[ENG23]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSC MECHANICAL ENGINEERING / ELECTRICAL ELECTRONIC ENGINEERING / BIOMEDICAL ENGINEERING / ELECTRICAL VEHICLE / DIGITAL DENTAL TECHNOLOGY

SEMESTER TWO EXAMINATION 2023-24

ADVANCED ENGINEERING MODELLING AND ANALYSIS

MODULE NO: MSE7002/MSE7006

Date: Monday 13th May 2024 **Time: 10:00 – 13:00**

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions. Answer ANY FOUR questions.

Please NOTE FOR Question 2: Mechanical/Electrical/Vehicle Technology- Answer Part A and Biomedical/Dental- AnswePart B.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

PAST EXAMINATION

School of Engineering
Msc Mechanical Engineering / Electrical Electronic Engineering / Biomedical Engineering / Electrical Vehicle / Digital Dental Technology
Semester Two Examination 2023-24
Advanced Engineering Modelling and Analysis
Module No: MSE7002/MSE7006

PAST EXAMINATION

QUESTION 1

a) Explain how finite element analysis (FEA) is applied in assessing stress within materials.

[05 Marks]

b) Given a cantilever beam subjected to a uniform distributed load, outline the steps you would take to model this scenario using FEA in ANSYS Workbench. Include considerations for boundary conditions and element type selection.

[15 Marks]

c) Consider the four element types presented in FEA: Linear Tetrahedron (4-noded), Quadratic Tetrahedron (10-noded), Linear Hexahedron (8-noded), and Quadratic Hexahedron (20-noded).

For a critical load-bearing component in an engineering application, which element type would be most appropriate to use for the finite element analysis? Include in your answer a comparison of the element types in terms of their nodal composition and the general rule of accuracy versus computational cost.

[05 Marks]

[Total: 25 Marks]

Mechanical/Electrical/Vehicle Technology:

Q2-Part A

Biomedical/Dental:

Q2-Part B

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QUESTION 2

Part A

a) How does Finite Element Analysis (FEA) apply to conducting steady-state thermal analysis in engineering? Include the significance of this application in predicting material behavior and design optimisation.

[5 Marks]

b) You are in the process of designing a new cooling system for a high-performance computing unit. You are at a stage where you need to assess the temperature distribution due to heat generation by the CPU and its dissipation through a heat sink. A simplified geometry of a heat sink is shown in **Figure Q2a** (shown over the page) with a fin length, L of 10 mm. The heat sink is made up of copper with a thermal conductivity of 400 W/(m.K).

According to **Figure Q2a**, the prescribed temperature at the base of the fin of the heat sink is 250°C. Assume that the outermost face of the fin is maintained at 30°C.

Study the temperature and heat flux distribution in the heat sink.

i. Derive the equation for temperature distribution along the length, L of a single fin, and then calculate the temperature at z=2 mm, 4 mm, 6 mm, and 8 mm. Must show the calculations for each z.

[10 Marks]

ii. Plot the temperature distribution from one end to the other along the length of the fin on a graph. Annotate the graph appropriately.

[5 Marks]

iii. Calculate the heat flux in Y direction.

[5 Marks]

Question 2 Part A continues over the page…

Question 2 Part A continued…

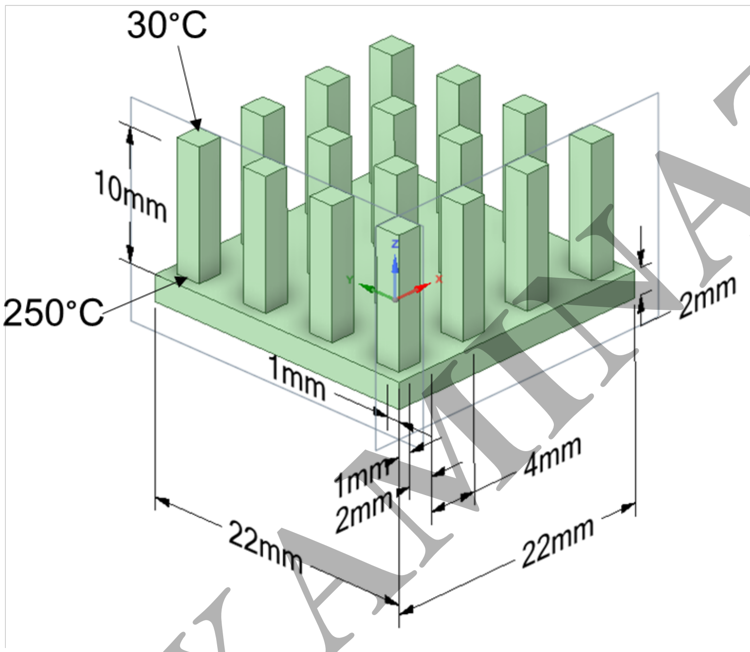

Figure Q2a: A heat sink with termperature boundary conditions.

