Compression Test

Objective:

The compression test is used to:

- Observe the stress - strain behavior of some metals under compression load.
- Determine the strength and other properties of various materials.

Introduction:

In theory the compression test is just the opposite the tensile test. However, there are special limitations on the compression test:

1- Appling a truly axial load is difficult.
2- There is always a tendency for bending stresses to be set up.
3- Friction between the heads of the testing machine or bearing plates and the end surfaces of the sample.

Theory:

For a compression test, the stress – strain diagrams have different shapes from those of for tension. Ductile metals such as steel, aluminum, and copper have proportional limits in compression very close to those in tension; and therefore the initial regions of their compression stress – stain diagrams are very similar to the tension diagrams. However, when yielding begins, the behavior is quite different. In a tension test, the specimen is stretched, necking may occur, and fracture ultimately takes place. When a small specimen of ductile material is compressed, it begins to bulge outward on the sides and become barrel shaped. With increasing load, the specimen is flattened out, thus offering increased resistance to further shortening (which means the stress-strain curve goes upward). These characteristics are illustrated in Fig. 1, which shows a compression stress-strain diagram for copper.

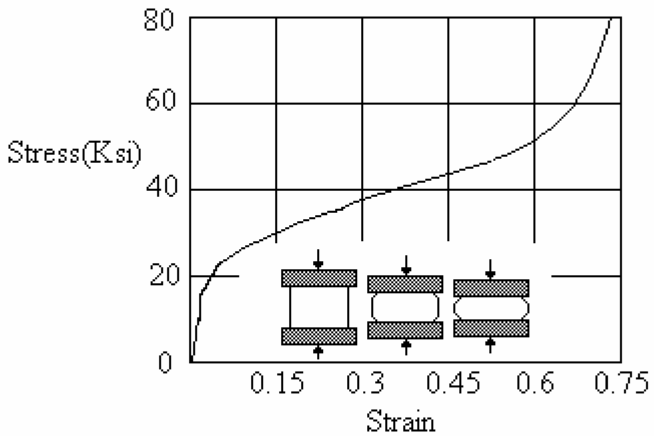


Figure 1

Brittle materials in compression typically have an initial linear region followed by a region in which the shortening increases at a higher rate than does the load. Thus, the compression stress-strain diagram has a shape that is similar to the shape of the tensile diagram. However, brittle materials usually reach much higher ultimate stresses in compression than in tension. Also, unlike ductile materials in compression, brittle materials actually fracture or break at the maximum load.

Apparatus:

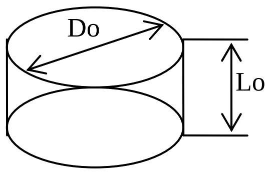
Same apparatus of tension test, but the clamps of the tension test were replaced by the compression jig parts.

Precautions:

1- Machined surfaces should be finished to 1.6μm or better.
2- Test specimens ends should be flat and parallel within .0005 in/in.
3- Test specimens should be loaded concentrically.

Procedure:

1- Measure Do and Lo at three locations along the circumference, or any other dimensions of the used specimen.



2- Lubricate bearing surfaces using suitable lubricant.
3- Start the machine, and apply a compressive force to the ends of the specimen until failure occurs.
4- The results are taken as a load deflection curve.

Results & Analysis:

1. From the load – deflection curve construct the stress – strain curve.
2. From the stress – strain curve determine the following properties for tested material:
    a- Proportional limit.
    b- Yield point.
    c- Yield stress for an offset of .2%.
    d- Ultimate and fracture stress.
3. Percentage elongation and reduction in area at fracture.
4. Modulus of Elasticity.
5. Modulus of Resilience.
6. Modulus of Toughness.
7. Shear Modulus of elasticity (G)
8. Bulk Modulus of elasticity (K).
9. Compare between engineering and true stress measures and comment on the difficulty in obtaining a uniform measure in tension and compression with the engineering stress - strain.
10. Comment in the calculated values of E, G, and ν as compared to known values in tension.
11. In compression test a greater load is necessary to cause yielding than that required in tension test for the same sample. State the reason.

Tensile Test

Objective

The tensile test is used to

- Observe the behavior of materials under tensile load.
- Determine the strength and other several elastic and plastic
- Properties of various materials
- Study the fracture of metallic material.

Introduction

The Tensile test is used to obtain basic design information on the strength of materials. When the standard methods of test are employed the results are acceptable criteria of quality of materials and a given level of quality means satisfactory behavior in service.

Apparatus

Universal Testing Machine (UTM): The machine is digital type Tensile Strength Test Machine. Capable doing the following tests:

1. Tensile test.
2. Compression test.
3. 3 points bending test.
4. Direct shear test.

It uses sensor which has high accuracy of the load value. Experimenters can get well-done results. Experimenter can save the result by mean of connecting the U.T.M. and Computer. The machine is composed of:

- Loading part:
  Main body, crosshead, crosshead moving part, jig part, load cell sensor, and displacement sensor.
- Measuring part:
  Load display, strain display, and speed control device.

Theory

They typical stress-strain diagram with some of common nomenclature for a typical low-carbon steel specimen is shown in fig (1). And fig (2) shows a typical stress - strain diagram for brittle materials.

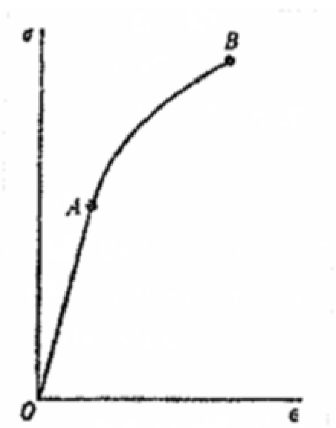


Figure 2: typical stress-strain diagram for a brittle material.

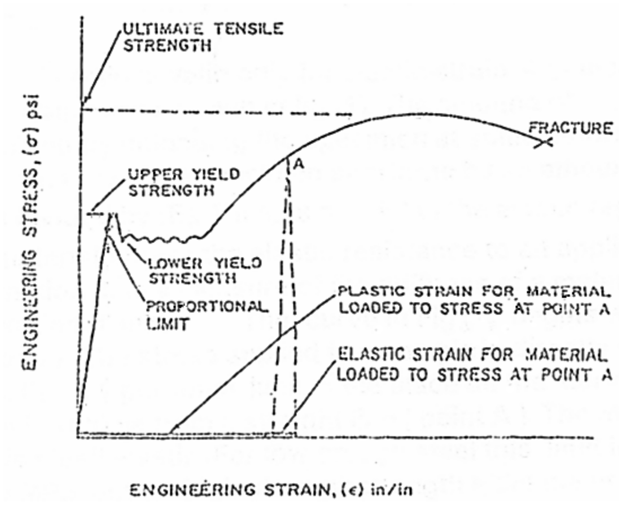


Figure 1: Engineering stress-strain Diagram for carbon steel showing important properties.

Figure (1) & (2) are plotted in terms of engineering stress,σ, and engineering strain ,ε, These are quantities based on the original dimensions of the specimens defined as:-

$$\sigma = \frac{Load}{Original^\circ Area} = \frac{P}{A_o}$$

$$\varepsilon = \frac{Deformed \circ Length - Oridinal \circ length}{Original \circ Length} = \frac{L - L_o}{L_o}$$

There are a number of definitions are shown in fig. (1):-

The Modulus of elasticity (E): It is the ratio of stress to strain,

$$E = \frac{\sigma}{\varepsilon}$$

This ratio is valid only for elastic strain, and measured from the stress stain curve shown in fig (1), The amount of elastic strain can be determined by unloading the specimen at some deformation, when the load is removed, the specimen shortens by an amount equal to the stress divided by (E), Thus, ($\varepsilon = \sigma / E$) in the elastic region. The value of E for a material shows the elastic resistance to an applied load that causes deformation. It is a measure of the stiffness of materials.

