

STUDENT FEEDBACK FORM (CLAUS SCHILKE)

This section details the *extent* to which the assessment criteria are demonstrated by you, which in turn determines your mark. The marks available for each category of skill are shown. Lecturers will use the space provided to comment on the achievement of the task(s), including those areas in which you have performed well and areas that would benefit from development/improvement.

Generic Assessment Criteria	Marks available	Marks awarded
1. Engagement with Literature Skills		
Good engagement with a suitable range of literature, including sources retrieved independently and generally your work contained good depth and scope. References were sometimes missing.	20	13
2. Knowledge and Understanding Skills		
Good knowledge of the basic underlying concepts and principles is accurate with some good understanding of the field of study. Use of terminology was appropriate throughout although some minor issues were identified and at times some topics could have been investigated further.	30	19
3. Cognitive and Intellectual Skills		
Very good attempt at the evaluation of the underlying concepts and principles. You did interpret the data correctly, and you demonstrated an ability to use evidence to support the argument. Some areas of the evaluation were detailed,	20	13
4. Practical Application Skills		
A good and appropriate application of basic methods, materials, tools, and/or techniques. Clear appreciation of the context of the application. Good set of calculations, and reasonable values of E and G obtained. Minor issues with units and labelling identified. Beam stress included but error noted. I would have liked to have seen more on the practical application of the work covered.	15	10
5. Transferable Skills for Life and Professional Practice		
Coherent, organised and accurate work in a suitable structure. Work is generally well written but descriptive at times. Referencing was provided throughout. Summary also needed to be extended (see comment in the report). Ensure that the correct tense and party is always used). Content page was incomplete.	15	10

Assessment Mark (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)	Late Submission Penalties (tick if appropriate)	%	65
	Up to 1 week late (40% Max)		
	Over 1 week late (0%)		

HNC Mechanical Engineering

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Assignment Title:

Investigation into Elastic Constants

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↑ section numbering system needed.

Please write in third person.

Summary

Our assignment to investigate the reactions of forces on beams and cylinders take us into a subject that is too big to cover in this 2000 word report.

Through research it does touch on some basic theory of strains and stresses that materials suffer when subjected to loads, and their reactions to it. We learn that these strains and stresses form forces that deliver tensile, compressive or shear forces. These we learn have a relationship to one another as we discover four elastic constants within materials.

Our examination of the subject into elastic constants gets us into their relative mathematical equations and how we can use these constants to establish engineering design considerations.

These considerations are vital to engineering solutions being safe, efficient and of purpose.

The purpose of the lab experiment was to identify the relevant elastic constant in that instance (testing of a beam and two cylinders of differing materials) and use this to report on in conjunction with the theory researched.

The Summary need to list the aims

- (i) to determine E for Aluminium
- (ii) to determine G for Brass & 0.4% C Steel.
- (iii) to investigate the practical significance of elastic constants

Also, you needed to state your results and then the main conclusions.

Introduction

See comment in summary

The purpose of this assignment is to investigate the effects on materials in differing forms and makeup and report on findings found in the real world compared to the science theory.

In this instance this is a aluminium beam subjected to a load at its central point supported at two ends, a 0.4% carbon steel cylinder and a 70/30 brass cylinder subjected to a torque force.

The results being tabulated, graphed and reported on in comparison to relevant science theory. A discussion will report on aspects to real life considerations.

Theory – Beams and Torsional Shafts

Engineering materials are found to be related as stresses and strains they suffer when subjected to a force.

Robert Hooke in 1667 stated 'The power of any springy body is in the same proportion with the extension.' Mathematical stated as $F=ku$

(use standard convention for referencing)

Third person needed.

His statement means that if a material is subjected to a applied force (F) a deformation (u) will occur. K can be applied to a spring constant in relation to this theory.

The theory, a change in length of a stretching or compressing of an object is proportional to the force applied up to the proportional limit.

Stresses

An object which is subjected to external forces, experiences internal forces which opposes or you may say resist the external forces.

