STRENGTH OF MATERIALS LABORATORY

1. TESTING OF MATERIALS IN TORSION

OBJECTIVE

To apply an increasing torque to straight cylindrical specimens of material, to observe the deformation of the specimens, and thus in particular to derive values for the modulus of rigidity and the shear stress at yield of the materials.

INTRODUCTION

If a straight cylindrical bar is subjected to a torque T, it can be argued on the basis of symmetry that cross-sections remain plane and rotate relative to each other. Further, that for a particular torque T, the shear stress at any point will be proportional to its distance from the axis of the specimen provided that behaviors is elastic.

This result is normally summarized as $\frac{T}{J} = \frac{I}{r} = \frac{G\theta}{L}$

Where	T	=	Applied Torque
	J	=	Polar second moment of area of cross section
	R	=	Shear stress at radius r from the axis
	L	=	Length of bar considered
	θ	=	Twist in radians of the bar of length L
	G	=	Modulus of Rigidity

This result shows that if the applied torque T is plotted against the twist per unit length of the bar, then the Modulus of rigidity can be derived from the gradient of the graph.

When this graph starts to depart from a straight line, it may be assumed that the shear stress at the outer radius of the bar is just causing plastic deformation at the outer surface. Use of the thus permits an estimate of the shear yield stress of the material.

As the torque is increased beyond this stage some of the material in plastic and some elastic and thus interpretation of the torque versus twist per unit length graph in terms of material properties would be complex. Intact the only easily derived property is a relative indication of ductility of materials by the deformation which they can sustain before fracture.

This being the case on might question the value of torsion testing as against tension on compression testing, in which all the material within the gauge length may be assumed to be subjected to uniform stress and strain. This undoubtedly is the reason why torsion testing is not so widely used, but there are arguments on its favors for specific circumstances.

(a) The material is to be used in torsion, it is more reliable to use properties derived from torsion test.

(b) Fundamentally it is the shear stress developed in a material that causes yielding whatever the type of loading. A test that applies shear stress directly therefore has a theoretical attraction although this virtue is tempered by the no uniformity of stress-referred to above. This disadvantage can be overcome to a large extent by using thin tubular specimens, but then the specimens are expensive to make and difficult to grip. Thus provided that one is prepared take the trouble. Torsion testing also has application in specialized theoretical studies.

APPARATUS

The T equipment Torsion machine can measure torques up to 30 Nm and is graduated in units of 10^{-2} Nm. Angular rotation is applied to one end of the specimen by means of a reduction gear, protractors being provided to measure this rotation and torque developed in the specimen is balanced and measured at the other end of the specimen.

This measurement of angular rotation is not accurate enough t examine the elastic behavior of the specimen because we do not know the length of the specimens to which it applies. Consequently as separate torsiometer is used during the elastic range to measure the twist of the specimen over a know gauge length (50mm)

PROCEDURE

1) The first step is to determine the measurements of twist that should be applied to the specimen, so that about 10 readings are obtained before the outer fibers reach the elastic limit.
2) The twist that will reduce this condition may be roughly estimated in the following way: The shear strain at any point in the specimen is given by $\frac{r\theta}{L}$ and the strain at the outer fibers is given by substituting the outer radius of the specimen. Now it is known that for most metals the maximum elastic shear strain is of the order 0.003, and thus estimating the length of the specimen (L) the twist θ, which will produce initial yield, may be obtained approximately.
3) Measure the specimen, make the estimate and choose your increment of twist. Attach the torsion meter to the specimen set in the machine and apply a small twist and torque to the specimen. Set the zeros for twist measurement on the torsion meter and at the machine head.
4) Apply increment of twist and measure torque applied at each increment as well as twist from the torsion meter and rotation of machine head. Never reverse the direction of twisting.
5) When the limit of proportionality has been exceeded remove the torsion meter to avoid damage to it during later stages of the experiment. Continue with experiment using rotation of the machine head as the measure of twist. Increments of twist can be increased during the later stages f the test. Rotation of the machine head can be interpreted as twist for the gauge length from a comparison of reading in the elastic region under point (3)

GRAPHS AND COMPUTATION

1. Plot graph of T against O, one with a large scale for the elastic range and one with a small scale for) to cover the whole experiment.
2. Derive the Module of Rigidity and the shear stress at yield for each material tested.
3. Estimate the accuracy which the Modulus of Rigidity has been determined.

