ENGG103 MATERIALS IN DESIGN LABORATORY

EXPERIMENT 1: 3-Point Bending test

Objectives

1. Determine the Young's modulus of Steel, Brass and Aluminum using 3-point bending test.
2. Determine the effect of different dimensions on the Force-Deflection to confirm the theoretical equations.

Background

Elastic Modulus

The degree to which a structure deforms or strains depends on the magnitude of the imposed stress. For many materials that are stressed in tension and at relatively low levels, stress and strain are proportional to each other through the relationship (Hooke's Law):

$$\sigma = E\,\varepsilon \qquad (1)$$

where σ is the applied stress (force/area) and the unit for stress is Pa or N/m^2, ε is the strain and it is dimensionless and E is a constant of proportionality, called the Young's modulus or modulus of elasticity and it has the same unit as the stress.

Deformation in which stress and strain are proportional is called elastic deformation: a plot of stress (ordinate) as a function of strain (abscissa) results in a linear relationship. The slope of this linear segment corresponds to the modulus of elasticity, E. This modulus may be thought of as material stiffness, or the resistance of a material to elastic deformation. The modulus is an important design parameter used for determining elastic deflections in engineering components. There are five main factors that affect how much a beam will deflect:

- The material the beam is made from
- The load, the type, and where it is placed
- The beam's cross section and dimensions
- The type of support and its fixing conditions,
- The span or length of the beam.

These factors combine together to form the general beam equation:

$$\delta = \frac{FL^3}{KEI} \quad \text{or} \quad E = \frac{FL^3}{\delta KI}$$

where δ is the elastic deflection and has the unit of m (meter) , F is the load in N(Newton), L is the span of the beam in meters , K is a constant relating to the type of support and has no unit and I is the second moment of area and has the unit of m^4.

The general beam equation as stated only works for specific simple types of beam configurations.

The beam material

The material property as used in the beam equation is its stiffness, different materials have different values.
The stiffness of a material is given by its Young's modulus, with the symbol E. It is the ratio of stress to strain, or how much a material stretches elastically when a known load is applied. For most engineering materials, this ratio is constant until too much load is applied resulting in permanent (plastic) deformation.
E, the Young's modulus is material dependent. The above equation can be re-expressed with E as the subject to give:

$$E = \frac{FL^3}{\delta KI}$$

The load

Only point loads will be used in this laboratory.

The beam dimensions

Imagine that you have two beams which are identical ***except*** for their thickness. Intuition should let you predict that if you try to bend each one, that the thicker beam would bend less at equivalent loads. That is the thicker one would be more rigid (Figure 1).

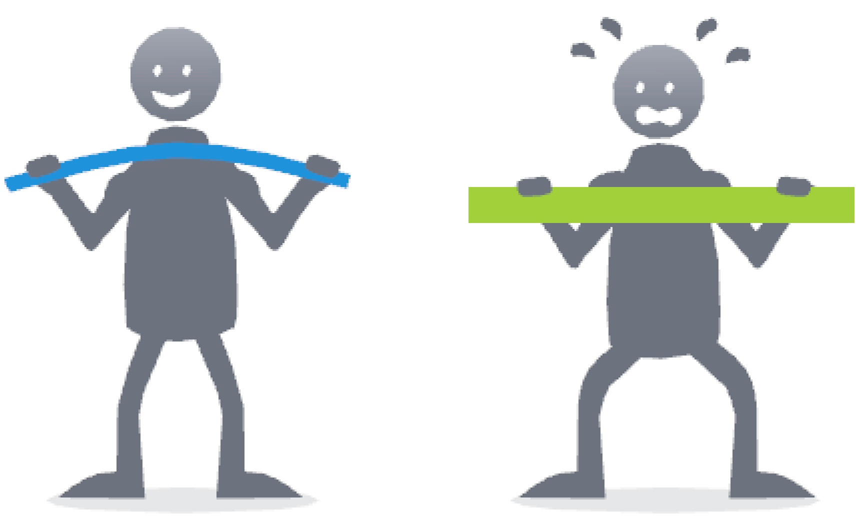


Figure 1: Beam bending.

However, it is not intuitive that this extra rigidity is not proportional to the thickness; it is in fact the cube of the thickness. Hence, a small change in thickness has a large effect on the rigidity.

This dimensional property of the beam is called the second moment of area I (Figure 2).

For a rectangular section beam, the second moment of area is:

$$I = \frac{bt^3}{12}$$

where b is the breadth and t is the thickness of the beam.