To illustrate, a bar that we may visualise as having a constant cross section but when it's ends are subjected to a stretching or compressing as per picture courtesy of W. Bolton in the book Mechanical Science p.25 is the said to be in Tension or Compression. (Bolton, 2006, p. 25)

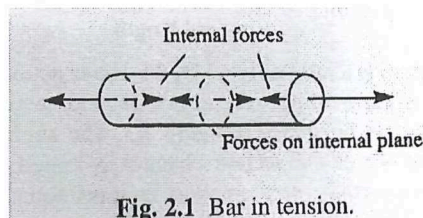


Fig. 2.1 Bar in tension.

Note the plane of the bar which is in right angles to its axis. The internal forces being in right angles to the plane. This subjects the bar to *direct stresses* for the value of the force per unit area of the plane. Mathematically we can understand this ratio as, Direct stress (σ) = Force / Area.

A unit of force (N) and area (m^2), therefore (N/m^2), or Pascal (Pa) for $1 N/m^2$.

When a body is subjected to a force, the internal forces may be in right angles to and parallel to a plane within the body. The parallel component can be understood as a shearing force and providing a *shearing stress*. Mathematically stated as, Shear stress (τ) = force / area

Figure 2.2 courtesy of W. Bolton in his book Mechanical Science provides us with a visual explanation. (Bolton, 2006, p. 26)

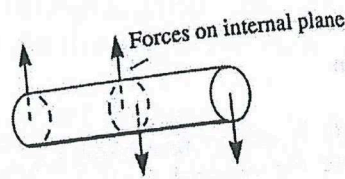


Fig. 2.2 Bar in shear.

Strains and Shears

Strain is the material's response to that stress. This strain leads to material deforming either by external forces that are Tensile, Compressive or Shear.

When the force is tensile, it would equate to be in direct tensile strain, and the object would grow in length.

If the force is compressive, it would equate to be in direct compressive strain, and the object would decrease in length. Mathematically stated as Direct Strain (ϵ) = change in length / original length.

Strain is the ratio between the change in length and its original length, therefore no units.

Shear forces would change an object shape of rectangular shape when suffering a shear strain into a shape similar to a parallelogram. The change in in angle from the right angle originally is the shear strain. Let's visualise as per W. Boltons example, Figure 2.3 in his book Mechanical Science. (Bolton, 2006, p. 26)

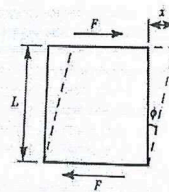
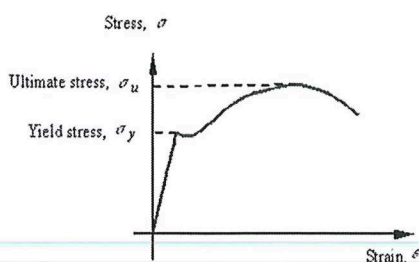


Fig. 2.3 Shear strain.

Mathematically stated, Shear strain = Φ , Φ being x/L . Usually, this would be a very small change, and uses the unit radian.

When an Isotropic material (glass, plastics, and metals are materials whose properties remain the same when tested in different directions) is subjected to a force, it reacts by the way of deforming. It's behaviour displays that strain is proportional to the stress.

Notice the graph to simulate relationship. (Negahban, 1996-2004)



This relationship is what Hooke's law tries to describe. Seeing that the ratio of stress versus strain is a constant, it is also called modulus of Elasticity or Young's modulus.

When an object returns to its original figure after being subjected to a force, this is called the elastic limit. The plastic area is after this point where the object will not return to its original state and stays in a bent state.

The object will snap in two if further forces were applied. The maximum tensile strength is the force an object can withstand without breaking in two.

Elastic Constants

1) Young's Modulus

According to encyclopaedia Britannica Young's modulus 'is a measure of the ability of a material to withstand changes in length when under lengthwise tension or compression.' (Britannica, 2024)

Also known as the modulus of elasticity (E), and constitutes to the measure of rigidity or stiffness of a material.

Young's modulus is the ratio of applied stress to the strain. This will be a constant and known as Young's modulus.

