UNIVERSITY OF JOHANNESBURG

PROGRAM	:	BACCALAUREUS INGENERIAE *MECHANICAL ENGINEERING*
SUBJECT	:	**SCIENCE OF MATERIAL 3A**
CODE	:	**MTK3A11**
DATE	:	WINTER EXAMINATION SUPPLEMENTARY JUNE 2018
DURATION	:	3 HOURS (1-PAPER)
WEIGHTING	:	50 : 50
TOTAL MARKS	:	100

EXAMINER	:	Engr. O. M. IKUMAPAYI
MODERATOR	:	MTL LEKWANA
NUMBER OF PAGES	:	7 PAGES

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

QUESTION 1 [16]

1.1. A great deal of the information about the control of the phase structure of a particular system is conveniently and concisely displayed in a phase diagram. Sketch a portion of the iron-carbon phase diagram up to a carbon content of 6.7% and cite:

1.1.1. The phases present. (8)
1.1.2. At which temperatures phase transformation takes place. (2)
1.1.3. The eutectic and eutectoid composition. (Indicate and distinguish between them.) (4)

1.2. List two parameters that will affect the eventual phase structure of such a system. (2)

QUESTION 2 [32]

Perhaps one of the most important tasks that an engineer may be called upon to perform is that of materials selection with regard to component design. Inappropriate or improper decisions can be disastrous from both safety and economic perspectives.

2.1. Name three families in the engineering material kingdom and list two attributes of each family. (9)

2.2. Discuss a material selection strategy that you can employ in the design process. (8)

2.3. Consider a thin-walled spherical tank of radius r and thikness t as shown in figure 2.1 below. The tank is subjected to an internal pressure p and has a radial crack of length $2a$.

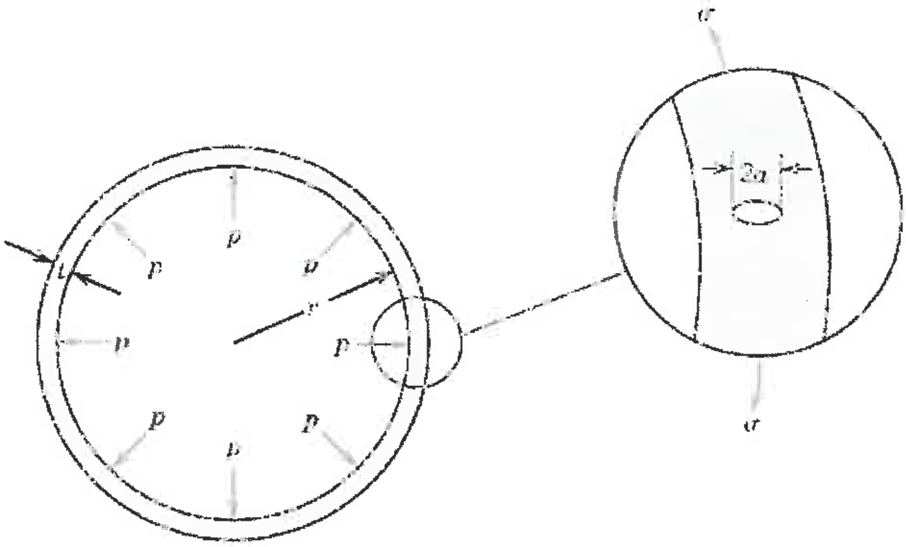

Figure 2.1—Schematic diagram showing the cross section of a spherical tank that is subjected to an internal pressure p

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 $\sigma = \frac{pr}{2t}$.

i. Define the term plain strain fracture toughness, K_{Ic} (5)

ii. What assumption can be made regarding the critical crack length in order to meet the *leak-before-break* criterion? (2)

iii. 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 2.1 (8)

Table 2.1—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*

QUESTION 3 [26]

A bearing that had been in service for a year and a half was sent to undergo failure analysis (Figure 3.1). This bearing had been installed in the drive of a #P-40 centrifugal pump in a R-8 plant. It was located on a long shaft to separate the pump from the drive due to the presence of concentrated sulphuric acid. The shaft was belt driven at about 800 RPM. No special events were noticed in the pump operation.