- ***Proportional limit:*** The curve in Fig (1) begins with a straight line from 0 to A. The stress applied to a sample is directly proportional to the strain; the proportional limit is the place on the curve where it deviates for the first time from a straight line (point A). The material in this point is steel elastic. For low carbon steel this limit is in the range 200 to 280 MPa, but for high strength steel the proportional limit is 550 MPa and more.
- ***Elastic limit:*** The elastic limit is the maximum load that can be applied to the specimen without permanently deforming it.
- ***Yield stress:*** If a slight increase in loading is applied to the elastic, the elongation occurs for the first time without any increase in loading. The Method for finding the yield stress of the sample is to draw a line parallel to the original straight portion of the stress-strain curve, but offset from the origin of this curve by some value of ε (usually between 0.001 and 0.003, indicated as 0.1% to 0,3%), the value of σ is taken from a point of Intersection of this line and the curve.
- ***Ultimate stress:*** It is the point on the curve that represents the maximum stress that can be applied to a ductile material before fracture (point D). For brittle materials the fracture point is essentially the same as the ultimate stress.
- ***Rupture stress:*** The stress at which the fracture occurs, the fracture is located at the last point in the curve (point E).
- ***The Modulus of Resilience (U_R):*** is the amount of energy stored in stressing the material to the elastic limit as given by the area under the elastic portion of σ - ε curve. This quantity is important in selecting materials for energy storage such as springs; the Modulus of Resilience is given by,

$$U_R = \int_0^{\varepsilon_{Elastic}} \sigma d\varepsilon = \int_0^{\varepsilon_e} E\varepsilon d\varepsilon = \frac{1}{2}E\varepsilon^2 = \frac{1}{2}\sigma_e \varepsilon_e = \frac{\sigma^2}{2E}$$

- ***The modulus of Toughness (U_T):*** is the total energy absorption capabilities of the materials to failure and it is given by,

$$U_T = \int_0^{\varepsilon_{fracture}} \sigma d\varepsilon \cong \frac{\sigma_{yi} - \sigma_{ult}}{2} * \sigma_{Ult}$$

and is given by the total area under the σ - ε curve, it is often approximated by ($2/3*\sigma_{max}*\varepsilon_{max}$), this quantity is important in selecting materials for applications where high overloads are likely to occur and large amounts of energy must be absorbed.

- ***The ductility of material:*** is ability of material to deform under load, ductility is indicated by the tensile property of percentage of elongation. The percentage of elongation, which is the percent strain to fracture, is given by,

$$\% Elongation = \frac{L_f - L_o}{L_o} * 100\%$$

Where:

L_o: the original length between gage marks.

L_f: the length between gage marks at fracture.

Percentage of reduction in cross-sectional area of a specimen is another way to indicate the tensile property of ductility, thus

$$\% \mathrm{Re}\,duction\ Of\ \ Area = \frac{A_f - A_0}{A_0} * 100\%$$

Where :-

A_o: is the original cross-sectional area

A_f: is the cross-sectional area at fracture

If the percentage of elongation and reduction of cross-sectional are large, the material is said to be ductile; when they are low, the material is said to be brittle.

The stress-strain diagram previously discussed, using engineering quantities σ & ε, are based on area and lengths that no longer exist at the time of measurement. To correct this, situation true stress (σ_T) and true strain (ε_T) quantities are use. The true stress and true strain quantities are defined as:

$$\sigma_T = \frac{P}{A_i}$$

Where:

A_i: the instantaneous area at the time is measured and,

$$\varepsilon_T = \int_{L_o}^{L} \frac{dL_i}{L_i} = Ln\frac{L}{L_o} = -\int_{A_o}^{A} \frac{dA_i}{A_i} = Ln\frac{A_o}{A}$$

Where

L: the instantaneous length between gage marks at the time P is measured.

A: the instantaneous cross-sectional area at the time P is measured.

These two definitions of true strain are equivalent in the plastic region where the material volume can be considered constant during deformation. Since

$$A_o.L_o = A.L$$

This is only true in the plastic region of deformation, in the elastic region the change in volume (ΔV) per unit volume is given by the bulk Modulus (K), and,

$$K = \frac{E}{3(1-2v)}$$

Where the Shear modulus of elasticity is given by the equation:

$$G = \frac{E}{2(1-v)}$$

The relation ship between the engineering values and true values are given below:

Since

$$\varepsilon_T = Ln\frac{L}{L_o} = Ln\frac{L+\Delta L}{L_o}$$

Then

$$\varepsilon_T = Ln(1+\varepsilon)$$

And

$$\frac{A_o}{A} = \frac{L}{L_o} = \frac{L_o+\Delta L}{L_o} = 1+\varepsilon$$

Then

$$A = \frac{A_o}{1+\varepsilon}$$

$$\sigma_T = \frac{P}{A}$$

So

$$\sigma_T = \frac{P}{A_o}(1+\varepsilon) = \sigma(1+\varepsilon)$$

Procedure

1. Check the specimen dimensions, measure the diameter or width, thickness of the specimen and compute the cross-sectional area and measure the gauge length.
2. Tight the specimen at the grippes located at the machine.
3. Calibrate the machine in such a manner that the extension and load are set to zero.
4. Choose a suitable loading rate.
5. Apply the tension load on the specimen.
6. Obtain the load-extension (stroke) curve from the machine.

Results & Analysis:

1. Determine the following properties:
   a. Proportional limit.
   b. Yield point.
   c. Yield stress for an offset of .2%.
   d. Ultimate and fracture stress.
1. Percentage elongation and reduction in area at fracture.
2. Modulus of Elasticity.
3. Modulus of Resilience.
4. Modulus of Toughness.
5. Shear Modulus of elasticity (G)
6. Bulk Modulus of elasticity (K).
7. Compare your values of Modulus of elasticity, yield stress, Ultimate stress, with the typical values for the tested specimen(s).
8. State difficulties when testing brittle materials.
9. Comment on the type & shape of fracture for tested specimen(s).
10. What are the advantages of a stress- strain curve over a load-elongation curve?
11. Based on the observations of your test, forecast the stress-strain curve for glass and draw its stress-strain curve. Comment in your graph stating why it should be drawn that way.

Torsion test

Objective

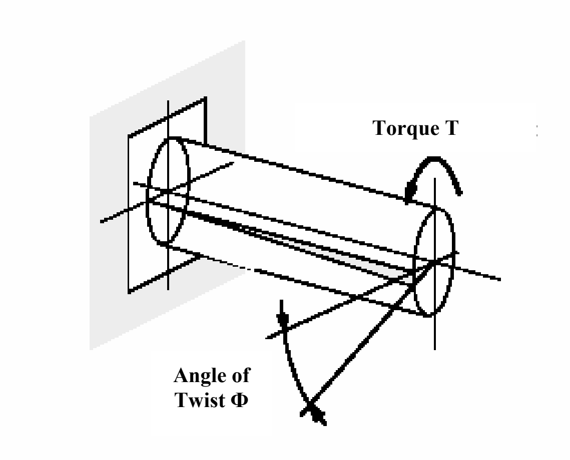
To determine the behavior of materials when subjected to torsion, and to obtain some of their mechanical properties.