According to Hooke's law where a body subjected to a tensile stress or compressive stress, the stress applied is directly proportionate to the strain within the elastic limits of that object, mathematically equated to,

$$E (\text{Young's Modulus}) = \text{Stress} / \text{Strain}$$

2) Bulk Modulus

The constant in this instance being related to a object that's subjected to a ratio of direct stress versus a volumetric strain, mathematically equated to,

$$\text{Bulk Modulus (K)} = \text{Direct Stress} / \text{Volumetric Strain}$$

Reference needed

3) Rigidity Modulus

When an object is subjected to a shear stress the shape of the object is inadvertently changed. This ratio of change corresponding to the shear stress is called the modulus of rigidity, mathematically equated to, Rigidity modulus (G) = Shear stress / Shear strain

In our lab tests this is measured in the unit of N.

Modulus of rigidity is also known as shear modulus and rigidity modulus values of materials are determined by torsional (twisting) tests.

Reference needed

4) Poisson's Ratio

When an object is subjected to tensile stresses within elastic limits a change in dimension of the object results. This is in the direction of the force and in the opposite direction. We may use the example of a rubber band which when pulled becomes longer but also thinner.

These changed dimensions are divided with their original, a longitudinal strain and lateral strain are the result.

Mathematically this can be equated to

$$\text{Poisson's Ratio} = \text{Lateral Strain} / \text{Longitudinal Strain}$$

It has no measure of units but has a maximum ratio for an incompressible material is a value of 0.5. For most materials the ratio is between 0.25 and 0.33.

The relationships between each modulus can also be mathematically stated.

Young's Modulus and Rigidity Modulus

$$G/E = [m^2(1+m)] \quad GE = [m^2(1+m)]$$

Good, but reference needed.

Young's Modulus and Bulk Modulus

$$K/E = [1/3(1-2\mu)]$$

Young's, Bulk, and Rigidity Modulus

$$E = 9KG/G + 3K$$

It would have been good to see theoretical values for the materials tested. (E for aluminium & G for Brass and steel).

Poisson's Ratio, Bulk, and Rigidity Modulus

$$\mu = (3K - 2G)/(6K + 2G)$$

Theory to beams

Standard Convention needed.

W. Bolton in his book Mechanical Science states that 'A beam can be defined as a structural member that is designed to resist a load applied transversely at various points along it, subjecting it to bending. When these beams bend they deform to curve with the result that one surface becomes shorter than the other side.' (Bolton, 2006, p. 43)

There are different beams described as a cantilever, a simply supported beam, an overhanging beam, a built-in beam.

The loads that are supported by the beams are described as *concentrated loads* (applied at one point) or *distributed loads* (applied across a length)

When a force is applied to a beam internal forces are opposing, hence resulting in direct and shearing stresses.

To determine stresses, the internal forces and direct loading forces that act on this cross section of the beam needs to be determined.

"Shearing forces are internal forces developed in the material of a beam to balance externally applied forces in order to secure equilibrium of all parts of the beam.

Bending moments are internal moments developed in the material of a beam to balance the tendency for external forces to cause rotation of any part of the beam." (Mott, 2008, p. 258)

A *bending moment* is a measure of the bending effect due to forces acting upon a beam. It's the moment due to internal forces introduced by an external force that introduces rotational movement in a beam causing it to bend.

Mathematically, the bending moment at a certain point along a beam is calculated from the force and the distance from the point to the point the force acts upon. It's expressed as $M = F \times d$

Calculating bending moments helps in designing structures that withstand applied forces, in a safe and efficient manner through weight distribution.

A bending moment is to be considered positive when the moment on the left of the section is clockwise and that on the right is anticlockwise, producing a sagging of the beam.

A bending moment is to be considered negative when the moment on the left of the section is anticlockwise and that on the right is clockwise, producing a hogging of the beam.

I can see why you included this section but you used a lot of words for little return I think.

The *shearing force* of a beam is where the tendency for a portion of the beam to slide or shear side to side to the other portion. Consider Figure 3.1 as cited by W. Bolton in his book Mechanical Science for a cantilever beam. (Bolton, 2006, p. 44)

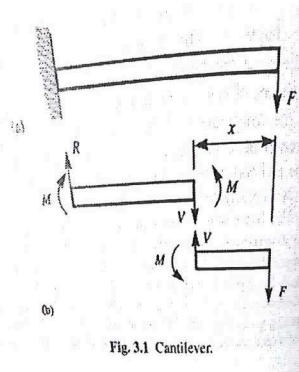


Fig. 3.1 Cantilever.