APPARATUS USED: = **TORSIOMETER**
MATERIAL: ………..………… DIAMETER:……………………..……. GAUGE LENGTH: = **50mm**

ANGLE TURNED BY HEAD (degs)	**TORSIOMETER READINGS (rads x10^{-3}**	**TORQUE (Nm)**	**ANGLE TURNED BY HEAD (degs)**	**TORQUE (Nm)**

MODULUS OF RIGIDITY (G): =
MAX. SHEAR STRESS: =
SHEAR STRESS AT YIELD: =

2. BEAM DEFLECTION

OBJECT:
To study the deflection of a beam for varying loads, varying spans, varying cross-section and to demonstrate the reciprocal theorems.

APPARATUS:
Bed, hardened steel knife-edges, supports load shackles with knife-edge, dial indicator on arm weights steel and wooden beams.

METHOD:

1. Measure the width (b) depth (d) of each beam (fig 2. table 2)
2. Mark the center of each beam
3. Using the thickest beam over the longest span, determine the centers deflection for central point loads. Repeat for five different values of loads. (fig 3 table 3)
4. For given central point load determine the central deflection to five different spans of one beam (move the supports one step each towards the center (fig 4 Table 4)
5. For various beams, using a constant span and central point load, determine the central deflection (as in 3 but L is of your choice.)
6. For one beam of given span determine the central deflection due to two equal loads overhanging the support by equal amounts. Repeat for five different values of loads (fig 6, table 6)
7. Determine the deflection (∂ ak) at a point at distance

   I. "a" from the left hand support due to a load W at distance "b" from the left hand support. (Fig7I, Table 7I)
   II. Find the deflection (∂ kb) but interchanging values of "a" and "b" (fig 7II Table 7II
   III. Determine also the deflection at both points when loads W each are applied at the two points simultaneously. Repeat for five different values of 'a' and 'b' (Fig 7III table III

Calculations

For a central point load w on a simply supported beam of span L, the central deflection is given.

$$\partial = \frac{WL^3}{48EI}$$

For two equal loads w overhanging the supports by distance "C" the central deflection is given

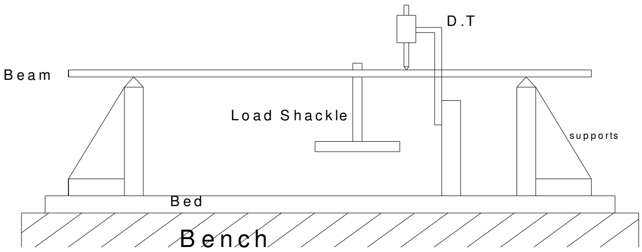
$$\partial = \frac{WCL^2}{8EI} \qquad\qquad \partial = \frac{W}{EI}\left[\frac{a^2L}{EI} - \frac{a^3}{2} - \frac{aL^2}{8}\right]$$

I, the moment of inertia of cross section = $\frac{bd^3}{12}$ for rectangular sections where b is the beam width and d is the beam depth.

Graphs:

1. Plot w against ∂ for L constant for steps 3 and 6
2. Plot log L against log∂ for W constant for step 4
3. Plot log **d** against log ∂ for constant w and L for step 5
4. Determine E young's modulus from graphs 1, 2 and 3

Conclusions: Write down the conclusions briefly, and comment on the different values of E calculated above the values of deflection measured in step 7 in relation to the superposition principles and reciprocal theorem.



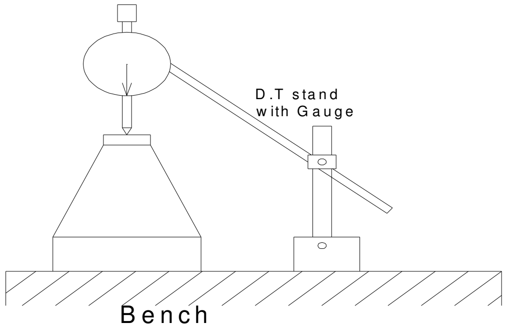


Table 2, Beam details

Beam	A	B	C
b (mm)			
∂ (mm)			

Table 3, step 3

W (g) =			**Beam=**		
L (mm)=					
∂ (mm)					

Table 4, step 4

W (g) =			**Beam=**		
L (mm)=					
∂ (mm)					

Table 5, step 5

W (g)=		**L (mm)=**	
Beam	A	B	C
∂ (mm)			