[Total: 25 Marks]

PAST EXAMINATION

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<u>QUESTION 2</u>
<u>Part B</u>

a) How does Finite Element Analysis (FEA) apply to conducting steady-state thermal analysis in engineering? Include the significance of this application in predicting material behavior and design optimisation. **[5 Marks]**

b) The lower cylinder of dental implant of length L = 15mm is exposed to temperatures of T_1=50 ^oC at z=0 mm and T_1=10 ^oC at z=15 mm as is shown in **Figure Q2b**. Assuming that the thermal conductivity of Zirconia is 3 W/(m.K).

i. Derive the equation for temperature distribution along the length of the dental implant, and then calculate the temperature at z =2 mm, 4 mm, 6 mm and 8 mm. Must show the calculations for each z.

[10 Marks]

ii. Plot the temperature distribution from one end to the other along the length of the fin on a graph. Annotate the graph appropriately.

[5 Marks]

iii. Calculate the heat flux in Z direction. **[5 Marks]**

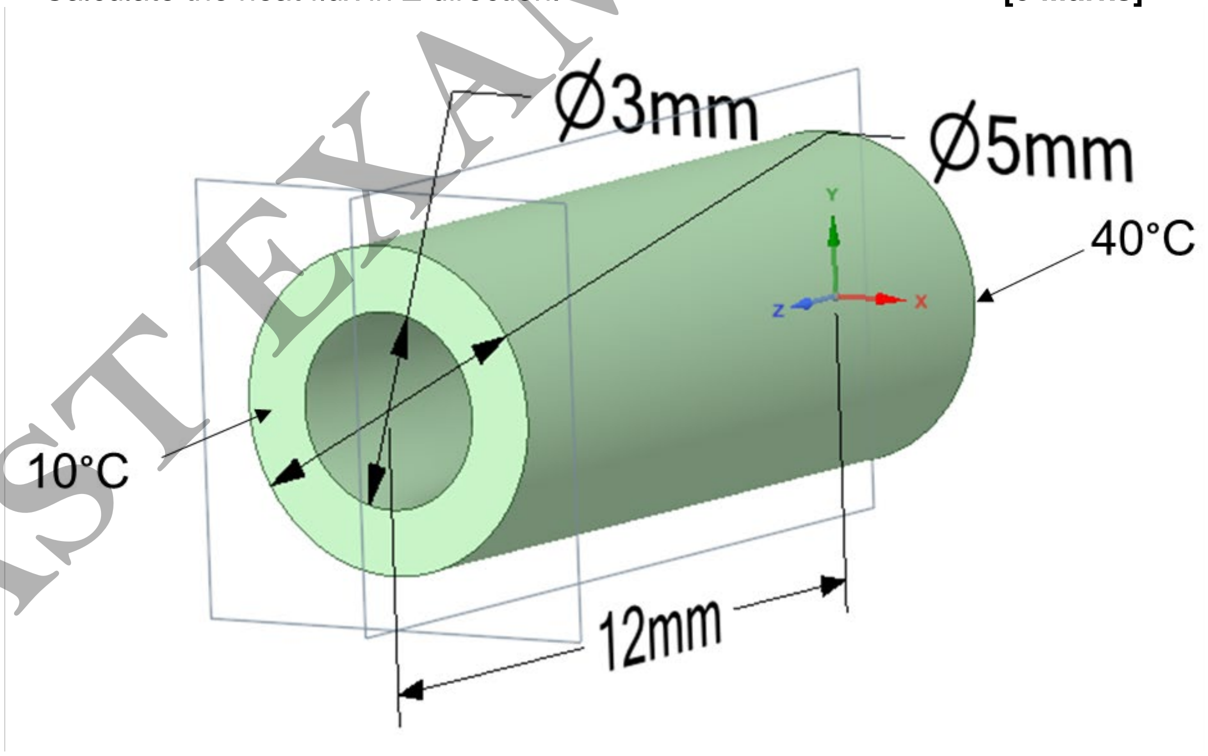

***Figure Q2b**: Dental implant with temperature boundary conditions.*

[Total: 25 Marks]

