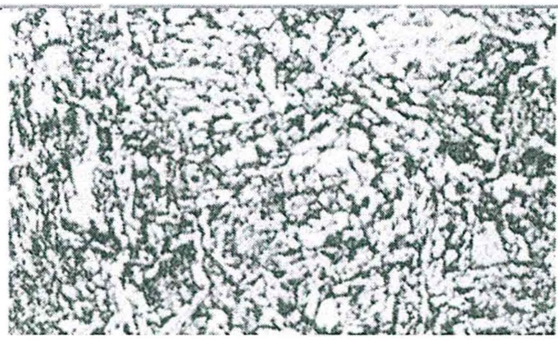

Figure 4-3. Microstructure of the coarse bainite. Metallographic microscopy, X400.

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