Table 6, step 6

L (mm)=			**C (mm)=**		**Beam =**
W (g)					
∂ (mm)					

TABLE	7I	**7II**
Beam=		
W (g)=		
"a" (mm)=		
"b" (mm)=		
∂ (mm)=		

Table 7III

Beam=			**W (g)=**		
"a"					
"b"					
∂ "a"					
∂ "b"					

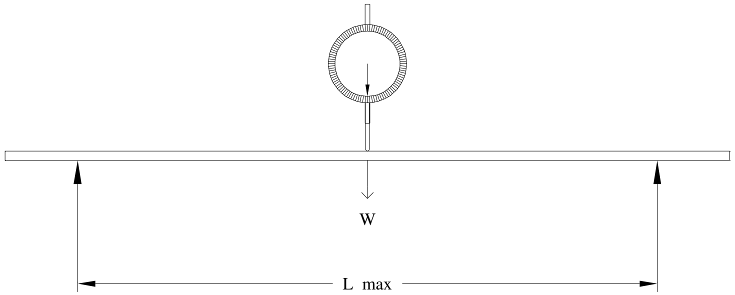


Fig 3, Step 3

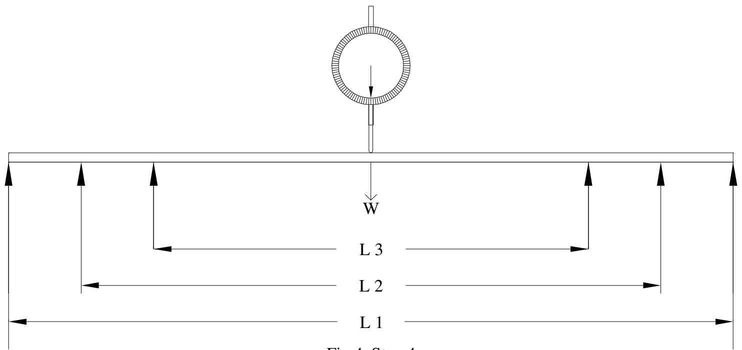


Fig 4, Step 4

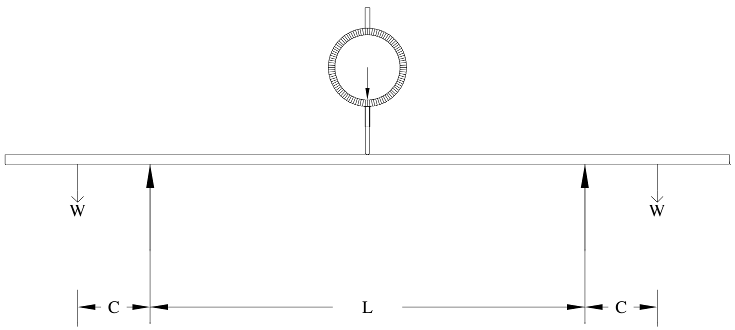


Fig 6, Step 6

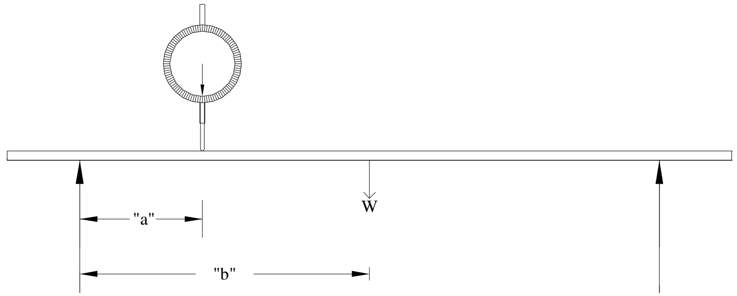


Fig 7, Step (i)

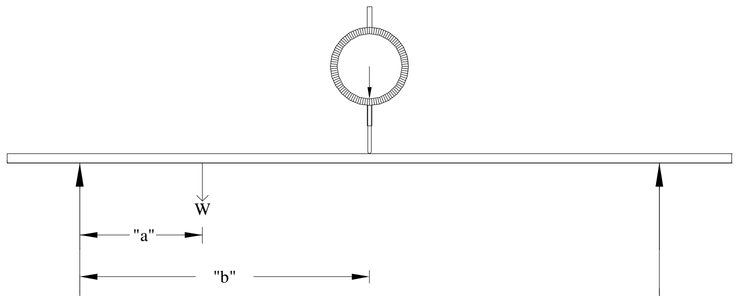


Fig 7, Step (ii)