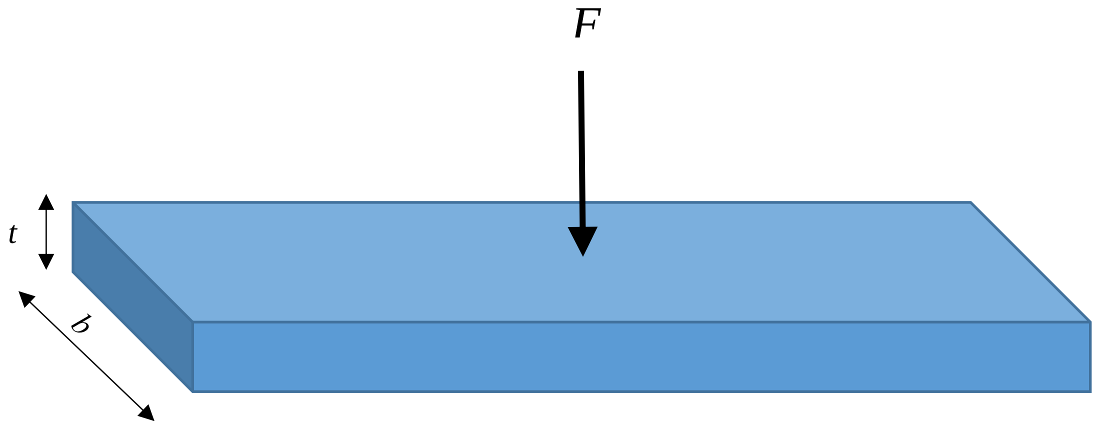
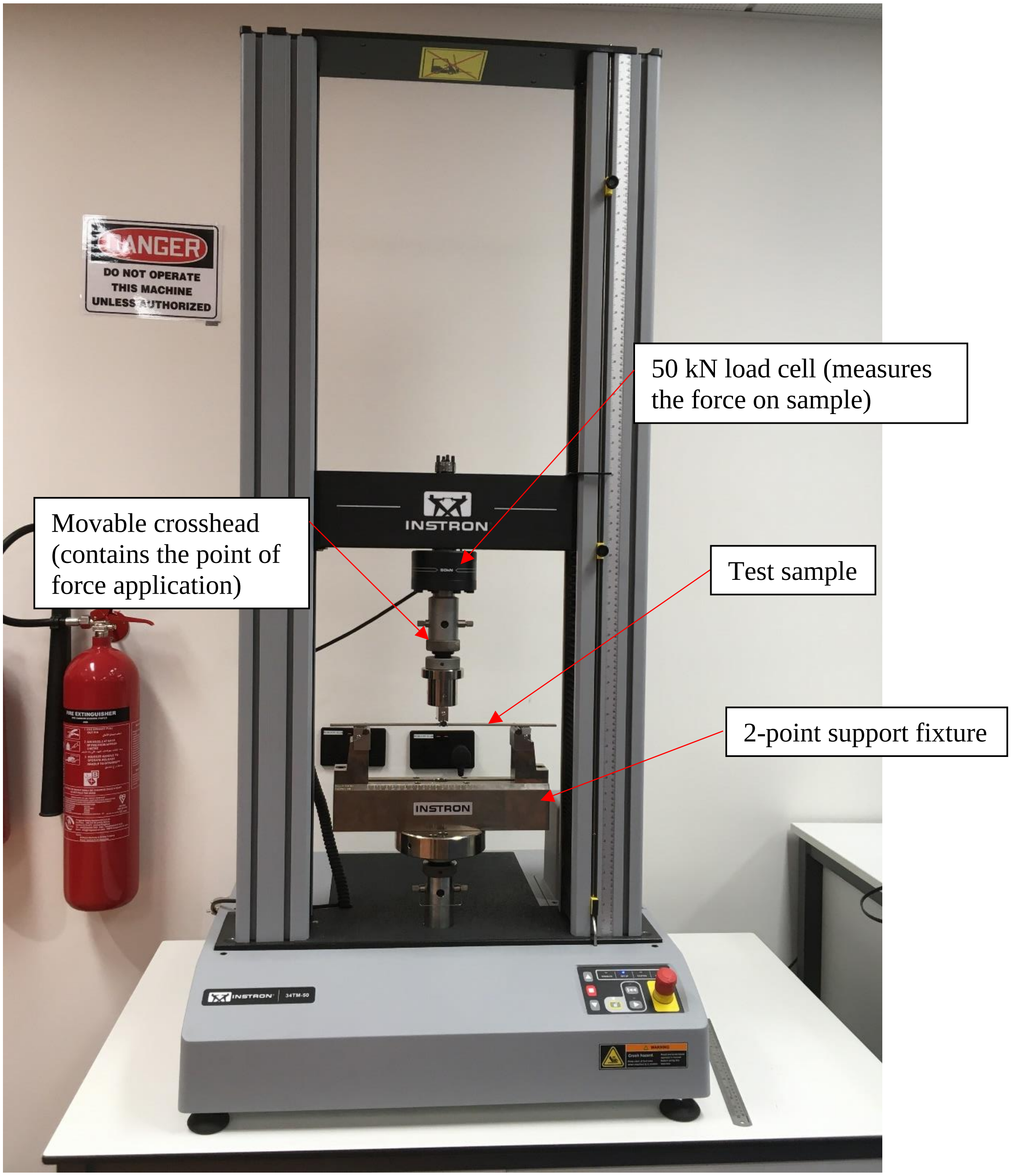


Figure 2: Second moment of area.