Introduction

In many applications, such as axles, coil springs, and derives shafts; an engineering material must have good resistance to stresses induced by twisting (TORSION). The stress resulting from such torsion load can be determined by means of the torsion test. This test resembles the tension test in that a load deflection curve is also development (which is transformed to a shear-strain curve).

In a torsion test, a solid or hollow cylindrical specimen is twisted and the resultant deformation, measured as the angle through which the bar is twisted. The test then consists of measuring the angle of twist, Φ (rad) at selected increments of torque, T (N.m). Expressing Φ as the angular deflection curve per unit gage length, one is able to plot a T-Φ curve that is analogous to the load deflection curve of the torsion test.

To be useful for engineering purpose, its necessary to convert this T-Φ curve to the shear stress **τ**, and shear strain **γ**.



Theory

To obtain a relationship between the internal torque and the stresses it sets up in members with circular and tubular cross sections, it is important to make few assumptions:

1. A plane section of material perpendicular to the axis of a circular member remains plane after the torque is applied (note that this is not true for large deformations).
2. In a circular member subject to torque, shearing strains vary linearly from the central axis.
3. Shearing stress is proportional to shearing strain.

Consider a bar, or shaft, of circular cross-section, twisted by torque T acting at its ends (fig. 1a). A rotation at one end of the bar relative to the other end will occur. The rotation angle of the cross section, Φ is known as the angle of twist.

Also, there is a longitudinal distortion formed along the length of the shaft at angle, γ.

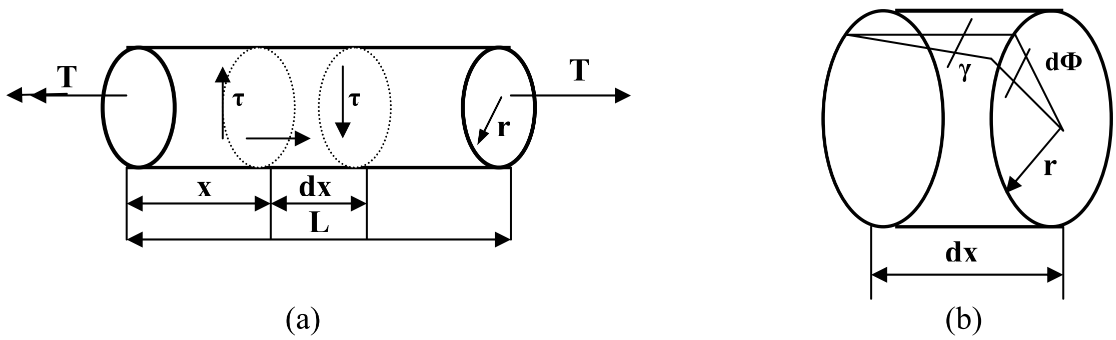


Fig 1: Circular bar in pure torsion

If we take a longitudinal section of length dx (fig. 1b), we find

$$\gamma = r\frac{d\phi}{dx} \qquad (1)$$

In pure torsion, the rate of change $\frac{d\phi}{dx}$ is constant. This constant value is defined as θ, Where, $\theta = \frac{\phi}{l}$ then:

$$\gamma = r\theta = r\frac{\phi}{l} \qquad (2)$$

For linear elastic material, the shear stresses τ in the bar is proportional to the shear strain γ by Hook's law in shear, that is:

$$\tau = G\gamma \qquad (3)$$

Where G is the modulus of elasticity (modulus of rigidity).
Also the shear stress distribution is uniform across the section as shown in figure 2.

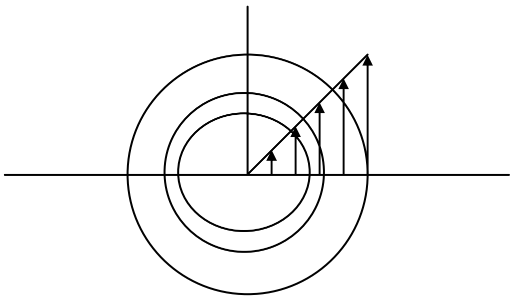


Fig. 2: Elastic shear stress distribution.

Considering the very thin circumferential ring shown, the torque resisted by this ring is given by:

$$dT = \tau\, dA \times a = 2\pi a^2 \tau\, da \qquad (4)$$

Since the distribution is linear, the shear stress τ at any radius a is related to the maximum shear stress τ_{max} at r thus; $\tau = \tau_{\max}\frac{a}{r}$, substituting into equation 4 to give:

$$dT = 2\pi\frac{\tau_{\max}}{r}a^3 da \qquad (5)$$

Integrating over the entire cross-sectional area, the total external torque is

$$T = \frac{2\pi}{r}\tau_{\max}\int_0^r a^3 da = \frac{\pi}{2}\tau_{\max} r^3 \qquad (6)$$

Solving equation 6 for τ_{max}

$$\tau_{\max} = \frac{2T}{\pi r^3} = \frac{T.r}{J} \qquad (7)$$

Where J is the polar moment of inertia given by $\frac{1}{2}\pi r^4$ for solid circular shaft.

When the metal starts to deform plastically, the shear stress distribution is no longer linear. The torque at a very thin ring of radius a is again given by equation 2 so the external torque resisted across the section is then

$$T = 2\pi\int_0^a \tau\, a^2 da \qquad (8)$$

The shear strain γ at any radius is still valid, and given by $\gamma = \frac{a\phi}{L}$. Thus $a = \frac{L}{\phi}\gamma$, and $da = \frac{L}{\phi}d\gamma$

Substitute the last equation into equation 8

$$T = 2\pi \int_0^{\gamma_{max}} \tau \left(\frac{L\gamma}{\phi} \right)^2 \frac{L}{\phi} d\gamma \quad \ldots\ldots (9)$$

The shear stress at any radius (a) is also a function of γ only, then:

$$T\phi^3 = 2\pi L^3 \int_0^{\gamma_{max}} f(\gamma) d\gamma \quad \ldots\ldots (10)$$

Differentiating both sides of equation 8 with respect to Φ:

$$\frac{d}{d\phi}\left(T\phi^3\right) = 2\pi L^3 \tau \gamma_{max} \frac{d\gamma_{max}}{d\phi} \quad \ldots\ldots (11)$$

But: $\frac{d\gamma_{max}}{d\phi} = \frac{r}{L}$. Substituting in equation 11 we get:

$$3T + \phi \frac{dT}{d\phi} = 2\pi \tau r^3 \quad \ldots\ldots (12)$$

Solving for the shear stress:

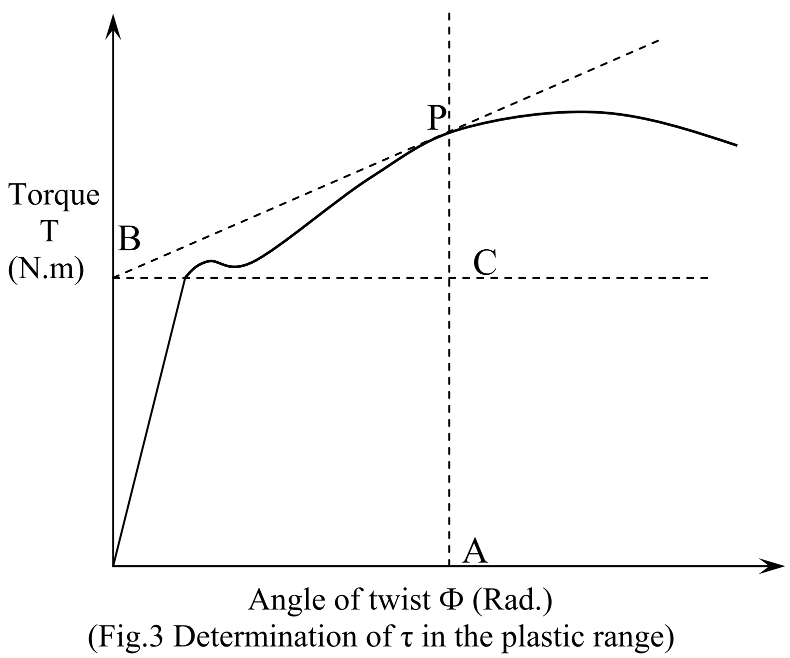
$$\tau = \frac{1}{2\pi r^3} \left(\phi \frac{dT}{d\phi} + 3T \right) \quad \ldots\ldots (13)$$