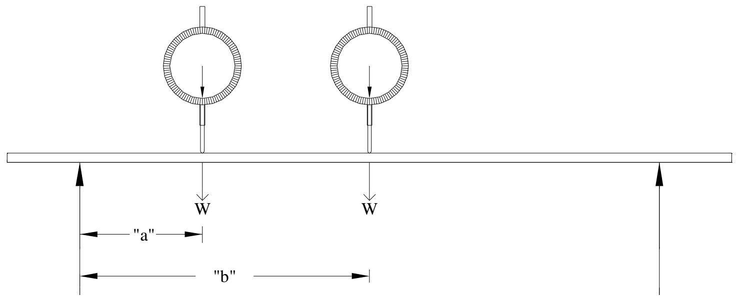


Fig 7, Step (iii)

3. INDENTATION OF METAL BY A BALL

OBJECT:

To examine the deformation of a metal specimen when a hardened steel ball is pressed into it under different normal loads and to determine how such indentations should be used to give an indication of the properties of the specimen.

INTRODUCTION

One often wants to obtain some indication of the mechanical properties of a piece of metal, but cannot perform compression or tension test. This may arise because,

- **a)** The piece of metal is so small that it is impossible to machine a tensile or compressive specimen from it.
- **b)** You cannot afford to destroy the piece of metal or machine part, because you want to use it for its proper pure purpose afterwards.
- **c)** You have not had time to prepare and test a tensile or compression specimen.

There is therefore a need for a simple, quick, and non destructive test that will tell us something about the properties of the material although it is unlikely that is will tell us as much as tensile test. This experiment is concerned with establishing the basis for such a test. Let us suppose that we apply a normal load on a hardened steel ball against the surface of a metal specimen as shown in fig. 1. and let us suppose that the load is great enough to cause plastic flow of the specimen when we remove the load and the ball in indentation.

Can we use the size of this indentation as some measure of the mechanical properties of the specimen? This is the question to which this experiment is directed.

The first step is to use different loads P and to examine now the indentation varies in size. If the load P is plotted against the curved surface area of the indentation it is found that the points lie on an approximate straight line through the origin although there is no obvious reason why this should be so. If the experiment is performed on another material, a straight line of a different gradient is obtained. This result gave Brinnell the idea that the gradient of this graph represented a property of the material and he suggested that this property should be called hardness. The connection between the hardness and other mechanical properties, such as yield stress was not understood at this time.

However it would be tedious in real life to perform a number of tests to obtain the gradient of this graph. It would be much more convenient if a reliable measure could be obtained from just one indentation but care must be taken that the load used is not too large or too small as the graph tends to depart from a straight line at these values of load. Supposing that we take that care, the Brinnell hardness Number is defined as: -

$$B.H.N = \frac{load}{curved\ surface\ area\ of\ impression} = \frac{P}{HDh} = \frac{2P}{\pi D\left\{D - \sqrt{\left(D^2 - d^2\right)}\right\}}$$

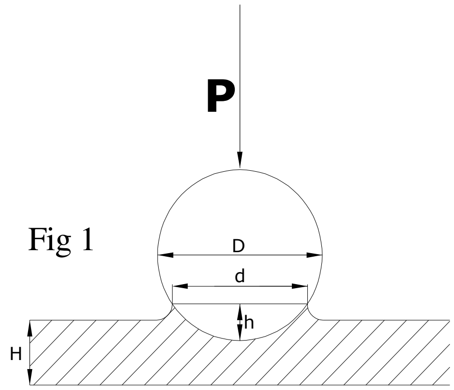
By convention the load P is measured in kg and linear dimension is mm, so that the units of BHN are kg/sq.mm, but the units are not normally stated.

GUIDANCE ON PROCEDURE

a) Apply a series of loads to two metal specimens via a 10mm diameter ball
   - **a)** Use loads 250,500,1000,2000,2500,3000kg
   - **b)** Do not place impressions closer together than $2\frac{1}{2}$ times the diameter of the impressions, otherwise the indentations affect each other. Do not place them within two impressions diameter of the edge of the specimen. Also for reliable results the depth of the specimen should be at least 10 times the depth of the impression.
   - **c)** Apply each load for 30 secs before you release it.

b) Measure the diameter of the impressions with a microscope.