Torsion on Shafts

The twisting of a shaft along its longitudinal axis, is called *torsion* as it's the result of a torque applied.

With a circular shaft this is called pure torsion as the cross section of the shaft keeps its shape. Therefore when a torque is applied to one end of the shaft this is transmitted through the shaft and results in a twisting of the shaft.

If we were to imagine this twisting action around the longitudinal axis of the shaft the surface will twist by a small angle.

Therefore, we notice there is a resulting shear strain experienced on the surface of the shaft as is pictured

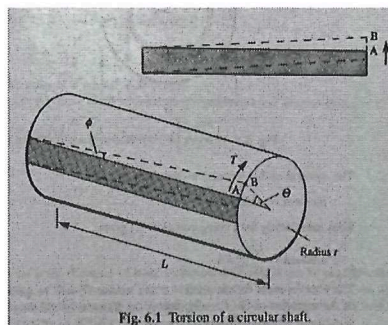


Fig. 6.1 Torsion of a circular shaft.

This provides us with the mathematical equations of shear strain $(\Phi) = r\theta/L$.

As modulus of rigidity is $G = \text{shear stress} / \text{shear strain } \Phi$ we can conclude that shear stress $(\tau) = G\Phi = G / r\theta/L$

The purpose of the Lab exercise is to test materials in the form of a Aluminium beam and two cylinders made from 70/30 Brass cylinder as well as 0.4% carbon steel, to identify / calculate the appropriate modulus, and test the affects upon them.

From our theory section we can identify that the beam test will provide us relevant information to calculate the Young's Modulus, and the cylinder test provide us with data to calculate its rigidity modulus when applied to a torque force.

Poisson's ratio is also applicable in these lab tests, however this was not measured nor calculated. From our discussed theory we could calculate this but not measure due to the very small deformations we would have to measure.

Method - Test 1, Beam Test

A beam of aluminium in a beam testing jig was used for our test. It's length between two supports being 800mm, 32mm wide by 5mm thick. A dial gauge set to zero in it's static state without weights attached. The dial gauge was in the centre position of the beams length. Once setup seven differing weights were added to the beam and deflection readings via the dial gauge were taken and recorded.

The inserted photograph helps us visualise the setup (pic 1)



Results – Test 1

Weights provided were in lbs. Therefore, for the exercise of plotting and converting the load into (N) the following calculations were completed.

To convert lbs into kg, we were had to multiply the load (lbs) by 0.454. This was entered into the tabulated data.

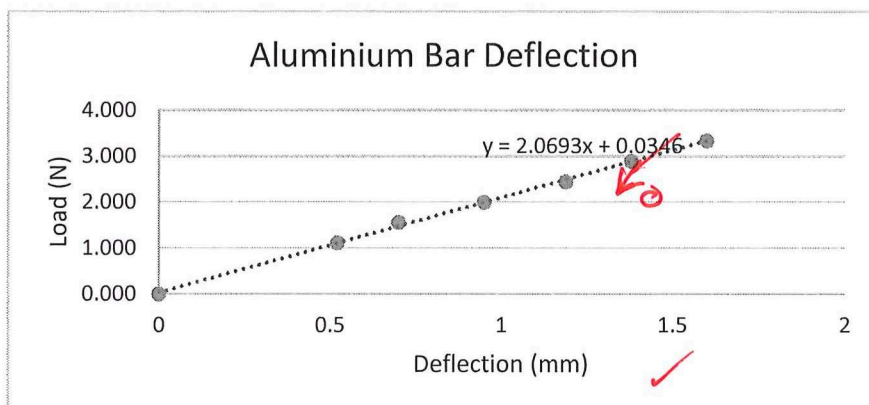
This made it easier to calculate the Load into N as this is required to provide us with concluding calculations completing in Nm. Therefore, the Load (kg) was multiplied by 9.81 (gravity) to provide a measurement in (N)

Table 1

Load (Lbs)	Load (Kg)	Load (N)	Deflection (mm)
0	0.000	0.000	0
0.25	0.114	1.113	0.52
0.35	0.159	1.559	0.7
0.45	0.204	2.004	0.95
0.55	0.250	2.450	1.19
0.65	0.295	2.895	1.38
0.75	0.341	3.340	1.6

This tabulated information was used to create a graph load (W) versus deflection (mm) and obtain the resultant gradient. (Figure 1)

Figure 1



This graph and its resultant gradient is helpful in calculating it's Young's modulus.