PAST EXAMINATION

QUESTION 3

A silicone rubber pad, acting as a pressure sensor, is attached to the bottom of a simple prosthetic limb to monitor the pressure distribution as the wearer walks.This pad can be approximated as a cantilever beam under a uniformly distributed load (UDL) **(Figure Q3)** caused by the wearer's weight and ground reaction forces. The silicone rubber is known for its non-linear elastic behavior, which is crucial for providing comfort and accurate pressure sensing. Assume the silicone has an average Young's modulus E=5 MPa and poisson's ratio of v=0.41 in the working strain range and exhibits significant non-linear stretch behavior at higher strains.

Displacement value measured at the free end of the beam for five different values of UDL are tabulated in **Table Q3** (shown over the page).

a) Compute the displacement for these UDL values using analytical expressions (Linear).

[10 Marks]

b) Draw the UDL vs Displacement graphs for analytical solution (Linear) and measured values on a graph paper. Annotate the graph appropriately.

[5 Marks]

c) Caclulate the shear modulus, bulk modulus and incompressibility parameter using analytical expression.

[5 Marks]

d) How do linear and non-linear materials differ in their properties and behavior?

[5 Marks]

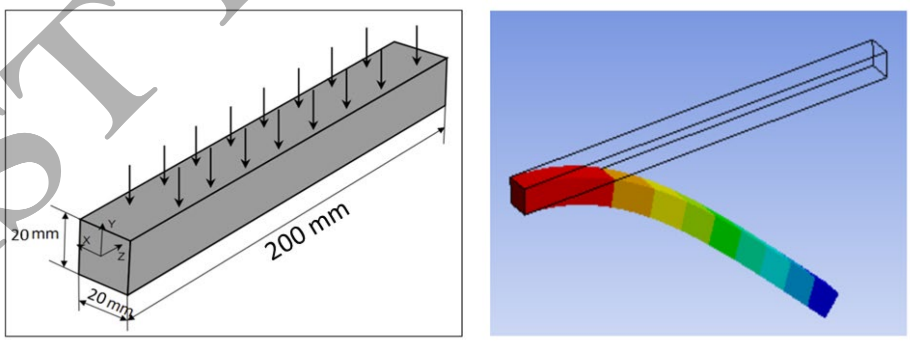

Figure Q3: (Left) Dimensions of the beam and (Right) Deformed shape of the beam.

Question 3 continues over the page…

…Question 3 continued

UDL (N/m)	Measured displacement (mm)
10	11.89
20	23.83
40	46.99
80	86.56
160	134.23

Table Q3: Displacement values measured for different UDL values.

[Total: 25 Marks]

PAST EXAMINATION

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QUESTION 4

You are tasked with choosing the material for a dental implant. In the preliminary stages of design, the implant can be assumed as a cylindrical bar of length L and diameter d, see Figure Q4. The implant needs to be light and strong.

a) Identify the function, objectives, constraints, and free variables for this problem, and then derive the material performance index.

[14 Marks]

b) Based on the material performance index derived in 4a, discuss how the performance could be improved with respect to material properties.

[6 Marks]

c) Based on the material performance index derived in 4a, choose the best material from the list of materials provided in Table Q4.

[5 Marks]

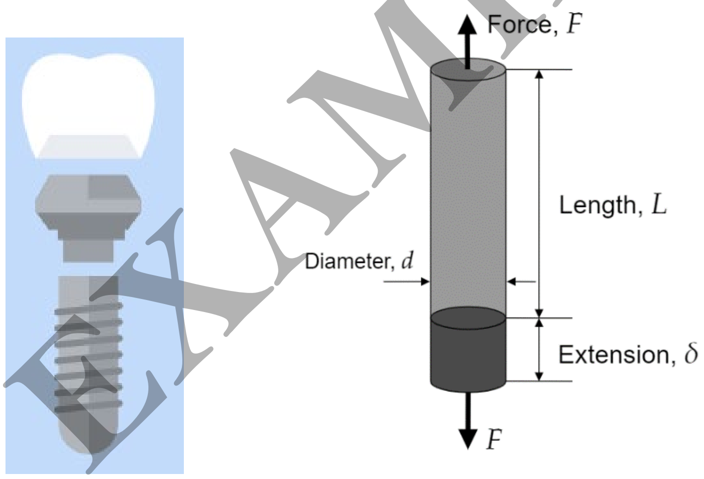

Figure Q4: (Left) Dental implant and (Right) Simplified model as cylindrical rod.