Refer to figure 3. At the typical point P at which it is desired to obtain the shear stress, we observe that:

$$\phi = BC, \frac{dT}{d\phi} = \frac{PC}{BC}, T = AP \quad \ldots\ldots (14)$$

Thus,

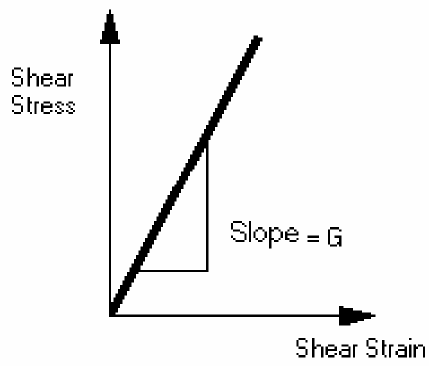
$$\tau = \frac{1}{2\pi r^3} \left(BC \frac{PC}{BC} + 3AP \right) = \frac{PC + 3AP}{2\pi r^3} \quad \ldots\ldots (15)$$



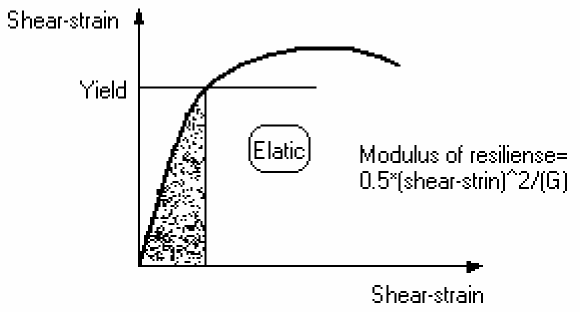
(Fig.3 Determination of τ in the plastic range)

Once the shear stress – strain curve is obtained, we can easily evaluate several engineering properties:

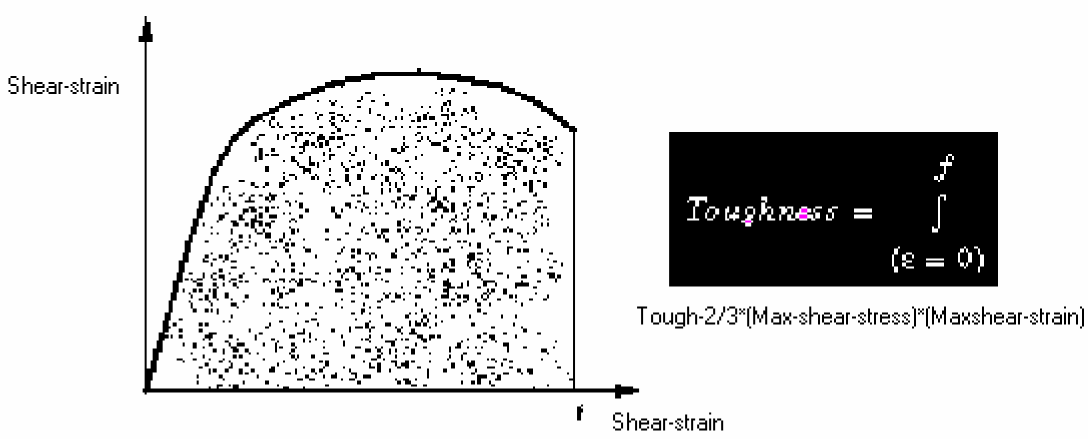
- The *Modulus of Rigidity,* **(G)** is the slope of the $\tau - \gamma$ curve in the elastic range and is compatible to Young's Modulus found in the tension test.



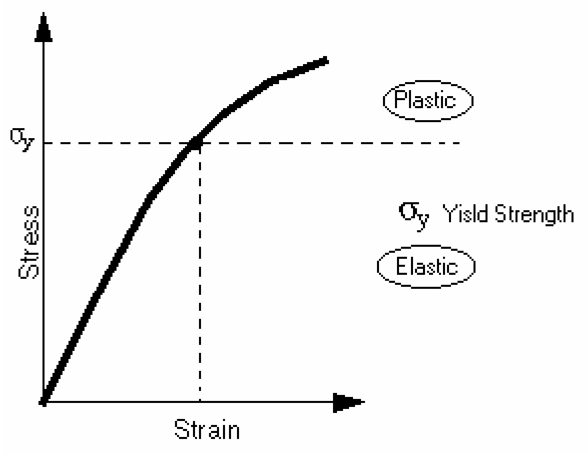
- The *Modulus of Resilience* is the area under the elastic portion of the $\tau - \gamma$ curve, which represents the energy absorbed by the material in the elastic region.

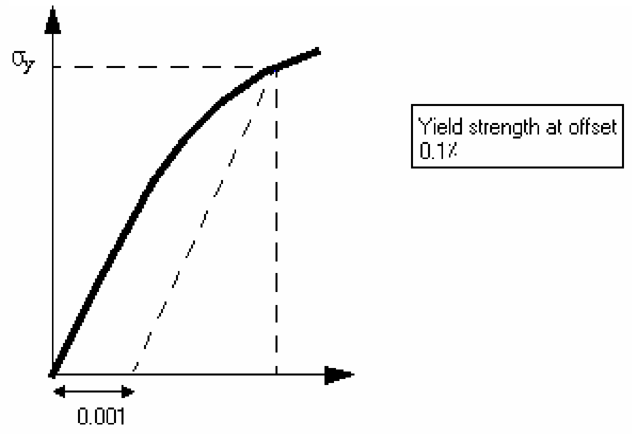


The *Modulus of Ruptur* is the total area under the $\tau - \gamma$ curve, which represents the total energy absorbed by the material before fracture.

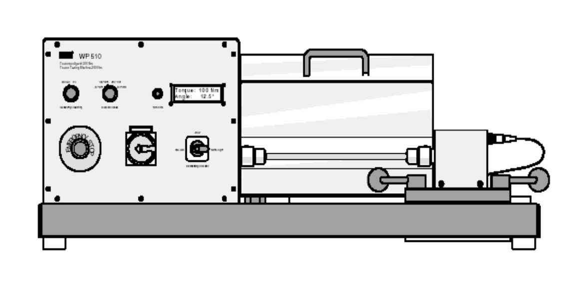


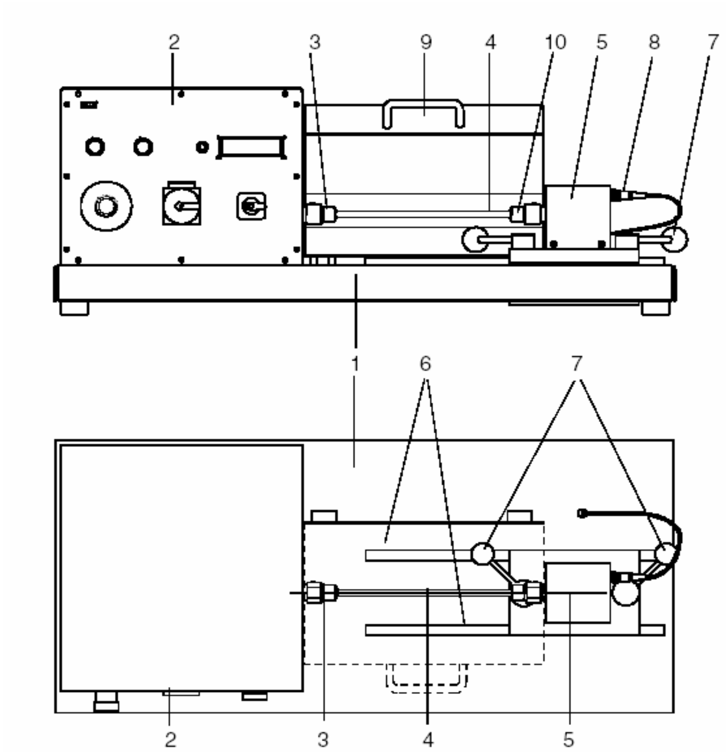
- The yield shear stress, the ultimate shear stress, the fracture shear stress.





