UNIVERSITY OF JOHANNESBURG

PROGRAM	:	**MECHANICAL ENGINEERING**
SUBJECT	:	**SCIENCE OF MATERIAL 3A**
CODE	:	**MTK3A11**
DATE	:	(WINTER SUPPLEMENTARY EXAMINATION)
DURATION	:	3 HOURS (1-PAPER)
TOTAL MARKS	:	100

EXAMINER	:	Mr. T Mathonsi
MODERATOR	:	Prof. RF Laubscher
NUMBER OF PAGES	:	6 PAGES

INSTRUCTIONS	:	QUESTION PAPERS MUST BE HANDED IN.
REQUIREMENTS	:	ANSWER BOOKLET.

INSTRUCTIONS TO CANDIDATES:

PLEASE ANSWER ALL QUESTIONS

QUESTION 1 **[12]**

Illustrate the key production stages in an integrated steel mill by:

1.1. Identifying the main raw materials used to produce steel.
1.2. Identifying the plant items used for each of the production stages.
1.3. Showing the order in which these process steps are carried out.
1.4. Identifying the input and output materials at each process stage.

QUESTION 2 **[52]**

One of two bolts supporting a load of 7400 kg failed while in service causing eight hours of downtime on an essential machine for production. The bolts were in operation on a crane used to transfer anodes into the machine. Figure 2.1 shows a drawing of the set-up and the location of fracture just above the nut. The crane cycled 600 times a day 7 days a week.

The broken bolt (Figure 2.2) and a new unused bolt, recommended by the supplier for the application, were supplied to conduct the investigation. The original designers of the crane specified a bolt that conforms to SAE standards grade 5. The supplier of the new bolt confirmed that it was made to conform with ASTM standard A 193 grade B7.

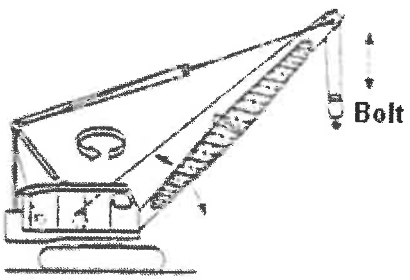

Figure 2.1. Drawing of the bolt and crane set-up.

Figure 2.2. Photograph of a broken bolt

Figure 2.3. Photograph of the fracture surface.

Examination of the fracture surface revealed characteristics such as a beachmarks associated with fatigue (Figure 2.3). The zone of the final fracture was located between two areas of fatigue propagation suggesting the presence of bending forces. The surface area of the final fracture was approximately 12% of the total fracture surface suggesting that the bolt was not overloaded. Cracks were also found between threads near the fracture surface indicating that the bolt was highly susceptible to fatigue initiation.

2.1 Briefly explain the difference between fatigue striations and beachmarks both in terms of size and origin (4)

2.2 Define fatigue and discuss 3 factors that affect the fatigue life of a component. (10)

Results from chemical analyses (Table 2.1) show that the original broken bolt had a carbon content slightly below those required by the SAE standards for a grade 5 bolt. The chemical composition of the new sample bolt conformed to the ASTM standard A193/A grade B7 that requires an AISI-SAE 4140 composition.

Table 2.1--Chemical analysis results on both bolts.

Element	Original broken bolt (%)	SAE Standard Grade 5 (%)	New Sample Bolt (%)	ASTM Standard B7 AISI 4140 (%)
Carbon	0.20	0.28-0.55	0.42	0.37-0.49
Manganese	0.65	--	0.85	0.65-1.10
Silicon	0.22	--	0.22	0.15-0.35
Phosphor	0.013	0.048 max.	0.015	0.035
Sulphur	0.011	0.058 max.	0.030	0.040
Chromium	0.08	--	0.79	0.75-1.20
Nickel	0.06	--	0.07	--
Molybdenum	0.01	--	0.15	0.15-0.25

2.3 List two effects that the sulphur and phosphorous could have had on the original broken bolt? (2)

2.4 What are the principal effects of the chromium and molybdenum on the new bolt? (6)

Microscopic examination of the bolts was done using longitudinal and latitudinal mounts for each. The sections taken from the fractured bolt were taken close to the fracture surface. Examination before etching of the two bolts showed no cracking or unusually large inclusions. The original broken bolt did show some flaking at the base of the threads (Figure 2.4) but this is expected for a bolt that has been in service. Etching the sections revealed a microstructure of coarse pearlite in a matrix of ferrite (Figure 2.5). The SAE grade 5 standard requires that the bolt be quenched and tempered to conform and therefore should have a tempered martensite structure. Martensite has higher material properties such as yield strength and hardness, which increases its resistance to fatigue initiation. The ferrite matrix of the original bolt has low yield strength, which in turn reduces its resistance to fatigue initiation.

