[ENG39]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

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

SEMESTER TWO EXAMINATIONS 2021-22

ADVANCED ENGINEERING MODELLING AND ANALYSIS

MODULE NO: MSE7002/MSE7006

Date: Wednesday 18th May 2022 Time: 10:00 – 13:00

INSTRUCTIONS TO CANDIDATES:

There are FIVE questions.

Answer ANY FOUR questions.

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.

QUESTION 1

a) Explain different modes of heat transfer and their practical applications

[5 Marks]

b) An aluminium rod of length $L = 200$ mm and diameter 10 mm (see **Figure Q1**) is exposed to temperatures of $T = 220$ ºC at $z = 0$ mm and $T = 20$ ºC at $z = 200$ mm. Assuming that the thermal conductivity of Aluminium is 200 W/(m.K)

i. Derive the equation for temperature distribution along the length of the bar, and then calculate the temperature at z=40 mm, 80 mm, 120 mm, and 160 mm.

[10 Marks]

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

[5 Marks]

iii. Calculate the heat flux in Z direction.

[5 Marks]

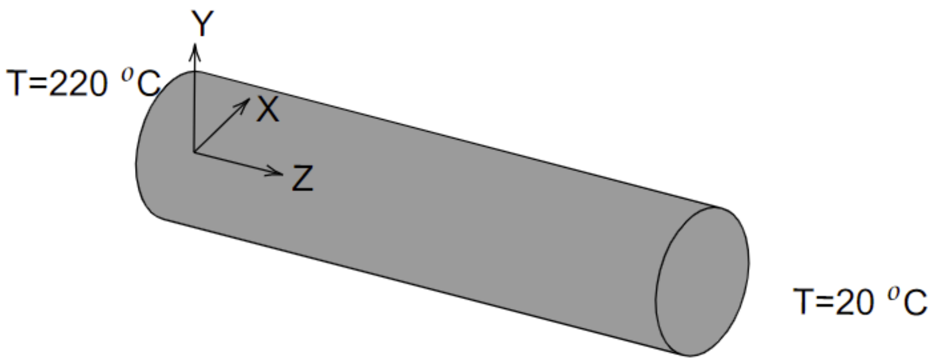

Figure Q1: Cylindrical bar with temperature boundary conditions.

Total: 25 Marks

School of Engineering
MSc Mechanical Engineering/Electrical Electronic Engineering/Biomedical Engineering/Electrical Vehicle/Digital Dental Technology
Semester Two Examinations 2021-22
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<u>QUESTION 2</u>

A thick rubber sheet with dimensions shown in **Figure Q2 is simply supported** and is subjected to a uniformly distributed load (UDL) in negative Y-direction. The material properties of the rubber are: Young's modulus, $E = 200$ MPa and Poisson's ratio, $\nu = 0.4$.
Displacement values measured at the midpoint of the beam for five different values of UDL are tabulated in **Table Q2**.

a) Compute the displacement for these UDL values using analytical expressions.
[10 Marks]

b) Calculate percentage errors in displacement obtained using analytical expressions relative to the measured values.
[5 Marks]

c) Draw the load vs displacement graphs for analytical solution and measured values on a graph paper. Annotate the graph appropriately.
[5 Marks]

d) Draw the UDL vs error graph and find an approximate value of UDL beyond which the error in displacement is above 10%.
[5 Marks]