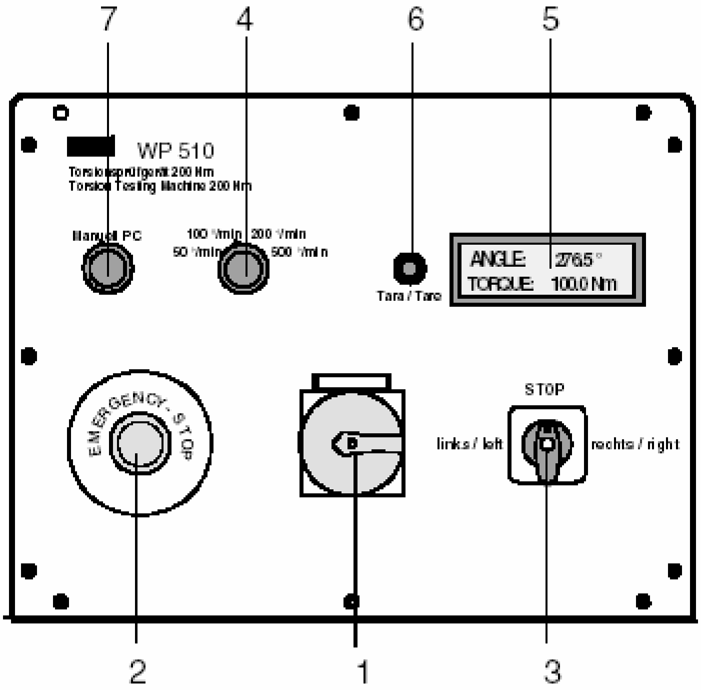
Apparatus:





The testing unit consists of the following components: base plate (1), drive unit (2) with geared motor to generate the testing moment. The moment is transferred to the testing rod (4) via a square drive (3/4") and standard socket spanners (3). The rotational angle sensor, the electronic system for the recording and display of the measured values, and the drive motor control are located in the drive unit housing. A frequency converter is used to adjust the speed of the drive motor. The other end of the testing rod (4) is fixed to the support (5) with torque measurement device. The support (5) can be shifted on guide rails (6) and can be braced with two clamp levers (7), to allow for the testing of samples of different lengths. The torque is measured using a metering shaft equipped with a strain gauge. The shaft has ball bearings on the sample side to avoid measuring errors resulting from friction. The electrical power is connected to the basic unit via a cable with a 5-pin plug (8). The base plate (1) is reinforced with box sections in order to ensure a high degree of torsion rigidity and low inherent distortion. This ensures that a high degree of precision during torsion measurement has been reached in conjunction with the high-resolution optoelectronic torsion sensor. A transparent protective hood (9) protects against flying fragments. This can occur when especially hard and brittle materials fracture.

All display and operating elements required for conducting the test are arranged on the front plate of the drive unit. The unit is turned on with the main switch (1). The unit can be stopped and de-energized with the emergency stop switch (2) at any time. The motor control switch (3) switches the drive motor in both rotational directions. The motor stops in the middle position, and rotates to the left in the left position and to the right in the right position. The switch has two positions. The first, non-locking position permits jogging operation; the motor stops when the switch is released. The motor runs continuouslyin the second, locking position. The speed selection switch (4) has 4 different deformation speeds: 50°/min, 100°/min, 200°/min and 500 °/min.



The LCD display (5) shows the current testing moment (torque) in Nm and the angle of rotation in degrees. Before the test run the displayed values can be set to zero with the tare key (6). The operating switch (7) is used to select between manual operation at the unit or remote control via a PC. Special control software is required for remote control with the PC.
The power supply connection (230 V / 50 Hz) and an interface socket are located on the back of the drive unit to link the PC. A button on the back panel is used to reset the overheating protection of the drive.The following block diagram provides an overview of the measuring and control technology of the test unit.

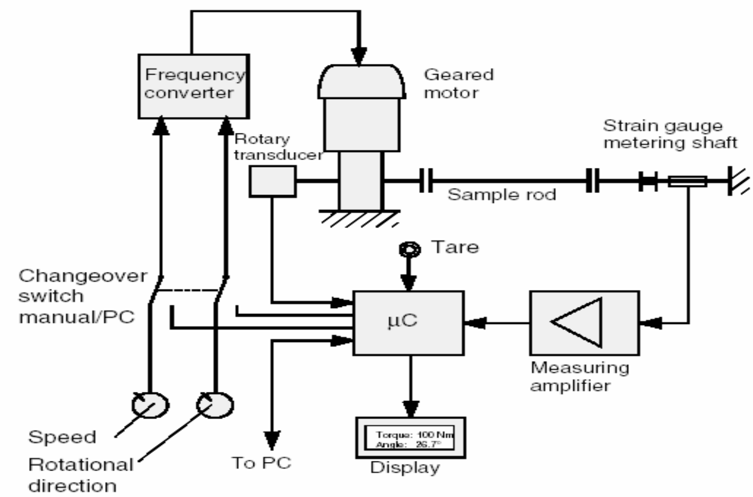
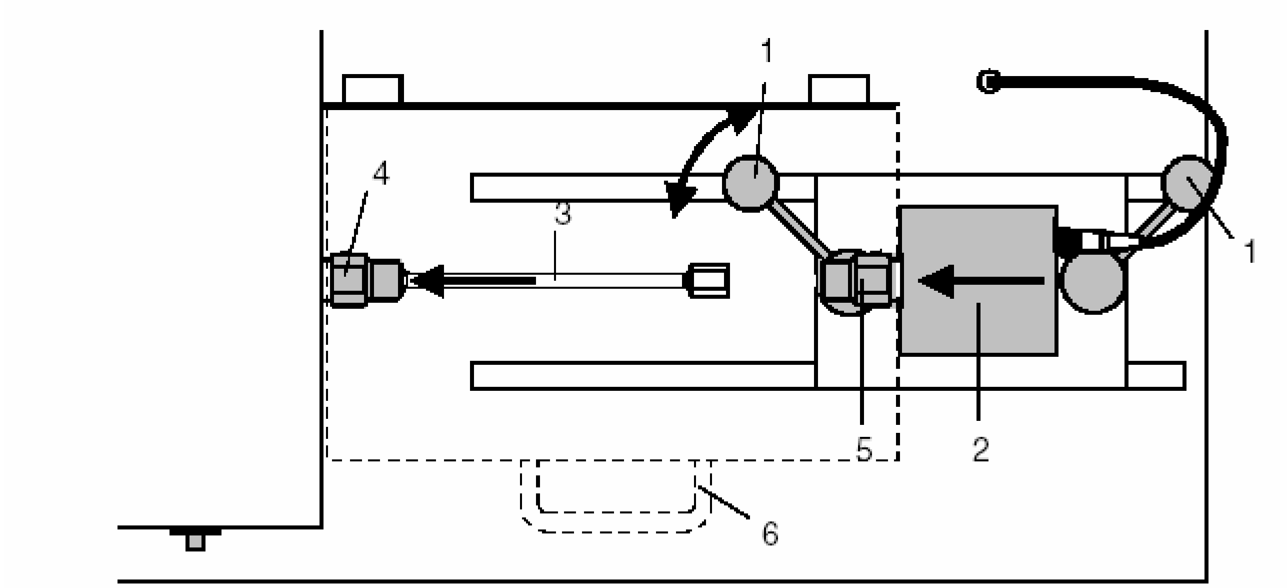