The formula to calculate the maximum deflection in a simply supported beam with a load at it's centre is given as

$$\text{Deflection} = WL^3 / 48 EI$$

where

W= the point load (N),

L= Distance between supports (m)

I= second moment of area also calculated by $(bd^3/12 \text{ (m}^4\text{)})$

E= Young's Modulus.

This formula needs to be transposed to find the missing details.

We need to find I before being able to calculate E, therefore $I = bd^3/12 = 32 \times 5^3/12 = 4000/12 = 333.3 \text{ mm}^4$

Having found a figure for I it is now possible to use the following transposed formula to find the Young's Modulus, $E = L^3/48I \times \text{slope of graph}$.

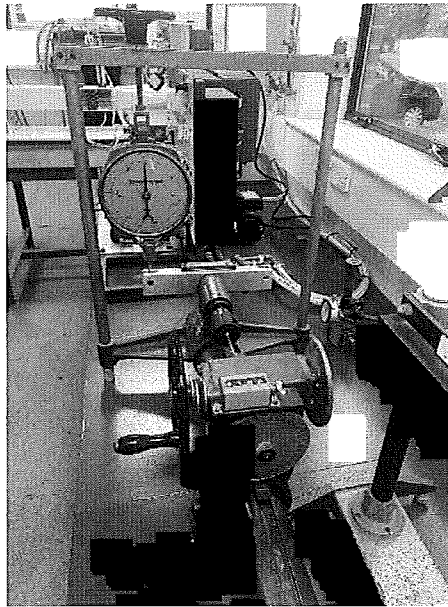
Inputting the data provides us with $E = 800^3/48 \times 333 \times 2.1 \text{ (2.098 rounded)} = 67.27 \text{ GN/m}^2$

Method – Test 2, Torsion Tests

Test 2 helped us to look at effects upon a cylindrical rod of two differing materials. A torsion test rig was used to load the cylinder via a worm and wheel drive applying a specific level of torque via a torque arm and spring balance. A protractor provided us with angle of twist. The results were

recorded.

The setup of the rig was photographed to provide us with a visual example. (Pic 2)



The cylinder was 90mm in length and 5mm in diameter.

Results – Test 2, 0.4% Carbon Steel

The data was tabulated for later evaluation. (Table 2 & Table 3)

Twist was first recorded in degrees and then converted to twist in rads by dividing degrees by 360 and then multiplying by 6.28.

The first material used to investigate the effects of torsion on a cylinder was completed on 0.4% carbon steel (Table 2)

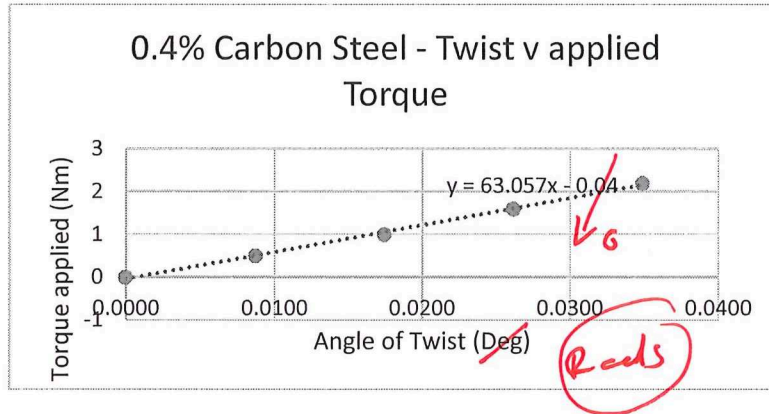
Table 2

0.4% Carbon Steel

Torque applied (Nm)	Angle of Twist in deg	Twist (Rads)
0	0	0.0000
0.5	0.5	0.0087
1	1	0.0174
1.6	1.5	0.0262
2.2	2	0.0349

This tabulated information was used to create a Torque applied (Nm) versus angle of twist in degrees graph to obtain the resultant gradient. (Figure 2)

Figure 2



The graph and it's resultant gradient is able to help us with calculations of Modulus of rigidity.