Fig 1



COMPUTATION AND GRAPHS

1. Plot load against curved surface area of the impression and derive the gradients of the graphs.
2. Examine your results more closely by plotting
   a) BHN against diameter of impression
   b) BHN against applied load.

The experimental point on these two graphs is likely to show considerable scatter. Think carefully about the likely experimental error before you attempt to draw curves through the experimental points and draw conclusions from the graphs. You may assume that the error on applied load will be within 1% or 2% of full load for the machine for each intended load. You may draw your own conclusions concerning the accuracy of the diameter measurement from the microscope.

DISCUSSION

1. From your graphs deduce what range diameter of impression compared with the diameter of the ball would be acceptable for a single indentation test.
2. From your graphs deduce what range of loads would be acceptable for each of your specimen materials for a single indentation test.
3. In practice when you have to make a hardness test you can by simple inspection tell whether the specimen is steel, aluminum or copper etc. You must then decide upon the indenting load which will use. As a guide a standard procedure is laid as follows: -

For steels, and cast iron $\frac{P}{D^2}=30$

For copper and aluminium alloys= $\frac{P}{D^2}=10$

For cooper and aluminium= $\frac{P}{D^2}=5$

For lead, tin and their alloys= $\frac{P}{D^2}=1$

Where P is the load is kg and D is ball diameter in mm. Compare this guidance with your deductions under 2 above.

4. TENSILE TEST

OBJECT

To examine the deformation of round metal specimen when an increasing load is applied to it and to determine the numerical constants that characterize the deformation behaviour of the material.

INTRODUCTION

To apply a load to the specimens a machine with a load capacity exceeding the strength of the specimen is required. Generally, testing machines fall into two categories; one in which the load is applied manually, e.g. Hounsfield Tensometer, and the other in which hydraulic pressure is utilized.

The choice between the two types depends on the required capacity. In either case, the machine incorporates some method of measuring the applied load. The machine that will be used is hydraulic with a hand-operated pump. The applied load is measured by a steel ring and a dial gauge as indicated on the sketch of the machine. The reading on the dial has to be transformed into kilonewtons by a calibration factor marked on the particular machine being used.

In order to compare and select materials for various applications, one must have access to the important properties of that material i.e. material constant. One of the most often used tests performed to determine a number of important mechanical properties of material is tensile test.

Based on the load and displacement obtained from the experiment, we can get:

(a) Engineering tensile stress,

$\varepsilon = F/A_o$ (N/mm²)

(b) Strain,

$\varepsilon = L_1 - L_o / L_o$

(c) Yield stress,

Σy = Yield load / initial cross-sectional area (N / mm²)

(d) Ultimate tensile stress,

Σm = Maximum load / initial cross-sectional area (N / mm²)

(e) Elongation percentage,

$\%EL = (L_1 - L_o / L_o) \times 100$ (%)

Reduction percentage in area

(%) = $(A_o - A_1 / A_o) \times 100$

Where:

F = Load (N)

A_o = Initial horizontal cross- sectional area, (mm²)

A_1 = Final horizontal cross- sectional area, (mm²)

L_o = Initial gauge length, (mm)

L_1 = Final gauge length, (mm)

The change in length, especially in the elastic region, is a very small, (e.g. when mild steel is stressed to two-thirds its yield point stress, the extension on 1 cm is about 0.0009 cm), and can only be measured by an extremely sensitive extensometer. Most of these extensometers are capable of detecting 1/2000 and as a result, when the specimen starts to yield, the sensitive extensometer has to be removed and some other course extensometer used. In this case, a hand extensometer (see diagram) will be used.

GUIDANCE ON PROCEDURE:

1. **<u>Note the following</u>:**
   - **a.** The principle of operation of the machine (Note particularly the load capacity. Over load the machine may result in bending the machine members)
   - **b.** The principle of operation and the gauge length of the extensometers (Note down the

multiplying or magnification factor). The type of material to be tested and specimen diameter. Estimate the load at which the specimen will start to yield.

   c. Take the yield stress value from the table of mechanical properties of materials which is attached. (See table on page 32).