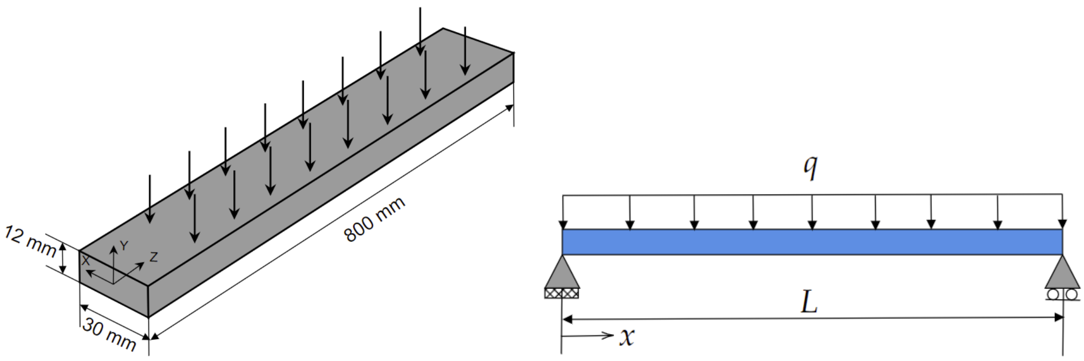

Figure Q2: Dimensions of the beam. The beam is simply supported.

UDL (N/m)	Displacement (mm)
5	30.93
10	61.01
20	114.61
30	156.81
40	188.63

Table Q2: Measured values of displacement for different UDL values.

Total: 25 Marks

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QUESTION 3

A soft tissue specimen with dimensions shown in **Figure Q3** is subjected to a uniformly distributed load (UDL) in negative Y-direction. The specimen is fixed on one end; that is, it is a cantilever beam. The material properties of the soft tissue are: Young's modulus, $E = 2.5$ MPa and Poisson's ratio, $\nu = 0.4$.
Displacement value measured at the free end of the beam for six different values of UDL are tabulated in **Table Q3**.

a) Compute the displacement for these UDL values using analytical expressions.
[10 Marks]

b) Calculate percentage errors in displacement obtained using analytical expressions relative to the measured values.
[5 Marks]

c) Draw the load vs displacement graphs for analytical solution and measured values on a graph paper. Annotate the graph appropriately.
[5 Marks]

d) Draw the UDL vs error graph and find an approximate value of UDL beyond which the error in displacement is above 10%.
[5 Marks]

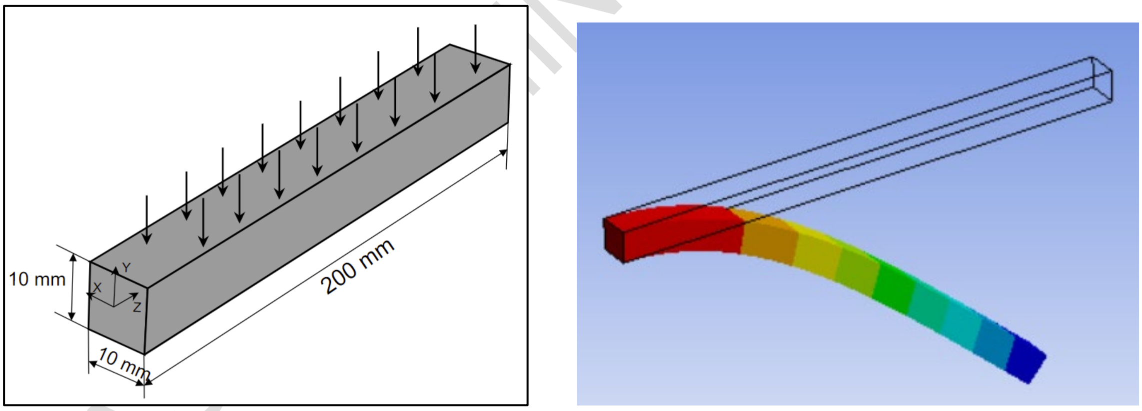

Figure Q3: (Left) Dimensions of the beam and (Right) Deformed shape of the beam.

UDL (N/m)	Displacement (mm)
0.2	19.12
0.4	37.82
0.8	72.54
1.2	97.41
1.6	116.81

Table Q3: Displacement values measured for different UDL values.