From the formula $T/J = \tau/r = G\theta/L$ we can derive $G = (L/J) \times (T/\theta)$

Identifying the letters as the following,

G = modulus of rigidity

T = torque (Nm)

θ = twist of angle (rads)

L = Length (m)

J = polar second moment of area (m^4)

We need to find G by using $L/J \times T/\theta$ or $L/J \times \text{slope of graph}$ as per Fig.2.

We don't have a figure for J so calculate this first.

$$J = \frac{\pi d^4}{32} = \frac{\pi (0.0005)^4}{32} = 6.13 \times 10^{-11}$$

G can now be calculated by using $G = L/J \times \text{slope of gradient}$

$$\text{In this instance } G = 0.09 / 6.13 \times 10^{-11} \times 61.529 = 90.3 \times 10^9 \text{ or } 90.3 \text{ GN/m}^2$$

Results – Test 2, 70/30 Brass

The second and last material to be used for the investigation to the effects of torsion on a cylinder is 70/30 Brass.

The tabulated data was populated and entered into Table 3

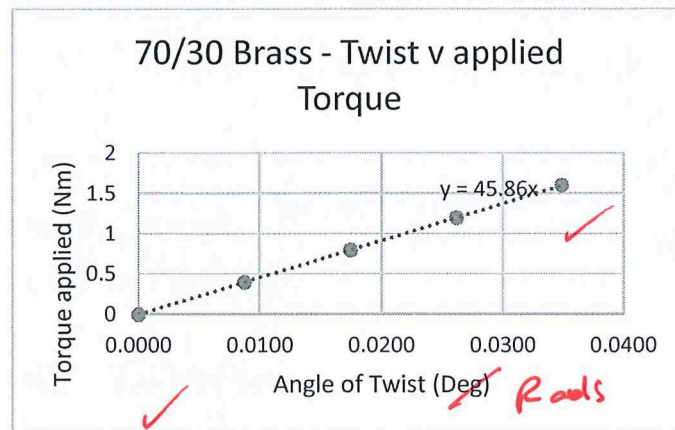
Table 3

70/30 Brass

Torque applied (Nm)	Angle of Twist in deg	Twist (Rads)
0	0	0.0000
0.4	0.5	0.0087
0.8	1	0.0174
1.2	1.5	0.0262
1.6	2	0.0349

This tabulated information was used to create a Torque applied (Nm) versus angle of twist in

degrees graph to obtain the resultant gradient. (Figure 3)



From the formula $T/J = \tau/r = G\theta/L$ we can derive $G = (L/J) \times (T/\theta)$

Identifying the letters as the following,

G = modulus of rigidity

T = torque (Nm)

θ = twist of angle (rads)

L = Length (m)

J = polar second moment of area (m^4)

We need to find G by using $L/J \times T/\theta$ or $L/J \times \text{slope of graph}$ as per Fig.3.

We don't have a figure for J so calculate this first.

$$J = \frac{\pi d^4}{32} = \frac{\pi (0.0005)^4}{32} = 6.13 \times 10^{-11} \quad m^4$$

G can now be calculated by using $G = L/J \times \text{slope of gradient}$

$$\text{In this instance } G = 0.09 / 6.13 \times 10^{-11} \times 45.86 = 67.33 \times 10^9 \text{ or } 67.33 \text{ GN/m}^2$$

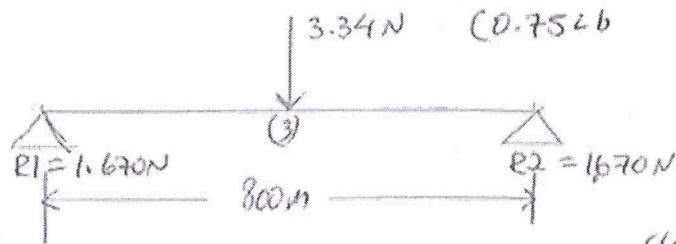
Discussion

Having compared our calculations for materials used and in their relevant tests as to Young's modulus and rigidity modulus, we can determine that there are differences to these figures compared to those obtainable via reference charts. This could be due to the fact our weights in the lab weren't calibrated at the time. We also used gravity to be that of 9.81, however depending on our position on earth this could vary by up to 0.7%. One other factor to be considered is that we don't know the purity of the materials we used nor how they were formed. Rolled materials or hardened materials would certainly provide us with differing results again. ✓

To these facts we have to work with our findings but are able to see a correlation between different materials used. For instance the steel cylinder used resulted in a higher rigidity modulus. This went hand in hand with the lesser angle of twist obtained per force increase.