2. Mount specimen in the machine and **apply a small load in order to hold the specimen.**
3. Mount the Lindley extensometer on the specimen.
4. To examine the elastic region of behaviour, chose increment of load which will give you about 10 readings before you reach the estimated start of yielding i.e. the load estimated in 1(c) above. After each increment of load, measure the extension. Continued with the increments of load until the material has started to flow plastically either by sudden yield or by departing far enough from the straight-line behavior for the 0.1% proof stress to be determined. Here it would help if the load readings were plotted against the extension readings currently as the experiment is performed. Make sure that the extension is greater than gauge length x 10^{-3}.
5. Set the hand extensometer to the distance between the two punch hold marks on the specimen. Set the extensometer dial gauge to read zero. The readings taken in the 2nd part of the experiment will be added to total extension at this stage.
6. **(a)**To examine the **plastic region** of the behaviour, continue to load the specimen and take the extension with the hand extensometer at each increment. During the plastic range it is not possible to specify in advance suitable increments of load or extension. One has to feel one's way. It can however be suggested that it is best to go by extension increment in the first part of experiment can be used as standard extension increment for about 5 readings. After that this can be doubled and so on until the specimen fractures.

Note: Always wait for the load and extension gauges to stabilize before taking the readings. You will find that as the experiment progresses, the load will tend to decrease. Wait until it is relatively steady.

   (b) During the plastic range, the diameter of the specimen changes significantly and therefore after each increment measure the diameter as well as the extension and the load.

7. After final fracture, fit the two parts together and determine the final diameter of the specimen and its total extension on the gauge length. Also sketch the form of the fracture.

COMPUTATION OF GRAPHS:

(1) **Elastic range:** Plot norminal stress against engineering strain and true stress against engineering stain for the whole experiment. Determine the yield stress and/or the 0.1% proof stress and Young modulus (note: Draw the mean curve through the points).

(2) Plot, on the same graph, norminal stress against engineering strain and true stress against engineering strain for the whole experiment. Determine the ultimate tensile stress and fracture stress of the materials.

(3) Determine the percentage elongation and the percentage reduction in area.

(4) Assuming that the volume of the material is constant in plastic range, estimate tensile strain in the neck just before the fracture.

(5) Plot norminal stress versus natural strain and norminal stress versus engineering strain on the same graph.

DISCUSSION

(1) If we had a different gauge length, what difference would it have made to the 100% elongation? What lesson has this for engineering practice?

(2) Comment on the type of fracture.

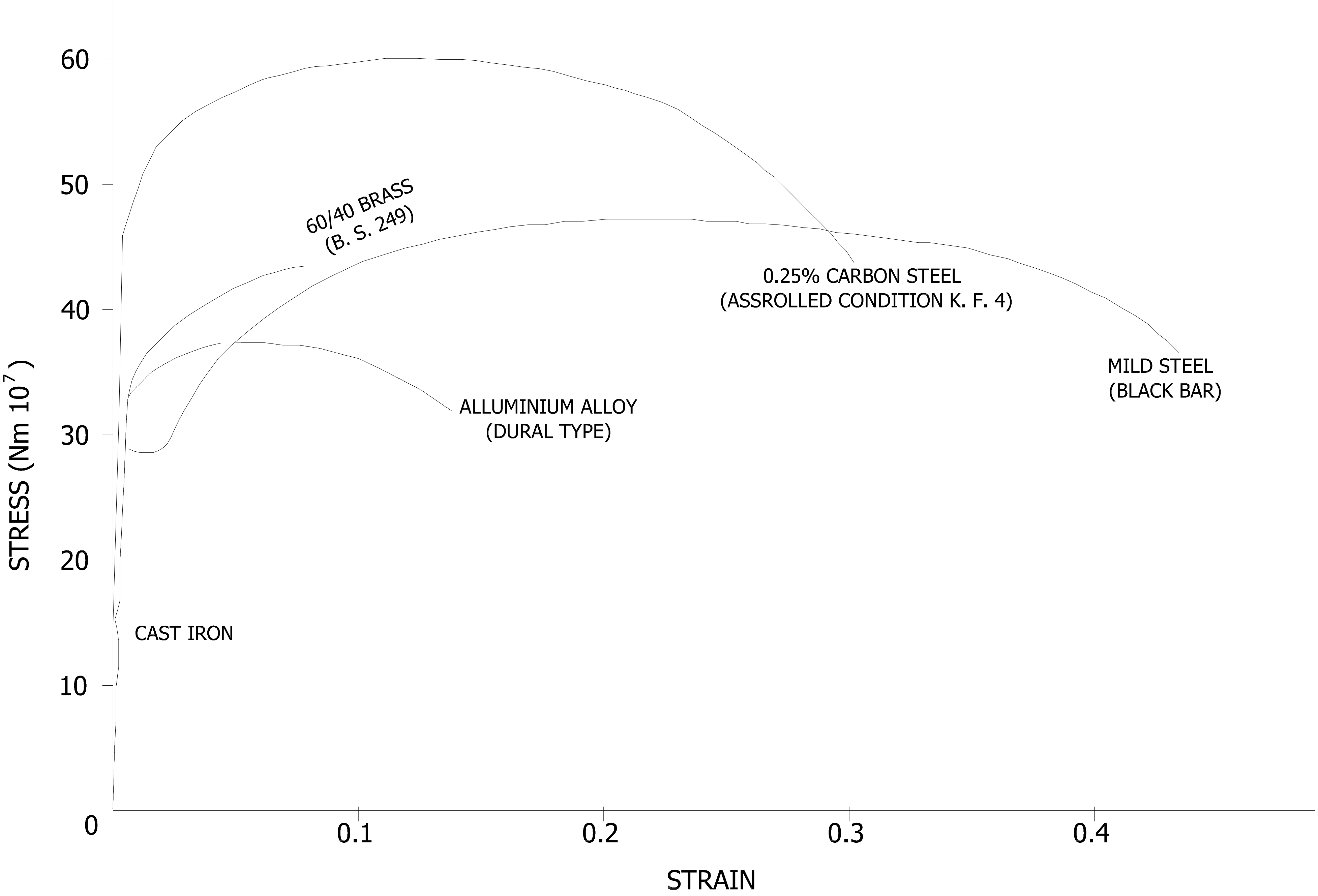
(3) What is the probable error in the value of Young's modulus determined from this experiment?

