Second Semester Examination
2022/2023 Academic Session

July / August 2023

EME 452 – Tribology
(Tribologi)

Duration: 3 hours
(Masa: 3 Jam)

Please check that this examination paper consists of SEVEN (7) pages of printed material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TUJUH (7) muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

Instructions: Answer ALL **FIVE (5)** questions.

*[**Arahan**: Jawab **LIMA (5)** soalan]*

1. A ceramic ball with a diameter of 7 mm is pressed into a steel ball of 15 mm diameter with a normal load of 320 N, producing a circular point contact. The material properties and surface parameters of the balls are given in Table 1.

Table 1: Material properties and surface parameters

Component	*Modulus Young, E* (GPa)	*Poisson's ratio, v*	Hardness, H (GPa)	Standard deviation, ß (μm)	Asperity mean radius, Rm (μm)
Steel ball	200	0.3	***X***	0.05	90
Ceramic ball	450	0.25	15.7	0.015	250

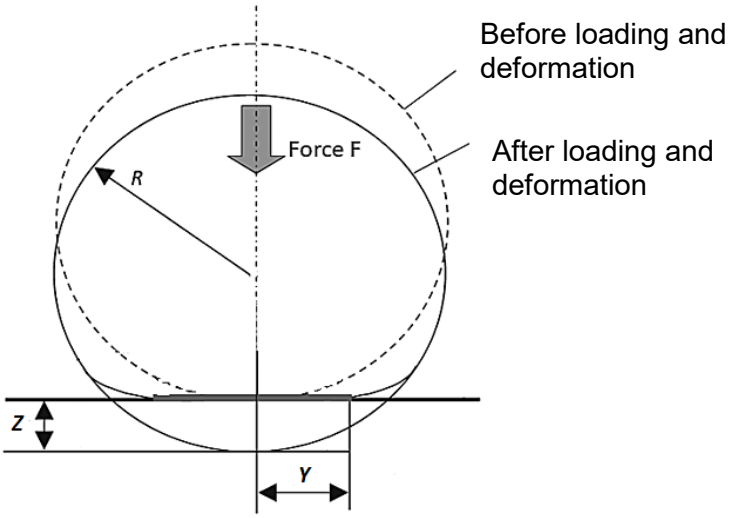

Figure 1: Equivalent sphere in contact with a plane surface

Based on the assumption that the contact between two spheres can be represented by an equivalent sphere in contact with a plane surface, as shown in Figure 1:

(a) Describe what is ***Y*** and ***Z*** and calculate the values.

(20 marks)

(b) Sketch the distribution of Hertzian pressure along the contact and calculate the maximum Hertzian pressure.

(30 marks)

(c) Calculate the minimum value of steel ball hardness ***X*** at which the deformation of the asperities is predominantly elastic. Based on Greenwood and Williamson (1966), explain how to predict the contact behavior based on the material hardness and surface parameter.

(20 marks)

(d) Minimizing wear and extending the lifespan of components are essential sustainability goals in tribology. Based on tribological practice, propose **TWO (2)** methods on how this can be accomplished.

(30 marks)

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2. (a) A four-ball tribometer is used for finding the properties of a lubricant by configuring the balls to point contact loads under pure rolling conditions. The upper steel ball is vertically loaded and rotated against a nest of three stationary balls confined by a clamping cup containing the grease to be tested. All four balls have a radius of 12.7 mm and are made of steel with Young's modulus of 200 GPa and Poisson's ratio v = 0.3. The lubricating grease viscosity is 0.01 Pa.s at atmospheric pressure and the viscosity-pressure coefficient is 15 GPa^{-1}. The test is run according to ASTM D2266 with a 392 N load and a running speed of 1200 rpm. Calculate the minimum film thickness based on the elastohydrodynamic (EHL) lubrication.

(50 marks)

(b) Surface roughness may influence the formation of lubricant film in EHL lubrication. Figure 2 shows the film thickness and EHL pressure distribution during the contact of the surfaces with three different roughness.