Figure 3.1—Photograph of bearing setup

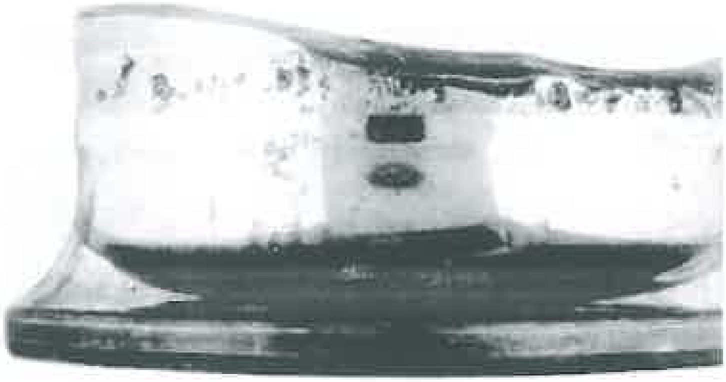

Figure 3.2—Photograph of inner ring showing spalling in groove.

Observations: The inner raceway showed severe plastic deformation around its circumference in the form of a groove, which is located above the area designed to be the ball raceway (Figure 3.2). Spalling, a flaking and cracking of the surface, was observed in the groove but was not evenly distributed around its circumference. Examination of the spalling using a scanning electron microscope (SEM) exposed flaking and the presence of surface cracks (Figure 3.3). Increased magnification of this area revealed fracture surfaces at 45° angles indicating shear loads were present (Figure 3.4).

Figure 3.3—SEM photograph of spalling, flaking and cracking, in the groove. 200X

Figure 3.4—SEM photograph showing presence of 45º sheer planes. 500X

The inner raceway fracture surface is perpendicular to the groove and is located where the spalling is most severe. Beachmarks revealed several initiation sites situated in the base of the groove (Figure 3.5). Closer examination with the SEM confirms that fatigue initiated from the spalling damage (Figure 3.6). Spalling was also seen to a lesser degree on the balls surfaces. The outer raceway revealed no major defects.

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

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

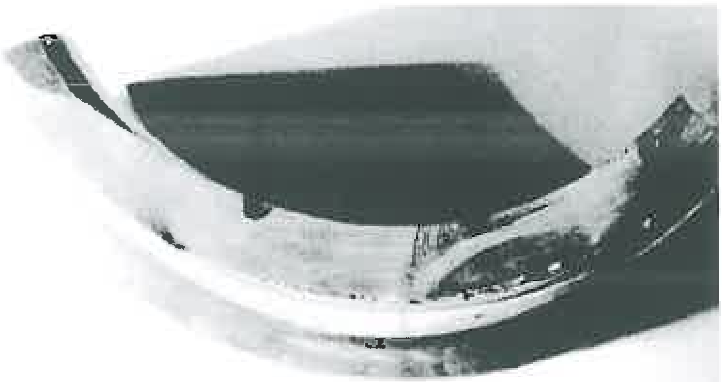

Figure 3.5—Photograph of the inner ring fracture surface.

Figure 3.6—SEM photograph of the inner ring fracture surface showing fatigue initiating at spall in the groove. 200X

Material characterisation and evaluation: Both the compositions of the ball bearing and the inner raceway were found to fall within the norms for 52100 steel, AISI-SAE standards, as shown in Table 3.1. The microhardness measurements of both pieces were found to be typical for this type of steel. Surface hardness measurements for both ball and inner ring are similar, which is required by this type of application.

Table 3.1—Result of chemical analysis.

Element	Analysed Composition of Ball (%)	Analysed Composition of Inner Ring (%)	AISI-SAE 52100 Standard Composition Ranges (%)
Carbon	0.97	1.02	0.98-1.10
Manganese	0.40	0.37	0.25-0.45
Silicon	0.24	0.23	0.15-0.30
Phosphorus	0.013	0.013	0.025
Sulphur	0.007	0.006	0.025
Chromium	1.21	1.36	0.025
Nickel	0.11	0.12	--
Molybdenum	0.02	0.05	--

Microscopic examination of a cross section of the inner raceway revealed surface cracks consistent with the spalling observed (Figure 3.7). Etching the sample revealed a homogeneous microstructure of a tempered martensite matrix with undissolved carbides present (Figure 3.8). This microstructure agrees with the chemical analysis and microhardness measurements.

Figure 3.7—Micrograph of cracks on the inner ring surface. 200X

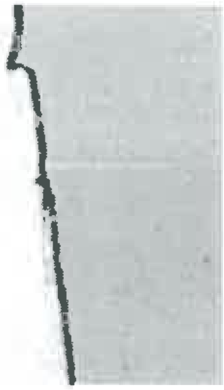

Figure 3.8—Microphotograph of the inner ring microstructure composed of martensite and undissolved carbides. 2% nital 200X

Microscopic examination of a quartered ball bearing also revealed surface cracks (Figure 3.9). A large crack extending towards the centre of the bearing was also found (Figure 3.10). The microstructure is heterogeneous, unevenly distributed; tempered martensite with undissolved carbides. The large surface crack ties along a border of the heterogeneity (Figure 3.11). Some decarburization was observed on the surface near spalling cracks.