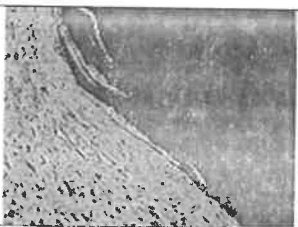

Figure 2.4. Micrograph of flaking found at the base of a thread in the fractured bolt. 2% nitial 100X

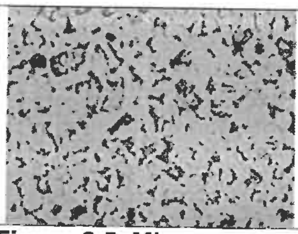

Figure 2.5. Micrograph of the fractured bolt. Ferrite matrix with pearlite. 2% nitial 200X

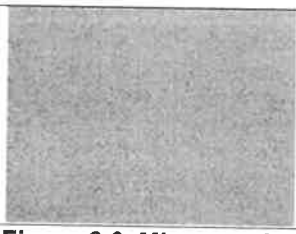

Figure 2.6. Micrograph of the new bolt. Tempered martensite. 2% nitial 500X

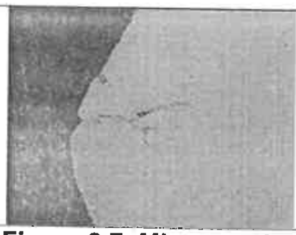

Figure 2.7. Micrograph of the new bolt thread showing a rolling seam. 2% nitial 200X

2.5 Various types of heat treatment processes are used to change the properties or conditions of steel. List 4 material properties that can be altered by heat treatment processes.

(4)

2.6 Discuss the difference between Austempering and Martempering. Illustrate heat treatments on a TTT diagram.

(8)

The new bolt was found to be quenched and tempered as required by the ASTM standard (Figure 2.6). However, rolling seems where found at the tips of the treads (Figure 2.7). This is not a serious defect because of the defects location in a low-stress area however, if the bolt was placed in a corrosive atmosphere these seams would corrode and then act as fatigue initiation sites.

2.7 Discuss 6 metallurgical factors that can affect corrosion. (6)

Tensile tests were done on the bolts to test their material properties in comparison with the standards. The results (Table 2.2) show that the yield strength and ultimate tensile strength of the original bolt are only two-thirds required by the standards. This conforms to the microstructural observations. The properties of the new bolt conformed to the standard even though they were slightly elevated.

Table 2.2--Results and standard requirements of tensile tests.

	Original Broken Bolt		**New Sample Bolt**		**Standard Grade 5 SAE**	**Standard Grade By AISI**
Sample #	1	2	1	2		
Ultimate Tensile Strength (KSI)	69.5	69.5	148	146	100	125
Yield Strength (KSI)	42.7	44.4	134	133	80	105
Elongation (%)	26	24	20	20	16 (min.)	16 (min.)
Surface Reduction (%)	67	67	59	59	50 (min.)	50 (min.)

2.8 After considering the observations made in this failure analysis, what conclusions can be drawn in terms of the mode of failure, chemical and microstructural analysis, and material properties?