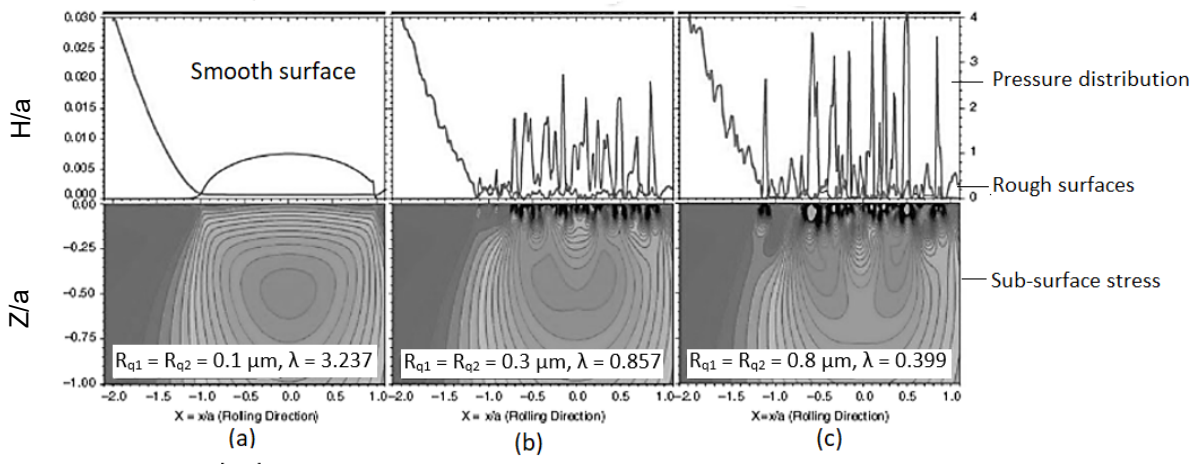

Figure 2: Film thickness, EHL pressure distribution and subsurface stress for surfaces with a composite roughness and λ of (a) $R_{q1} = R_{q2}$ = 0.1 µm, λ = 3.237 (b) $R_{q1} = R_{q2}$ = 0.3 µm, λ = 0.857 and (c) $R_{q1} = R_{q2}$ = 0.8 µm, λ = 0.399

(i) Based on the evaluation of Figure 2, explain the effect of surface roughness on the formation of film thickness and pressure distribution.

(ii) Provide **ONE (1)** effect of the lubrication regime in Figure 2 (c) on the tribological performance and **ONE (1)** effect on the environment.

(iii) Propose and explain **ONE (1)** method to solve the problem.

(50 marks)

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3. (a) Due to the uncertain working environment during journal bearing operation in a steam turbine, the lubricant in journal bearing is required to produce a minimum film thickness, h_o of 15 μm in order to ensure a steady-state operating condition. The journal bearing has 80 mm length and 160 mm diameter, with a radial clearance of 0.05 mm. The bearing is subjected to a load of 100 kN and rotates at 2700 rpm. The bearing is lubricated with oil lubrication, supplied at atmospheric pressure and the average operating temperature is maintained at 90 degrees Celsius. By using the Raimondi and Boyd design chart, find the absolute viscosity of the lubricant that is required to produce the desired minimum film thickness and suggest the SAE grade oil that is suitable for this case.

(50 marks)

(b) Figure 3 shows the oil wedge formed between moving two non-parallel surfaces during hydrodynamic lubrication.

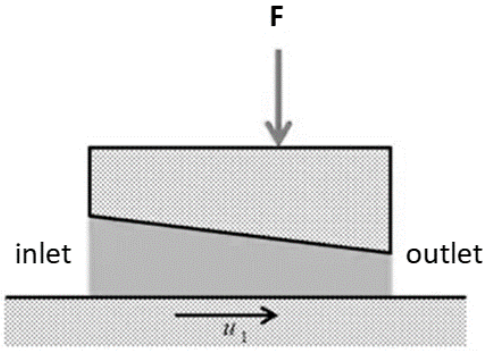

Figure 3: Oil wedge formed in hydrodynamic lubrication

(i) Explain **TWO (2)** laws that involve in the hydrodynamic pressure generation to ensure an equal fluid flow at the inlet and outlet of the surface separation.