Fig. 2.3 Block diagram - Torsion testing unit

Procedure:

- *Installing the sample*
  1. Release the clamping lever (1) on the torque measuring device (2) and push back.
  2. Place sample (3) into the socket spanner (4) on the drive side.
  3. Turn sample with the motor until it fits into the socket spanner (5) on the torque measuring device.
  4. Push torque measuring device (2) forwards again. Ensure that the samples have an axial play of around 2-3 mm.
  5. Brace the torque measuring device with clamping levers (1).
  6. Shut the protective hood (6).
  7. Carefully pre-stress the sample in jogging operation until there is no more play and the torque display moves.
  8. Set display for torsional moment and angle to zero with the tare function.
- *Stressing the sample:*
  1. Twisting the sample using the motor control switch at steps of 2-5°.
  2. Read the torsion moment from the display after every angular step. Record together with the displayed torsion.



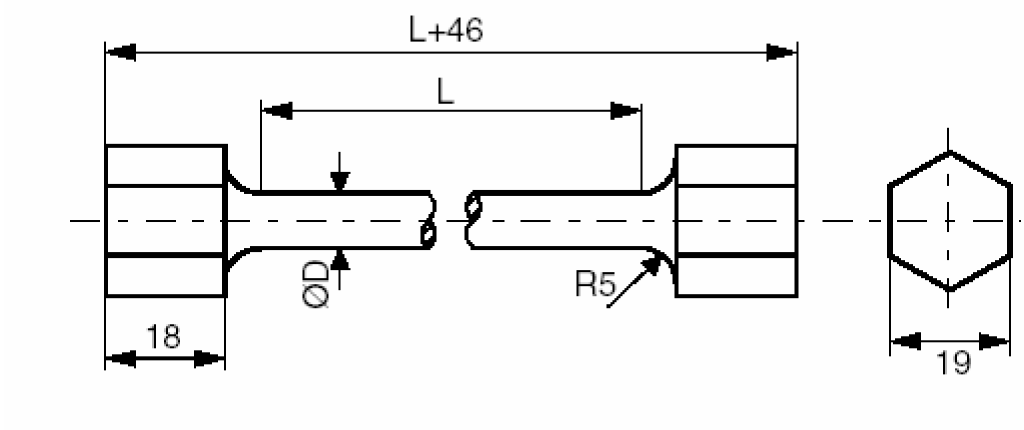
Results and analysis

1. Plot graph of torque (T) versus angle of rotation (Φ).
2. Calculate shear stress and shear strain in both plastic and elastic ranges.
3. Plot a $\tau - \gamma$ curve. Find the following:
   a. The proportional limit.
   b. Yield strength at an offset 0.1%.
   c. Modulus of Rigidity.
   d. Modulus of resilience.
   e. Modulus rupture.
4. The total angle of twist.
5. Draw the shape of fracture and explain.

DATA SHEET

Material:
Diameter D:
Gage length L:

Angle of twist (φ) Degree	Applied torque(T) N.m	Angle of twist (φ) Degree	Applied torque(T) N.m



Exp. # 1

Deflection of Beams

(Simply supported & cantilever)

Objective:

To investigate the support reaction forces and deflection of a simply supported beam and a cantilever beam.

Theory:

Simply Supported Beam.

Figure 1 shows a simply supported beam of length L, (A, B) are the reaction forces and F is a concentrated force acting at distance x from A. The reaction forces A & B are calculated using equilibrium equations:

$$\sum M_B = 0 \text{ , and } \sum M_A = 0$$

Solving for support forces A & B, as in figure 1 we get:

$$A = F(1 - \frac{x}{L}) \text{ , } B = F.\frac{x}{L}$$

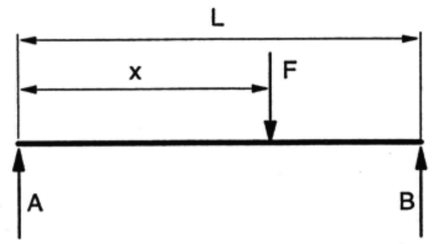


Figure 1: Supporting forces on the bar

The equation for the elastic line of a bar loaded in the center with the single force is as follows for the section between the left-hand support and the load with $0 \le x \le L/2$

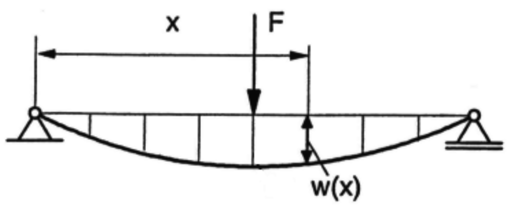


Figure 2: Bar on two supports.

$$w(x) = \frac{FL^3}{48EI}\left[3\frac{x}{L} - 4\frac{x^3}{L^3}\right]$$

The section between the load and the right-hand support is symmetrical to this. The maximum deflection is at the center of the bar

Where x = L/2 directly beneath the load.

$$w_{L/2} = \frac{FL^3}{48EI}$$

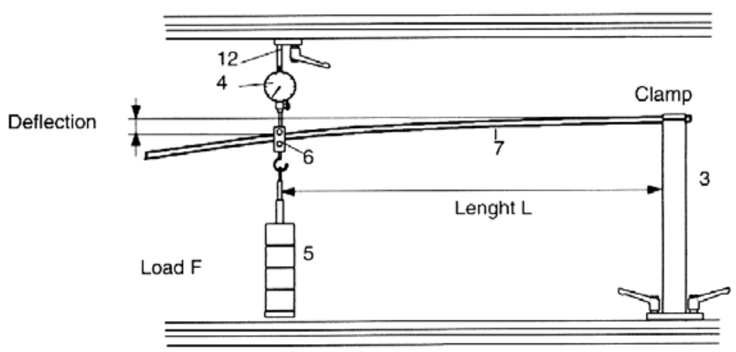


Figure 3: Deflection of cantilever beam

In a cantilever bar, one side of the bar is fixed and the other side free.

The equation for the deflection y of the bar at the point of application of force is

$$Deflection\,(y) = \frac{FL^3}{3EI}$$

Deflection is proportional to the load F and the cubed length of the bar; inversely proportional to the modulus of elasticity E and area moment of inertia I_y.

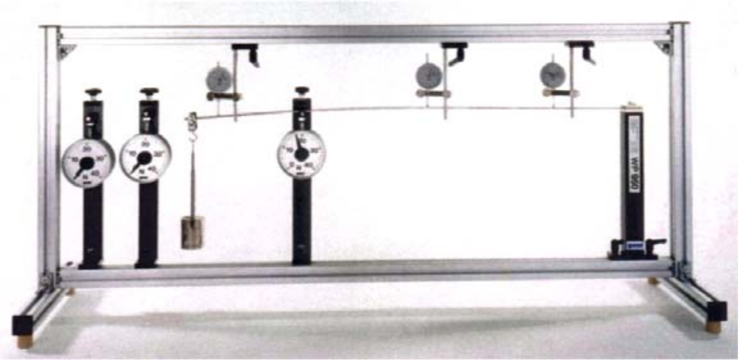
The influence of the Length L at the deflection should be demonstrated in this experiment.