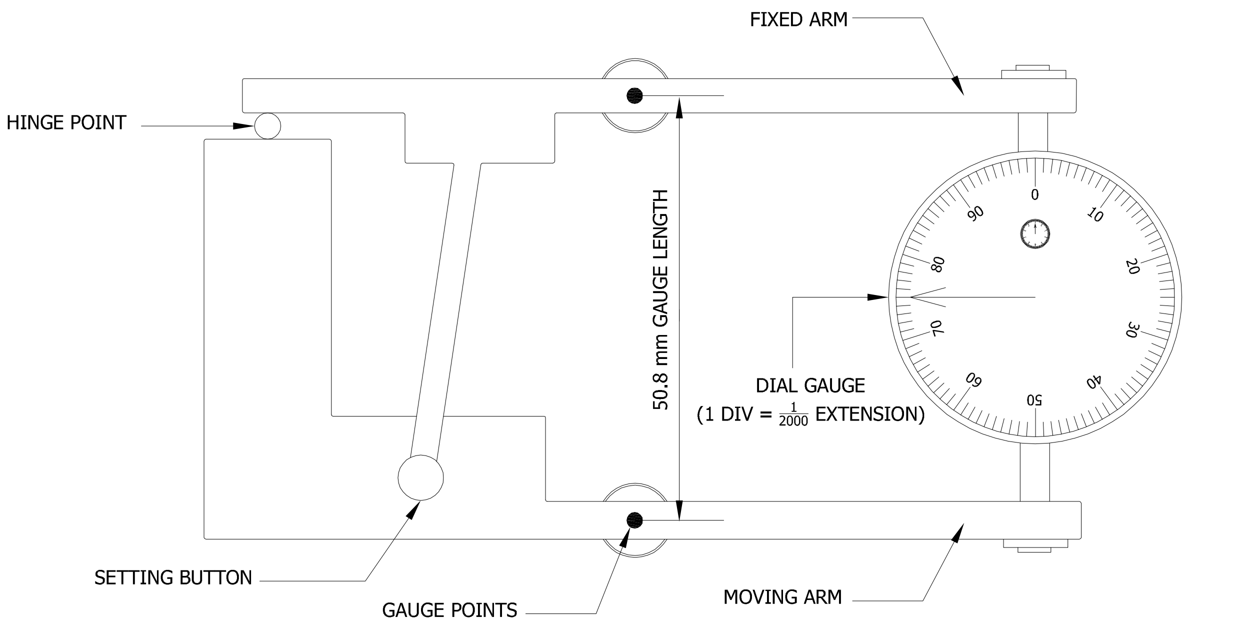
MECHANICAL PROPERTIES OF A FEW ENGINEERING MATERIALS