Although we only used one material for the beam a shear force and bending moment diagram is able to help us understand the deformation we were able to witness. Using the highest weight as our example I was able to produce a diagram which aided the visualization of forces to beam theory encountered.

DETERMINING THE SHEAR FORCE + BENDING MOMENT FOR OUR ALUMINIUM BEAM, USING MAX WEIGHT AS EXAMPLE.



TAKING MOMENTS ABOUT R1
CLOCKWISE MOMENTS = ANTICLOCKWISE MOMENTS.

$$\text{MOMENT (NM)} = \text{FORCE (N)} \times \text{DISTANCE (M)}$$

$$(3340 \text{ N} \times 0.4 \text{ m}) = (R_2 \times 0.8 \text{ m})$$

$$1336 \text{ NM} = R_2 \times 0.8$$

$$\frac{1336 \text{ NM}}{0.8} = R_2$$

$$1670 \text{ N} = R_2$$

$$R_1 + R_2 = 3.34 \text{ N}$$

$$R_1 = 3.34 \text{ N} - 1.67 \text{ N} = 1.67 \text{ N}$$

$$\text{MAX SF} = 1.67 \text{ N}$$

SF SIGN CONVENTION

↑ F +ve
↓ F -ve

BENDING MOMENT @ R1 = 0

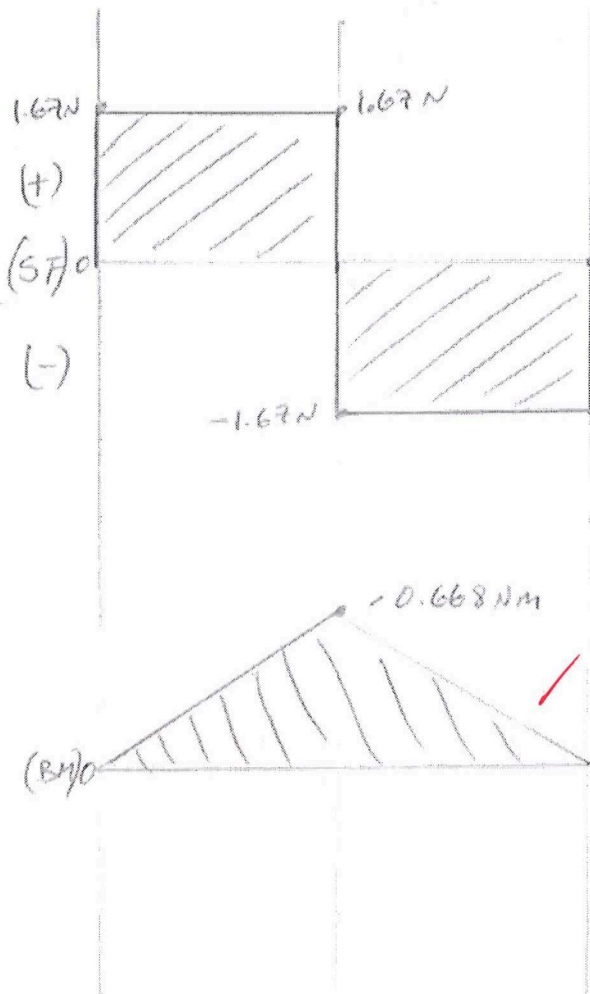
BENDING MOMENT @ R2 = 0

$$\text{BENDING MOMENT @ R3} = 1.67 \text{ N} \times 0.4 \text{ m} = 0.668 \text{ NM}$$

BM SIGN CONVENTION

↺ CW +ve
↻ ACW -ve

or not calculated.



The maximum stress is located in the middle of the beam at the point the force is located.

Considering the theory of beams, stress could be lowered by changing its size, shape or material.

Reference needed.

The topic on *flexural rigidity* will aid in supporting this fact. Flexural rigidity, is often symbolized by the term EI . It is a material property that evaluate a beam's resistance to bending deformation. It's fundamental in structural analysis, as it directly influences how a beam deflects under load.