(ii) The use of safe and environmentally friendly lubricant is one method for sustainable lubrication in journal bearing. Explain how this method can improve the labour working environment and community.

(50 marks)

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4. (a) Describe **TWO (2)** effective means in controlling corrosive and oxidative wear.

(20 marks)

(b) During a finishing process in production of integrated circuits, the process to form a very smooth and flat surfaces (planar surface) are critical aspects in the manufacturing these functional integrated circuits. Suggest **TWO (2)** methods, based on the tribological principles, to produce such surfaces.

(20 marks)

(c) Sketch and label the **FOUR (4)** phases of lamda (λ) to define the **FOUR (4)** types of lubricants on Stribeck curve for daily applications.

(20 marks)

(d) Vibration is often collated into stability margin which shows the transition between stable and unstable vibration as a function of eccentricity ratio and the load parameter as in Equation (4.1). The conversion formula of rpm (rev/min) to rad/s as given in Equation (4.2):

$$P = \frac{2F}{Mc\omega^2} \quad (4.1)$$

$$\omega = 2\pi \frac{x}{60} \quad (4.2)$$

where:

P: the stability parameter
F: the static load on the bearing (N)
M: the vibrating mass (kg)
c: the radial clearance (m)
ω: the angular velocity of the bearing (rad/s)
x: rev/min

(i) Determine the stability of a main wind turbine shaft with a turbine rotor that has a static load on the bearing at 1260 kg and its highest speed is 24.3 rev/min. The parameters of the power system are 850 kW rated output power and 1500 rev/min rated rotation speed. The turbine has an axial and radial clearance of 0.2 mm. The eccentricity varies from 0 to 1 as shown in Figure 4 (c).

(20 marks)

(ii) Analyse the significant of stability in lubrication condition in the wind turbine to the eccentricity, Ɛ, for sustainability of the turbine.

(20 marks)

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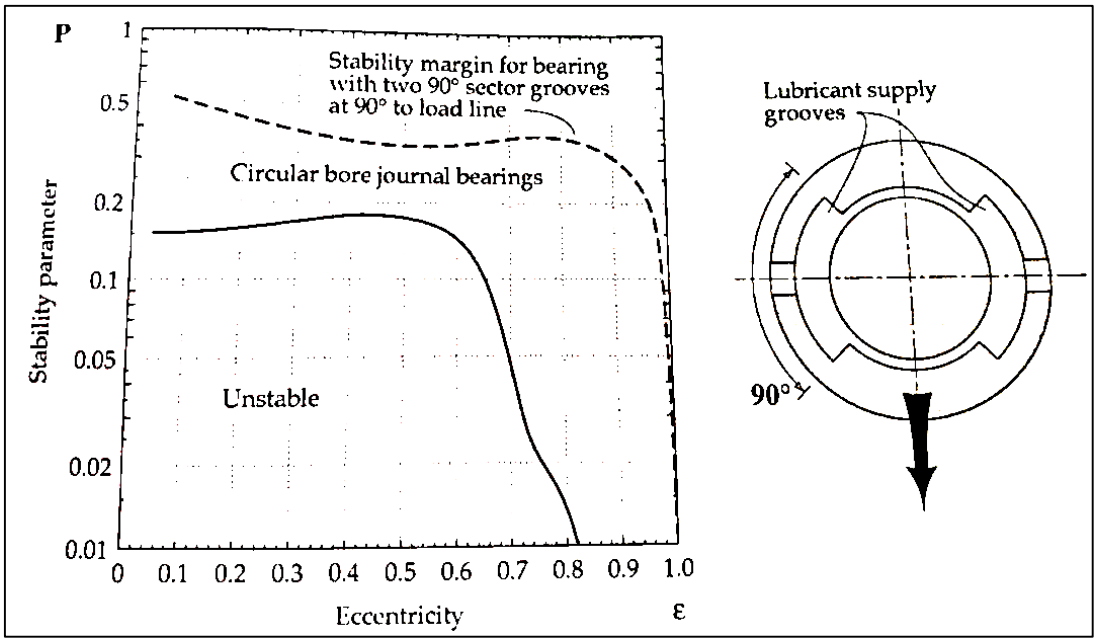