Material	Specific	Yield point stress x $10^6 N/m^2$	Ultimate Tensile Stress x 10^6 N/m^2	Specific Strength x 10^6 N/m^2	Young's Modulus x 10^9 N/m^2	Shear Modulus x 10^9 N/m^2	Elongation % on 50.8m	Principal Composition %
Mild Steel (Hot Rolled)	7.83	276	455	58	206	80	45	0.18C, 0.25Si
Caron Steel (Hot Rolled)	7.83	365	592	76	206	80.6	30	0.450
Nickel Steel	7.83	986	1235	158	206	81.4	14	0.4C, 2.4Ni, 0.5 Mo, 0.2Si
Grey Cast Iron	7.20	42 (Tension) - Compression	1.4 (Tension) 5.5 (Compression)	1.95 7.6	104	41.4	0.6	-
Aluminum Alloy (heat treated)	2.8	388	484	180	71.6	27.6	12	4C, 0.6 Mg, 0.5, 0.7 Fe, 0.7 Si
Brass	8.45	255	421	50	100	37.9	40	62 Cu, 38Z, 0.25C, 2.5W
Titanium	4.48	895	1020	227	105	39.3	12	0.25C, 2.5W
Concrete	2.4	40	42.5	19	18.6	-	0.45 (On 150mm)	1:2:4 mixture
Timber	6-8	30-59	32-70	5.3-8.0	7-11.6	About 0.7	-	-
Nylon	1.14	80	76	67	3	-	60	-

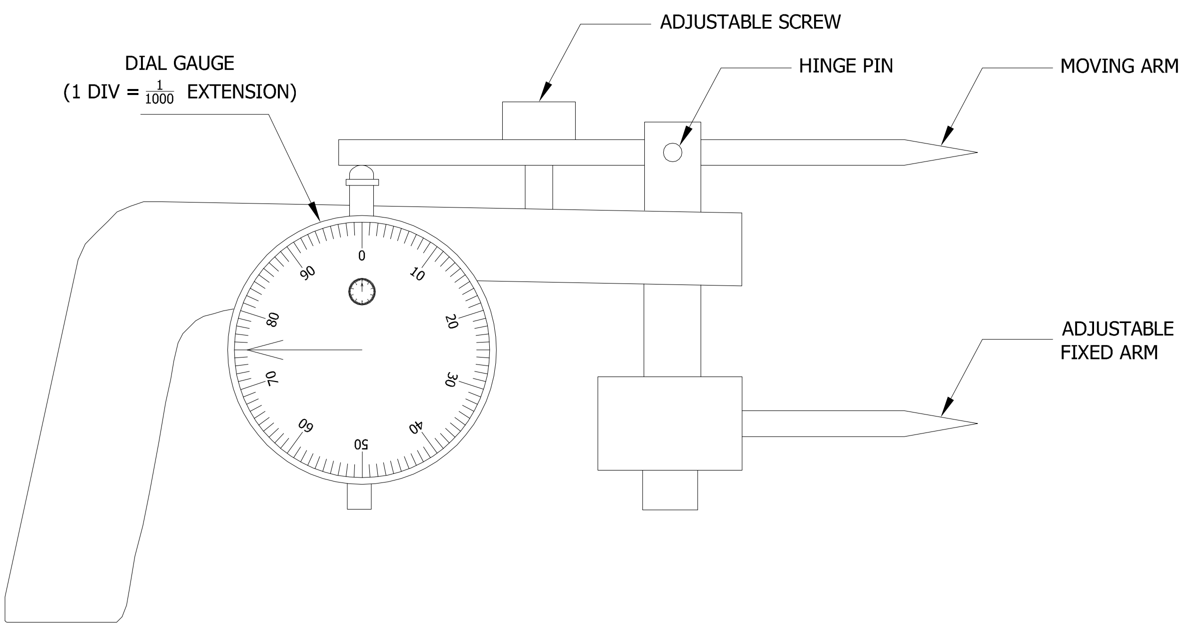
NOTE: This table is only intended to show the wide range of properties from various types of material. The numerical values are fairly typical, but can be varied in most cases very considerably by factors such as composition, heat treatment strain rate etc. For more detailed values of properties and other materials, published handbooks or the relevant British standard specification should always be consulted.

TENSILE TESTS ON VARIOUS MATERIALS
TYPICAL NORMINAL STRESS STRAIN GRAPH





LINDLEY EXTENSOMETER



HAND EXTENSOMETER