Total: 25 Marks

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QUESTION 4

You are assigned with the task of choosing a material for a cantilever beam to be used a sensor for applications in biosensing. The beam is of length L, width b, and thickness h, and is subjected to a uniformly distributed loading (UDL) , as shown in **Figure Q4**. The beam is of fixed-length L and fixed-width b. The beam needs to be lightweight, and it should be stiff enough to withstand the loads.

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

[13 Marks]

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

[5 Marks]

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

[7 Marks]

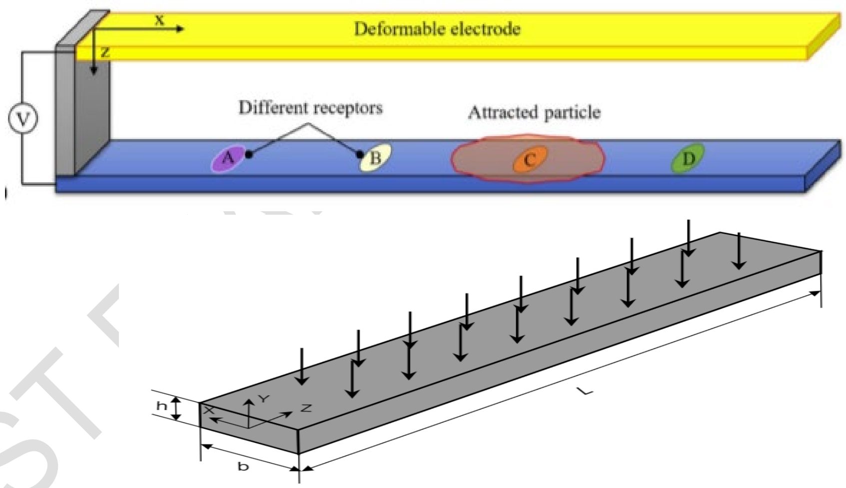

Figure Q4: (Top) Biosensor setup and (Bottom) Beam model.

Material	Density (kg/m^3)	Young's modulus (GPa)	Strength (MPa)
Aluminium	2700	69	90
Steel alloy	8000	200	380
Aluminium 7475 alloy	2600	75	530
Cupronickel	8950	150	350
Bronze	8900	100	240

Table Q4: Properties of materials for the beam model.

Total: 25 Marks

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QUESTION 5

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 Q5**. 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.

[13 Marks]

b) Based on the material performance index derived in 5a, discuss how the performance could be improved with respect to material properties.

[5 Marks]

c) Based on the material performance index derived in 5a, choose the best material from the list of materials provided in **Table Q5**.

[7 Marks]

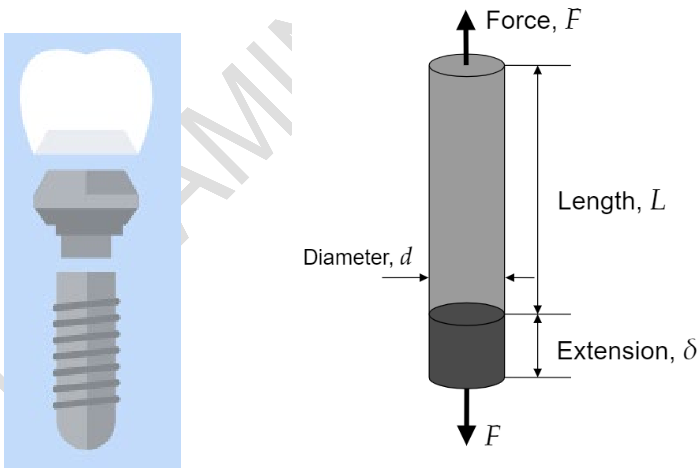

Figure Q5: (Left) Dental implant and (Right) Simplified model as cylindrical rod.

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 Q5: Properties of materials for the dental implant.

[Total: 25 Marks]

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FORMULAE SHEET

1. Heat transfer

Assumption is that the bar is oriented such that its axis is along the Z-axis.