Figure 4 (c)

5. The wear in polymer occurred in a manner that it follows Hooks law and characterized by their elastomeric characteristics. Under normal mechanical and practical procedures, the wear-rate normally changes through three different stages: primary stage or early run-in period, where surfaces adapt to each other and the wear-rate might vary between high and low; secondary stage or mid-age process, where a steady rate of wearing is in motion. Lastly, roll-on and detachment process occurred.

(a) Describe **TWO (2)** main types of wear in polymer industry and give **TWO (2)** examples for each application.

(20 marks)

(b) With the help of diagram in Figure 5 (b), explain the impact of the rubber wear mechanisms work.

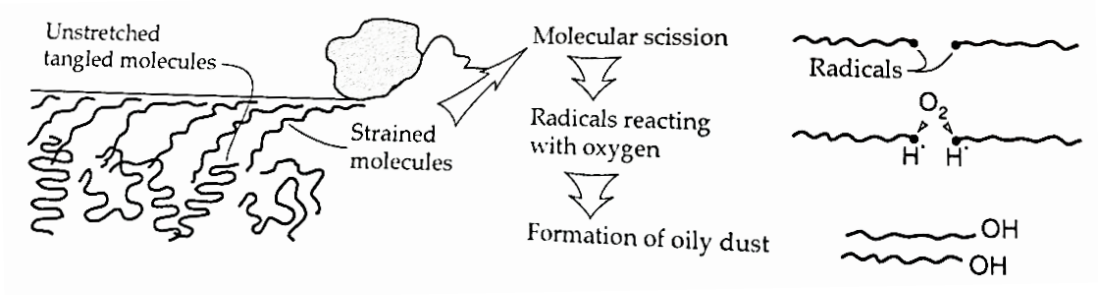

Figure 5 (b)

(40 marks)

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(c) In automotive applications, rubber lining has become essential in many components. Using the diagram on Schallamach waves effect on abraded rubber, describe the phenomenon that led to the waves effect as shown in Figure 5 (c).

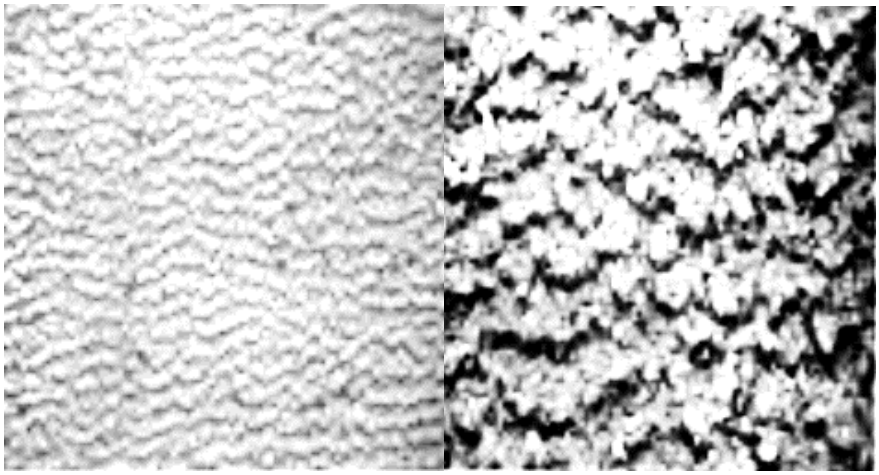

Figure 5 (c)

(40 marks)

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