(8)

2.9 Would you recommend an upgrade to the ASTM B7 bolt. Motivate your answer?

(4)

QUESTION 3 **[16]**

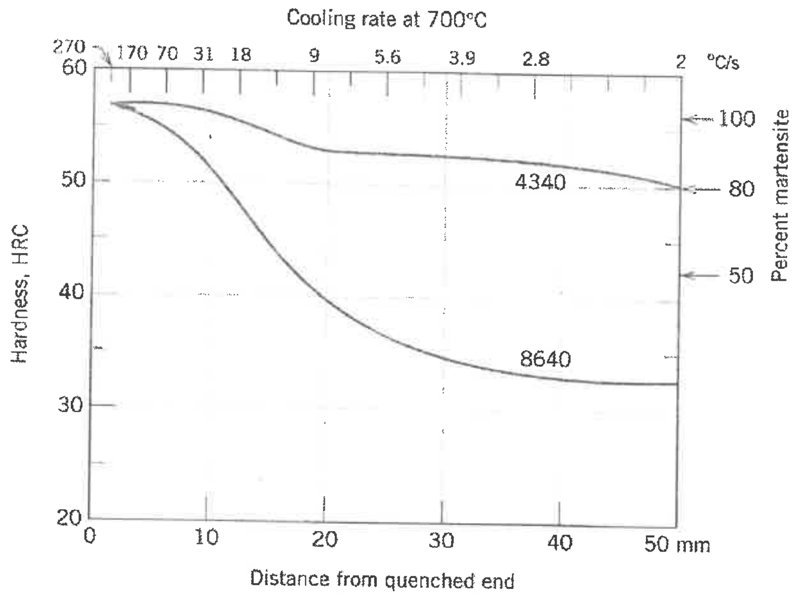

Figure 6. Hardenability curves of 4340 and 8640 alloy

Given the hardenability curves of 4340 and 8640 alloy steel generated from Jominy end-quench tests (seeFigure 6), discuss:

3.1 The hardenability of the various alloys;
3.2 The effect of carbon on the hardenability of steel;
3.3 The effect of the various alloying elements in 4340;
3.4 The connection between the cooling rate and the eventual microstructure.

QUESTION 4 **[20]**

4.1. Consider a thin-walled spherical tank of radius r and wall thickness t as shown in figure 5.1 below. The tank is subjected to an internal pressure p and has a radial crack of length 2a.

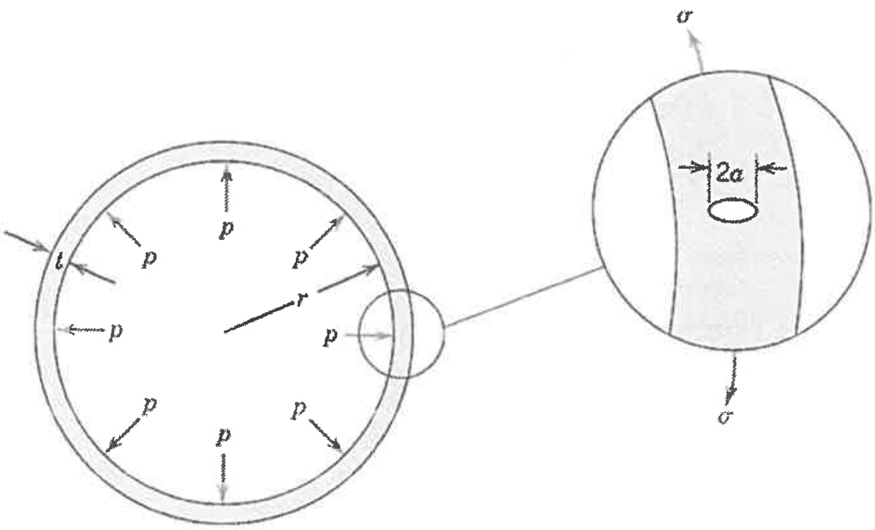

Figure 4.1—Schematic diagram showing the cross section of a spherical tank that is subjected to an internal pressure p

Assume that the circumferential wall stress σ is a function of the pressure p in the vessel and the radius r and the wall thickness t according to $\sigma = \frac{pr}{2t}$.

4.1.1. Define the term plain strain fracture toughness, K_{Ic}

4.1.2. What assumption can be made regarding the critical crack length in order to meet the *leak-before-break* criterion?

4.1.3. Using the *leak-before-break* criterion and principals of fracture mechanics, derive the appropriate material index by which one can rank the materials listed in Table 4.1

Table 4.1—Material properties of various engineering materials

Material	*Yield strength* (MPa)	*Fracture toughness* $(MPa\sqrt{m})$
1040	*290*	*54.0*
4140 tempered at 315°C	*1570*	*65.0*
17-7PH	*1210*	*76.0*