Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2019/2020

COURSE NAME	:	FATIGUE AND FRACTURE MECHANICS
COURSE CODE	:	BDC 40403
PROGRAMME CODE	:	BDD
EXAMINATION DATE	:	DECEMBER 2019 / JANUARY 2020
DURATION	:	3 HOURS
INSTRUCTION	:	ANSWER **FOUR (4)** QUESTIONS **ONLY**.

THIS QUESTION PAPER CONSISTS OF **SIX (6)** PAGES

Q1 (a) Describe the fracture mechanisms that are involved in two (2) materials as shown in **Figure Q1(a)**.

(10 marks)

(b) Based on the fracture mechanics approaches, state either true **(T)** or false **(F)** for the statement below:

(i) Do recognize that the presence of cracks or crack-like manufacturing and metallurgical discontinuities can significantly reduce the strength of a component or structure.

(ii) Don't consider that fracture toughness depends much more on metallurgical discontinuities and impurities than does ultimate or yield strength. Low impurity alloys have better fracture toughness.

(iii) Do expect doubling thickness or doubling ultimate strength of a component to double the fracture load. Cracks can exist and fracture toughness may drop appreciably with both thickness and ultimate strength increases.

(iv) Do recognize the importance of distinguishing between plane stress and plane strain in fracture mechanics analysis as fracture toughness, crack tip plasticity, and LEFM limitations can be significantly different for the two conditions.

(v) Don't neglect the importance of non-destructive flaw or crack inspection for both initial and periodic inspection periods.

(5 marks)

(c) A titanium alloy has a fracture toughness of 60 $MPa.m^{1/2}$ and contains a dispersion of hard oxide particles throughout its structure with a maximum size of 4 mm. These particles are assumed act as both surface and internal through cracks (this is an approximation). Assume a geometric factor of 1.

(i) Predict whether a tensile stress of 600 MPa result in catastrophic fracture.

(5 marks)

(ii) What is the greatest depth of surface crack that will produce a stress intensity factor equal to the critical value K_{IC} under the applied stress of 600 MPa?

(5 marks)

Q2 (a) Describe briefly the terminologies stated below in the fracture mechanics:

(i) Stress concentration. (4 marks)

(ii) Stress intensity. (3 marks)

(iii) Elastic-plastic fracture mechanics. (3 marks)

(b) Consider a structural component, made of 4340 alloy steel. The component is in the form of a very wide plate, thus the geometry factor, f, can safely be assumed equal to 1. Two sheets of this alloy, each with different heat treatments and thus different mechanical properties, are available. Material A has K_{IC} = 98.9 MPa.m$^{1/2}$, and yield strength of 860 MPa. Material B has yield strength of 1515 MPa and plane strain fracture toughness, K_{IC}, of 60.4 MPa.m$^{1/2}$.

(i) For each alloy, determine whether the plane strain condition is applied or not if the plate is 10-mm thick.

(10 marks)

(ii) It is not possible (in this problem) to detect flaw sizes less than 3 mm, because of the resolution limit of the NDT (non-destructive test) apparatus. If the plate thickness is sufficient, so that plane strain conditions obtain and one can use the K_{IC} values of the alloys, determine whether the critical flaw is detectable or not. Assume that the design (or working) stress is one-half of the yield stress.

(5 marks)

Q3 (a) Sketch and describe with diagram the classification of basic bulk forming processes below:

(i) Rolling

(ii) Forging

(iii) Extrusion (10 marks)

(b) Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated loads. Explain briefly how to distinguish fatigue failure based on the fracture surface appearance. (5 marks)

(c) A steel strap with 1 mm thick, 15 mm wide and 100 mm long has a 3 mm long central crack is loaded to failure. Assume that the steel is brittle and has Young's modulus, E = 207,000 MPa, yield strength, σ_{ys} = 1500 MPa, and plane strain fracture toughness, K_{IC} = 70 MPa.m$^{1/2}$. Determine the critical stress, σ_c, and the critical strain energy release rate.

The geometry correction factor is calculated by $f(a/w) = \sqrt{\frac{w}{\pi a} tan\left(\frac{\pi a}{w}\right)}$.

(10 marks)

Q4 (a) When a specimen subjected to cyclic load, a fatigue crack nucleus can be initiated on a microscopically small scale, followed by crack grows to a macroscopic size, and finally to specimen failure in the last cycle of the fatigue life as shown in **Figure Q4(a)**. Describe briefly the mechanism of stages below in fatigue failure:

(i) Fatigue crack initiation. (4 marks)

(ii) Fatigue crack propagation. (4 marks)

(b) A fatigue test was conducted in which the mean stress was 50 MPa and the stress amplitude was 225 MPa.