Apparatus:

1- Instron UTM with 50 kN load frame.



2- Test specimens

Sample number	1	2	3	4	5	6	7	8
Material	Steel	Brass	Aluminum Al	Al	Al	Al	PLA (100% infill)	PLA (50% infill)
Span length (L), mm	250	250	250	250	250	250	70	70
Thickness (t), mm	3	3	3	3	3	6	3	3
Width (b), mm	10	10	10	15	20	10	10	10

Experimental Procedure

1. You will be provided with 6 beams to test, with a target to estimate the modulus of elasticity for each of these materials.
2. The experiment is done using a Universal Testing Machine (UTM) by Instron with capacity of 50 kN.
3. For a beam, use the Verner calipers to measure the beam breadth and thickness. Calculate the value of I for the beam and note this in the results table.
4. The instructor will help you place samples on the machine and run the test. DO NOT USE THE MACHINE ON YOUR OWN.
5. Every sample will undergo a standard value of deflection (i.e. 3mm) using a rate of 2mm/min.
6. The instructor will hand you the results as an excel sheet, containing a column for Forces values in kN, and a column for the deflection values in mm. Use Excel to convert the units to N and m, respectively.
7. Use Excel to plot the Force-Deflection curves for each sample and find the slope of the curve.
8. From the theory, $E = \frac{FL^3}{\delta KI} = \frac{F}{\delta} \times \frac{L^3}{KI} = slope\ of\ chart\ (in\ SI\ units) \times \frac{L^3}{KI}$.
   For the beam geometry used here, $K = 48$.

Report requirements

1- **Cover page**
-Includes your name, ID, course title and code, name of teachers, etc.

2- **Results <u>(6 marks)</u>**
- Use the data provided in the excel sheets to:

a- Plot the Force-Deflection curves (N vs m) for each of the 6 metallic samples and the 2 3d printed samples. On each curve, you must show the slope of the graph. It is very important to include axis titles, axis units and legends (if needed). **<u>(4 marks)</u>**

b- Use the theoretical equations to estimate the modulus of elasticity for each of the 6 metallic samples only. **Show your calculations for one sample**.

Surf the internet or use the available text books to find the theoretical values of Elastic modulus for each of the materials. Tabulate your results in a table, that shows the **Beam number**, **Beam material**, **Estimated Elastic Modulus** and **Theoretical Elastic Modulus**. **<u>(2 marks)</u>**

3- **Discussion <u>(4 marks)</u>**
- You have to answer the following questions and include the questions and the answers in your report.

a- Which of the samples will you consider to have a fair comparison between the elastic moduli of the different materials? And why? Which material is stiffer? **<u>(0.5 marks)</u>**

b- Which of the samples will consider to study the effect of the beam width (b) on the Force? Why? What is the effect of the Beam width (b) on the measured force? Does your answer confirm the theoretical equations? Include the equations. **<u>(0.5 marks)</u>**

c- Which of the samples will you consider to study the effect of beam thickness (t) on the measured Force? Why? What is the effect of the Beam thickness (t) on the measured Force? Does your answer confirm the theoretical equations? Include the equations. **<u>(0.5 marks)</u>**

d- Which material that you tested would produce the lightest tie rod, that has the highest value of $\frac{E}{\rho}$? Use the following values of density and show your calculation: **<u>(0.5 marks)</u>**

Material	Density, ρ (Mg/m^3)
Stainless Steel	7.7
Aluminium	2.7
Brass	8.9

e- A mobile phone manufacturing company is looking to create a high-end mobile phone for that purpose they have hired your team, their idea is to create a phone that is Aesthetically pleasing, Mechanical rigid and Resistant to scratches (deformation), based on your understanding of materials and experimental result, which of the three material would you recommend to the company to use on their phone? **(0.5 marks)**

f- 3D printing is an evolutionary manufacturing method that allowed us to make complex geometries with minimal cost and time. 3D printing is commonly achieved through thermoplastic polymers (PLA, ABS), although metals are also possible to 3D print. In this lab, a 3D printing parameter (infill density) was introduced and tested through PLA samples. From the 3D printed samples, explain how the infill density influences the structural stiffness of the sample? What other parameters influence the stiffness as well? (Google it). **(1.5 marks)**