For this purpose, the force should be constant. The experimental bar is made of steel (modulus of elasticity E = 210000 N/mm^2) and has a cross-section of b x h mm.

$$Area\ moment\ of\ Inertia\ (I) = \frac{bh^3}{12}$$

Apparatus & Equipment Needed:

The table unit consists of a strong aluminum section frame. Beam specimens of varying thickness made of different materials. Loading is applied using sets of weights and the beam deformation measured using measurement gauges. The forces are determined using dynamometers integrated into the bearings. The height of the measurement gauges in their holders is adjustable. Like the figure below.



Procedure:

Part 1:

Measurement of the reaction forces:

1. Fasten the articulated supports at a distance of 1000mm.
2. Push the rider for the weight suspender onto the bar and place the bar on the supports.
3. Loosen the looking screw on the support. Adjust the height of the support using the rotary knob until the bar is horizontal. Re-secure the support using the locking screw.
4. Set the scale on the dynamometer to zero by twisting.
5. Suspend the weight of and load the bar.
6. Read the supporting forces on the dynamometer and record.

Part 2:

Deflection of simply supported beam:

1. The load remains constant and is applied in the center at x = 500 mm.
2. The deflection of the bar is measured with dial gauge at intervals of 100mm.
3. Take the readings of the two dynamometers and the dial-gauge at each time you relocate the applied load.

Note: The dynamometers experience spring excursion under load. In order to prevent measurement errors as a result of this additional deflection f, the results should be returned to their original position.

Part 3:

Deflection of cantilever beam:

1. Fasten the support pillar to the frame.
2. Clamp the bar to the support pillar.
3. Place the rider on the bar and lock in the required position.
4. Fasten the dial gauge to the frame with the holder in such a way that the tracer pin of the dial-gauge is touching the flattened part of the rider bolt.

5. Set the dial gauge to zero with the bar unloaded. To do so, adjust the holder and rotate the scale for precise adjustment.
6. Suspend the load weight, read the deflection on the dial gauge and record it.

Results and analysis:

1. Fill the experimental results at tables 1, 2 & 3.
2. Calculate the reaction forces and compare with experimental values (table 1).
3. Calculate the theoretical deflection and compare with the experimental values of simply supported beam (table 2).
4. Calculate the theoretical deflection and compare with the experimental values of cantilever beam (table 3).
5. Find percentage of error in each case compared to the theoretical ones.
6. Comment on your results and state specifically the source of error in each case.

Distance **x** from support **A** (mm)	Experimental		Theoretical		Percentage Error (%)	
	Reaction force **A** (N)	Reaction force **B** (N)	Reaction force **A** (N)	Reaction force **B** (N)	Reaction force **A**	Reaction force **B**
100						
200						
300						
400						
500 (Center)						

Table 1: Part 1, *Reaction forces.*

Distance **x** from support **A** (mm)	Deflection **W** (Experimental) (mm)	Deflection **W** (Theoretical) (mm)	Percentage Error (%)
100			
200			
300			
400			
500 (Center)			

Table 2: Part 2, simply supported beam deflection.

Length **L** from clamp (mm)	Deflection **W** (Experimental) (mm)	Deflection **W** (Theoretical) (mm)	Percentage Error (%)
200			
300			
400			

Table 3: Part 3, cantilever beam deflection.

Exp. # 3

Stability Of Columns

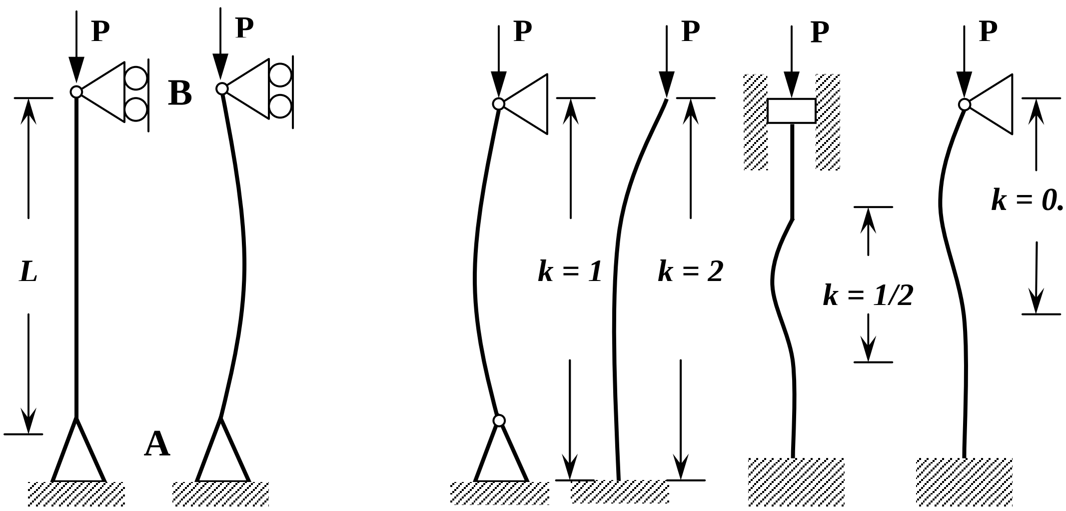
Objective:

The objective of this experiment is to study the behavior of axially loaded columns, determine experimentally the critical buckling load, and to compare results with Euler's formula.

Theory:

Euler's formula:

Figure 1. shows a column of length L supporting and axial load P, increased until it reaches a critical value Pcr and the column don't yield, and then the column will fail due to buckling. The critical load is given by Euler formula:



Buckling of a column due to an axial compressive load P

Case 1 Case 2 Case 3 Case 4

Euler cases of buckling

Apparatus & Equipment Needed:

The table unit consists of a strong aluminum section frame. Beam specimens of varying thickness made of different materials. Loading is applied using sets of weights and the beam deformation measured

Procedure:

1. Set up the test device in vertical and horizontal position. The force gauge can be turned 90 for this purpose.
2. Inert thrust piece with with V notch into attachment socket and fasten with clamping screw.
3. Insert long thrust piece with V notch into the guide bush of the load cross-bar and hold it firmly.
4. Insert the S2 rod specimen with edges in the V notch.

5. The load cross-bar must be clamped on the guide column in such manner that there is still approx. 5 mm for the top thrust pieces to move.
6. Align the rod specimen in such manner that its buckling direction points in the direction of the lateral guide columns. Here, the edges must be perpendicular to the load cross-bar.
7. Pretighten the rod specimen with low, nonmeasurable force.
8. Align the measuring gauge to the middle of the of the rod specimen using the support clamps. The measuring gauge must be set at right angle to the direction of buckling.
9. Pretighten the measuring gauge to 10mm deflection with adjustable support.
10. Slowly subject the rod specimen load using the load nut.
11. Read the deflection from the measuring gauge. Read the record the deflection every 0.25 mm up to 1mm.
12. Above 1 mm deflection, it suffices to record the deflection and force every 0.5 mm.
13. Repeat the experiment for the (Pin-Fixed) end condition column.