Material	Density (kg/m3)	Young's modulus (GPa)	Strength (MPa)
Stainless steel alloy 1	7654	190	280
Stainless steel alloy 2	7777	180	270
Titanium	4321	121	237
Aluminium alloy	2345	79	111
Zirconia	6789	95	321

Table Q4: Properties of materials for the dental implant.

[Total: 25 Marks]

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PAST EXAMINATION

QUESTION 5

a) How is the thermal conductivity of a material defined, and what criteria should guide the selection of materials for thermal applications based on their thermal conductivity?

[5 Marks]

b) A cylinderical bar of length, L = 100 mm is exposed to temperatures of T_1=80 °C at z=0 mm and T_2=20 °C at z=120 mm as shown in **Figure Q5**. Assuming that the thermal conductivity of the material is 70 W/(m.K).

i. Derive the equation for temperature distribution along the length of the dental implant, and then calculate the temperature at z =20 mm, 40 mm, 60 mm and 80 mm. Must show the calculations for each z.

[10 Marks]

ii. Plot the temperature distribution from one end to the other along the length of the bar on a graph. Annotate the graph appropriately.

[5 Marks]

iii. Calculate the heat flux in Z direction. **[5 Marks]**

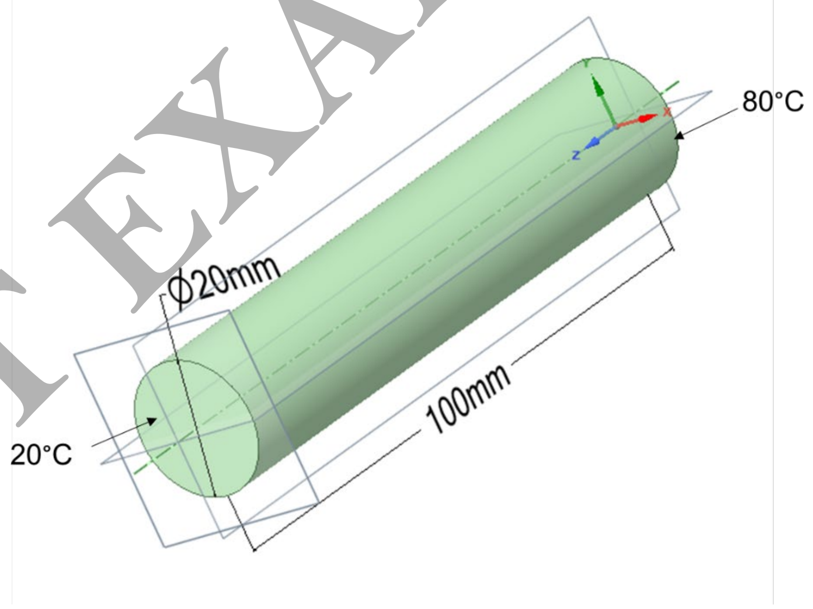

Figure Q5: Cylindrical bar with temperatures as boundary conditions.

END OF QUESTIONS

Formula Sheet Follows On Next Page

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PAST EXAMINATION

FORMULAE SHEET

1. Heat transfer

Assumption is that the bar is oriented such that its axis is along the Z-axis. The heat is flowing from high temperature end to low temperature end.

The analytical solution for temperature distribution is given by,

$$T(z) = T_1 + \frac{T_2 - T_1}{L} * z \qquad {}^0C$$

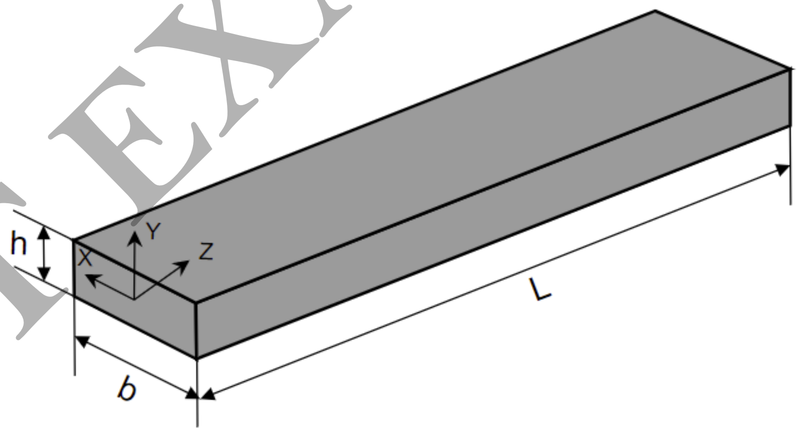
where, T_1 and T_2 are the temperatures at one end $(z = 0)$ and other end $(z = L)$ of the bar and $T_1 > T_2$.