Figure 3.9—Micrograph of cracks on the ball surface. 100X

Figure 3.10—Microphotographs of crack in a ball. 15X

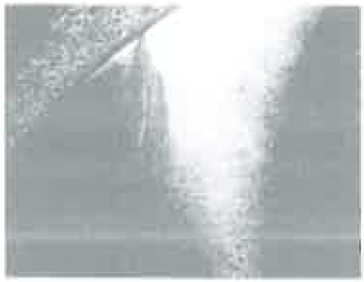

Figure 3.11—Microphotograph of figure 3.10 etched with 2% nital showing heterogeneous martensite structure with undissolved carbides. 15X

3.3. Discuss the difference between austempering and martempering and illustrate the heat treatments on a TTT diagram. (8)

3.4. After considering the observations made in this failure analysis, what conclusions can be drawn. (4)

QUESTION 4 [26]

4.1 Briefly describe/define the following concepts:

a) Pig iron *(1)*

b) Dynamic re-crystallisation *(3)*

c) B steel *(2)*

4.2 Define fatigure and discuss 3 measures that can be taken to extend the fatigue life of a component. (10)

4.3 5.2mm diameter cylindrical rod fabricated from 2014-T6 aluminium alloy is subjected to a repeated tension-compression load cycling along its axis. Determine the maximum and minimum loads (in Newton) that will be applied to yield a fatigue life of 1.0×10^8 cycles. Assume that the data in Figure 4.1 were taken from a mean stress of 35MPa.

(Hint: $2\sigma_a = \sigma_{max} - \sigma_{min}$ and $2\sigma_m = \sigma_{max} + \sigma_{min}$) (10)

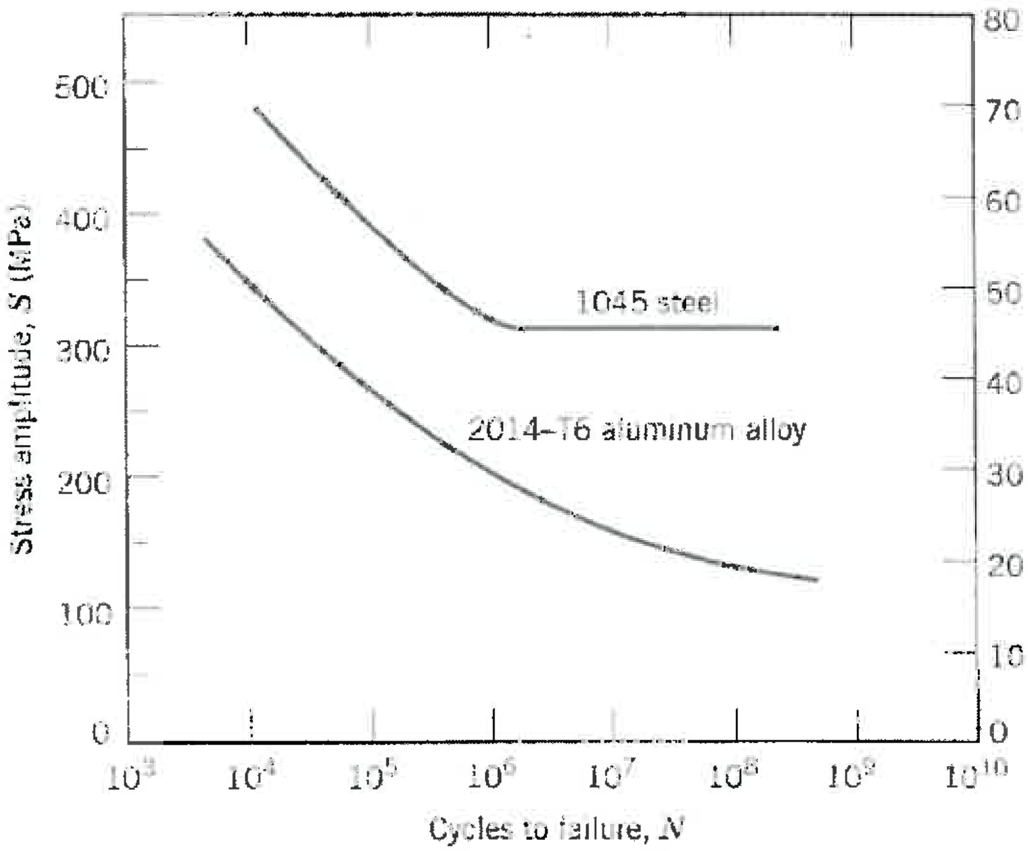

Figure 4.1—Stress amplitude S versus the number of cycles N