The analytical solution for temperature distribution is given by,

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

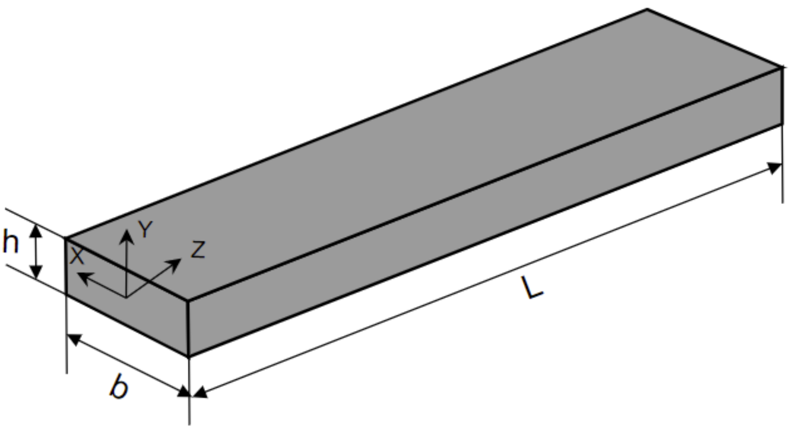
where, T_1 and T_2 are the temperatures at the left end ($z = 0$) and right end ($z = L$) of the bar.

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, $\mathrm{I} = \frac{b\,h^3}{12}$

Section modulus, $Z = \frac{b\,h^2}{6}$

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3. Equations for the simply supported beam

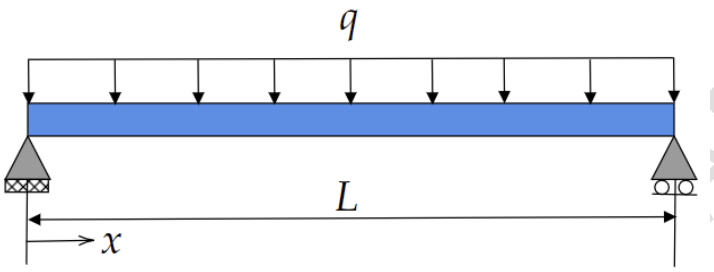

Figure: Simply-supported beam configuration.

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

Stress at $x = L/2$, $\sigma = \frac{q\,L^2}{8\,Z}$

4. Equations for the clamped-clamped beam

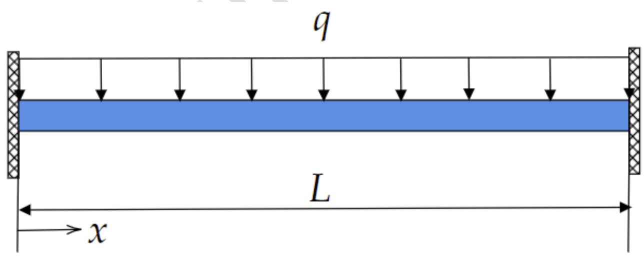

Figure: Clamped-clamped beam configuration.

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

Stress at $x = L/2$, $\sigma = \frac{q\,L^2}{24\,Z}$

5. Equations for the cantilever beam

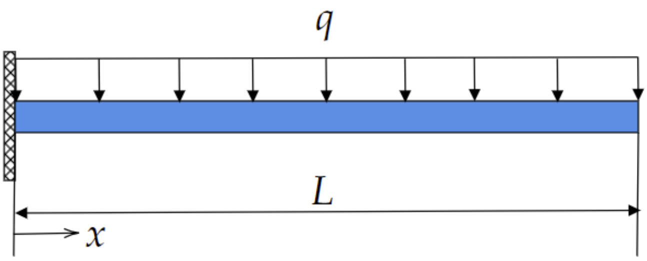

Figure: Cantilever beam configuration.

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

Stress at $x = 0$, $\sigma = \frac{q\,L^2}{2\,Z}$

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