(i) Compute the maximum and minimum stress levels. (3 marks)

(ii) Compute the stress ratio. (2 marks)

(iii) Compute the magnitude of the stress range. (2 marks)

(c) A steel bar is subjected to a repeating fatigue cycle in tension. The steel has fracture strength of 800 MPa and fracture toughness of 80 MPa.m$^{1/2}$. A fatigue crack propagates uniformly into the interior from the surface at a rate of 0.001 mm/1000 cycles. Using the simplifying assumption that the relationship between crack growth rate and number of cycle is linear, calculate how long it will take for the bar to fail suddenly if it loaded at a rate of 50 cycles/hour. Assume a geometric factor of $Y = 1$.

(10 marks)

Q5 (a) Explain the difference between fatigue striations and beachmarks both in terms of:

(i) size. (4 marks)

(ii) origin. (4 marks)

(b) Describe **two (2)** methods that could be considered to increase the resistance to fatigue of the metal alloy.

(4 marks)

(c) A large component is subjected to a cyclic loading under $\Delta\sigma = 300$ MPa and $R = 0$. The component need to endure 37,627 cycles, with an initial single-edge crack length, $a_i = 2$ mm. The material behaves according to Paris Law, $\frac{da}{dN} = 2 \times 10^{-8}(\Delta K_I)^{2.45}$, where da/dN is in m/cycles and ΔK_I is in MPa$\sqrt{m}$. Assume the geometry factor, $Y = 1.12$.

(i) Determine the final crack length, a_f, for the component. (8 marks)

(ii) Predict the plane strain fracture toughness for the component at the end of the loading cycles.

(5 marks)

- END OF QUESTION -

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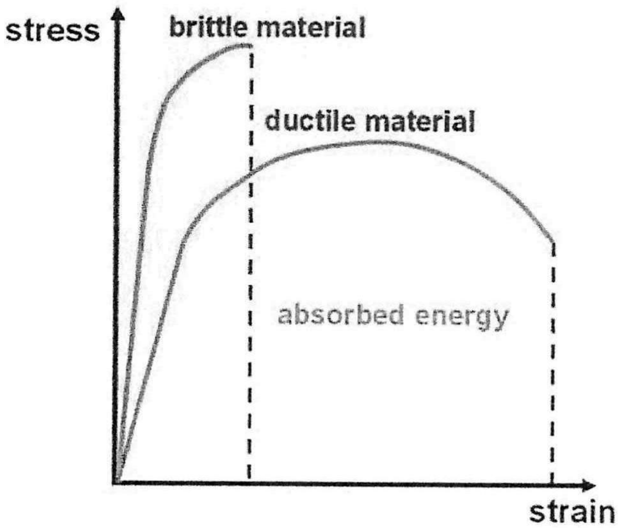

Figure Q1(a)

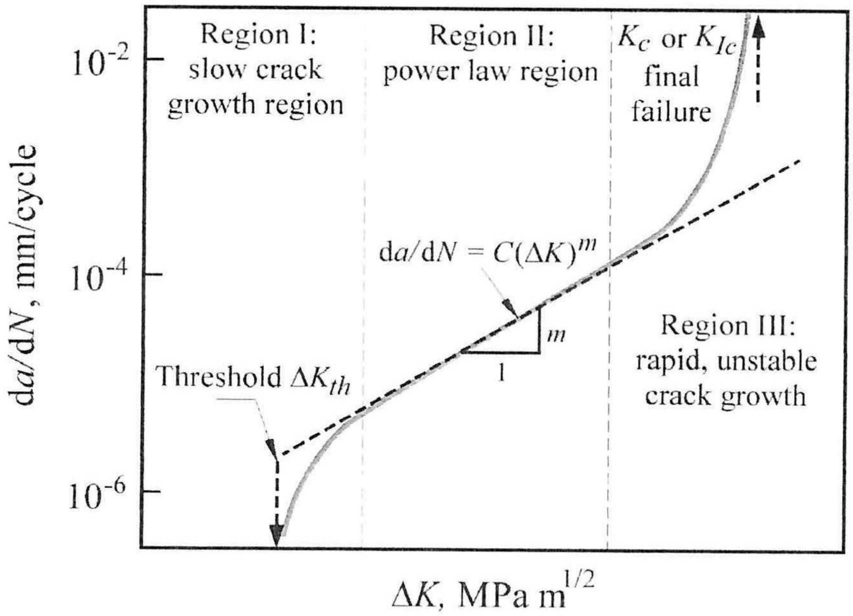

Figure Q4 (a)