The expression for heat flux is given by,

$$\text{Heat flux} = -k * \frac{dT}{dz}$$

$$\text{Heat flux} = -\text{heat transfer coefficient} * \frac{\text{temperature difference}}{\text{length of the bar}}$$

2. Section properties



Area moment of inertia, $\mathrm{I} = \frac{b\,h^3}{12}$

Perpendicular distance from the top/botom surface to the centroid, $\mathrm{y} = \frac{h}{2}$

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3. Equations for the simply supported beam

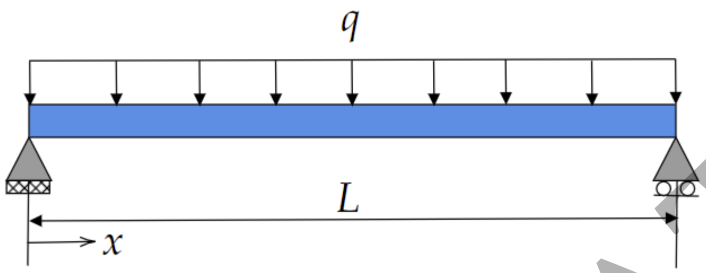

Figure: Simply-supported beam configuration.

Maximum displacement (at $x = L/2$), $\delta_{max} = \frac{5\,q\,L^4}{384\,E\,I}$

Maximum moment at $x = L/2$, $M_{max} = \frac{q\,L^2}{8}$

Maximum stress at $x = L/2$, $\sigma_{max} = \frac{M_{max} \cdot y}{I}$

4. Equations for the clamped-clamped beam

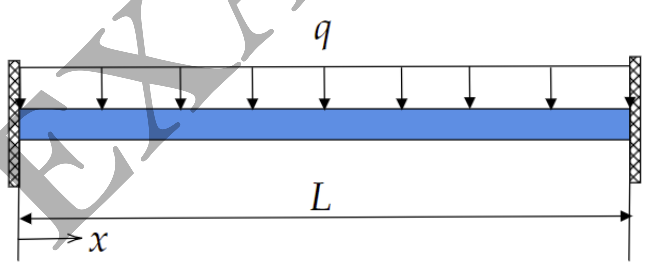

Figure: Clamped-clamped beam configuration.

Maximum displacement (at $x = L$), $\delta_{max} = \frac{q\,L^4}{384\,E\,I}$

Maximum moment at $x = 0$, $M_{max} = \frac{q\,L^2}{12}$

Maximum stress at $x = 0$, $\sigma_{max} = \frac{M_{max} \cdot y}{I}$

PAST EXAMINATION

5. Equations for the cantilever beam

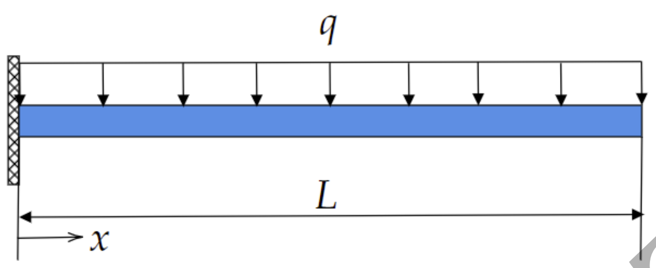

Figure: Cantilever beam configuration.

Maximum displacement (at $x = L$), $\delta_{max} = \frac{q\,L^4}{8\,E\,I}$

Maximum moment at $x = L$, $M_{max} = \frac{q\,L^2}{2}$

Maximum stress at $x = L$, $\sigma_{max} = \frac{M_{max} \cdot y}{I}$

6. Equations for the Neo-Hookean hyperelastic material model

From the Young's modulus, E, and Poisson's ratio, ν, the initial shear modulus (μ) and the incompressibility parameter (D_1) for the Neo-Hookean model are computed as:

Shear modulus, $\mu = G = \frac{E}{2(1+\nu)}$

Bulk modulus, $\kappa = \frac{E}{3(1-2\nu)}$

Incompressibility parameter, $D_1 = \frac{2}{\kappa}$

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