The two key factors E and I being the following:

1. Young's Modulus (E): This as previously mentioned is the material property representing the stiffness of a material. It's the resistance of a material when subjected to a tensile or compressive force to deform. The higher the Young's modulus of a material the less likely to deform as it represented a stiffer material. For example, steel has a significantly higher Young's modulus than Aluminium, making it much stiffer
2. Moment of Inertia (I): This is the size and shape of a material that resists bending. It corresponds to a measure of cross sectional area in comparison to it's neutral axis. The further away from the neutral axis, resulting in a greater moment of inertia makes the beams resistance to bending stronger.

Flexural rigidity can be mathematically formulated as, $MR = EI$

Where: EI = flexural rigidity, E = Young's modulus of the material, I = moment of inertia of the beam's cross-section, R = the radius of the curvature of the beam, M = bending moment

Flexural rigidity helps to select the correct beam for a desired purpose. A beam with higher flexural rigidity will be able to resist bending more than a beam with a lower flexural rigidity.

It's understanding helps us evaluate our aluminium beam scenario, that by changing either the material to one with a higher Young's modulus such as steel or changing the moment of inertia (I) we could create a beam with a higher flexural rigidity and therefore a beam with less likelihood to bend while being subjected to the same forces. Quite simply by changing its size and therefore being further from the neutral axis along the longitudinal axis help a beam from bending. ✓ Good.

Consider some engineering applications to considering the relationship of flexural rigidity.

Structural Design: Engineers use flexural rigidity calculations to determine the appropriate size and shape of beams for different structures. For example: Imagine two beams of same dimensions, one made of wood and the other of steel. The steel beam will have a much higher flexural rigidity due to its higher Young's modulus resulting in less deflection under the same load. ✓

Also consider, two beams with the same material (e.g. steel) but different cross-sectional shapes. One has a rectangular cross-section, and the other has an I-beam shape. The I-beam will have a higher moment of inertia due to its more efficient distribution of material further away from the neutral axis. Consequently, the I-beam will have a higher flexural rigidity and will deflect less than the rectangular beam under the same load. ✓

The relationship between Young's (E) and Rigidity (G) modulus are also real. Consider Aircraft Design: Aircraft wings are designed with specific flexural rigidity to optimize their aerodynamic performance and structural integrity. The wings must be stiff enough to maintain their shape under aerodynamic forces but also flexible enough to absorb shock loads during turbulence.

We could consider metals such as cast iron as brittle or mild steel as ductile. During the design stage these constants need to be considered. How? By using a factor of safety. Why is this important? Quite simply by keeping designs with safety limits also keeps us as users of the materials safe. For instance we wouldn't want a plane to fall out of the sky for parts to not be designed with this factor considered and used. ✓

As to our second test that involved the rigidity modulus by using two differing materials for comparison we found that the differing modulus of rigidity certainly affected the outcome for the same forces.

This same scenario is helpful when an engineer comes to examine which materials he may use. Take the example of a motorsports vehicle. Weight limits are in place to keep the sport competitive

as well as power outputs of engines. Depending on the car design and engine power output the engineer could be faced with making a decision on which materials to use for a driveshaft or a gearbox. Depending on how much weight he might need to reduce the car by or change the cars behaviour due to location of the centre of gravity will only allow him to use certain materials when designing a driveshaft or gearbox but yet be able to stay reliable and competitive in the teams' field of racing.

The relationship between Young's (E) & Rigidity (G) modulus are also real. Consider Aircraft Design: Aircraft wings are designed with specific flexural rigidity to optimize their aerodynamic performance and structural integrity. The wings must be stiff enough to maintain their shape under aerodynamic forces but also flexible enough to absorb shock loads during turbulence.

Conclusion

Good Consideration of E & G

Our lab tests worked hand in hand with theory of beams and cylinders. The theory was examined and explained to describe design considerations in the real world. The subject of beam and cylinder theory along with differing elastic constants is large. This assignment has only touched on some parts but helped to understand the seriousness of engineering material characteristics and the relevant considerations when working with these.

Its understanding quite simply aids engineers to ensure that structures can withstand the intended loads and perform as expected safely.

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