Results and analysis:

1. Fill the experimental results at tables 1, 2 & 3.
2. Calculate the reaction forces and compare with experimental values (table 1).
3. Calculate the theoretical deflection and compare with the experimental values of simply supported beam (table 2).
4. Calculate the theoretical deflection and compare with the experimental values of cantilever beam (table 3).
5. Find percentage of error in each case compared to the theoretical ones.
6. Comment on your results and state specifically the source of error in each case.

Distance **x** from support **A** (mm)	Experimental		Theoretical		Percentage Error (%)	
	Reaction force **A** (N)	Reaction force **B** (N)	Reaction force **A** (N)	Reaction force **B** (N)	Reaction force **A**	Reaction force **B**
100						

200						
300						
400						
500 (Center)						

Table 1: Part 1, *Reaction forces.*

Distance **x** from support **A** (mm)	Deflection **W** (Experimental) (mm)	Deflection **W** (Theoretical) (mm)	Percentage Error (%)
100			
200			
300			
400			
500 (Center)			

Table 2: Part 2, simply supported beam deflection.

Length **L** from clamp (mm)	Deflection **W** (Experimental) (mm)	Deflection **W** (Theoretical) (mm)	Percentage Error (%)
200			
300			
400			

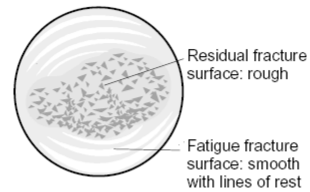
Table 3: Part 3, cantilever beam deflection.

Fatigue Test

Objective:

To investigate the failure of metals due to fatigue loading.

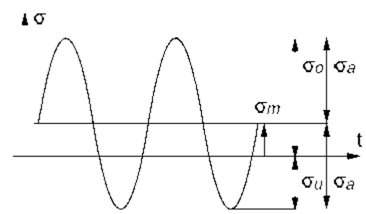
Theory



Appearance of the fracture surface of a sample

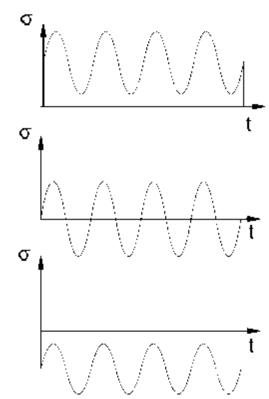
Oscillating stresses are far more dangerous for structural parts and components than a static force applied once.

In the event of frequent repetition of a static load which is in itself permissible, a machine part may rupture as a result of **material fatigue**. As the number of load cycles increases, the permissible stress level declines.



Even stresses which are below the yield point of the material in the elastic range may lead to minor plastic deformations as a result of local peak stresses inside the part. This effect gradually destroys the material due to the constant repetition and eventually results in rupture. The absolute **number of load cycles** is a more decisive factor for failure than the frequency.

Alternating cyclic stress

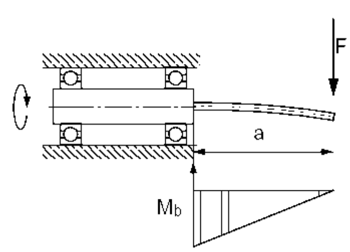


The cyclic stress is composed of a constant part, the mean stress σ_m caused by an initial load, and a superimposed cyclic part with the alternating stress amplitude σ_a.

The largest stress occurring is termed maximum stress $\sigma_o = \sigma_m + \sigma_a$, and the smallest stress is termed minimum stress $\sigma_u = \sigma_m - \sigma_a$. Three ranges are distinguished in alternating cyclic stress:

1. **Range of pulsating stresses (tensile force)** Mean stress larger than the alternating stress amplitude $\sigma_m > \sigma_a$
2. **Range of alternating stresses** Mean stress is smaller in total than the alternating stress amplitude $|\sigma_m| > \sigma_a$
3. **Range of pulsating stresses (compression)** Mean stress is smaller than the negative alternating stress amplitude $\sigma_m < (-\sigma_a)$

Loading of the sample



Loading of the sample corresponds to a clamped bending bar under a **concentrated force F**. This induces a triangular **bending moment Mb** in the sample.

As the bending moment is fixed but the sample is rotating, it is loaded by an alternating, sine-shaped bending stress. The highest bending stress occurs on the shoulder of the sample.

This is a pure reversed bending stress without mean stress. For this reason, it is only possible to determine fatigue strength under complete stress reversal σ_D with a revolving fatigue testing machine. It represents a special case of fatigue strength σ_D. The bending moment is calculated with the load and the lever arm as follows:

$$M_b = F.a$$

By using the section modulus of the sample

$$W_b = \frac{\pi d^3}{32}$$

It is possible to calculate the alternating stress amplitude.

$$\sigma_a = \frac{M_b}{W_b} = \frac{32.a}{\pi.d^3}.F = \frac{32*100.5mm}{\pi*8^3mm^3}.F = 2.0(1/mm^2).F$$

Fatigue Life:

It is the number of cycles to cause failure at a specific stress taken from S-N curve

Fatigue strength:

It is the stress at which failure will occur for a specified number of cycles e.g. 10^6.

Fatigue Endurance Limit:

It is the stress level at which fatigue will never occur, that is the largest value of fluctuating stress that will not cause failure for infinite number of cycles.

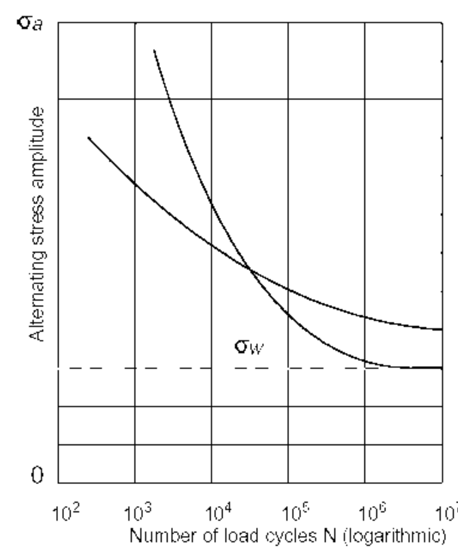
Endurance

Endurance refers to the number N of load cycles until rupture at a certain load.

Stress-number diagram

The stress-number diagram (S-N diagram) portrays the correlation between the number of load cycles until rupture and the corresponding load stress in graph form.

When plotting a stress-number curve, it is important that with alternating stress, the mean stress, or with pulsating stress, the ratio of maximum or minimum stress to mean stress, is kept constant for the various loads. As the mean stress is zero in the revolving fatigue testing machine, this condition is automatically fulfilled.

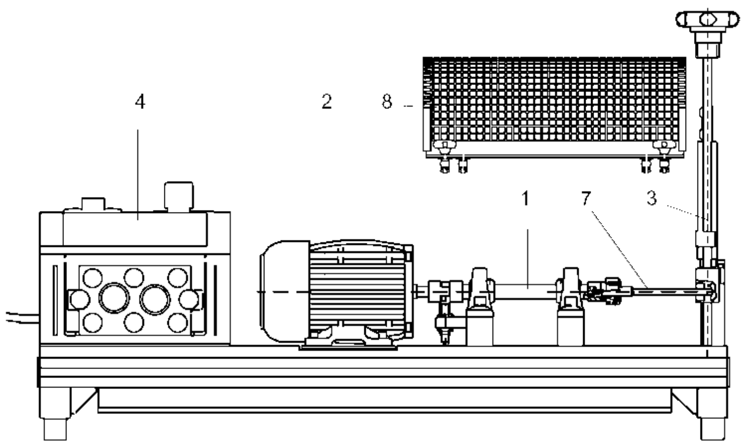


Stress-number diagram for two different materials

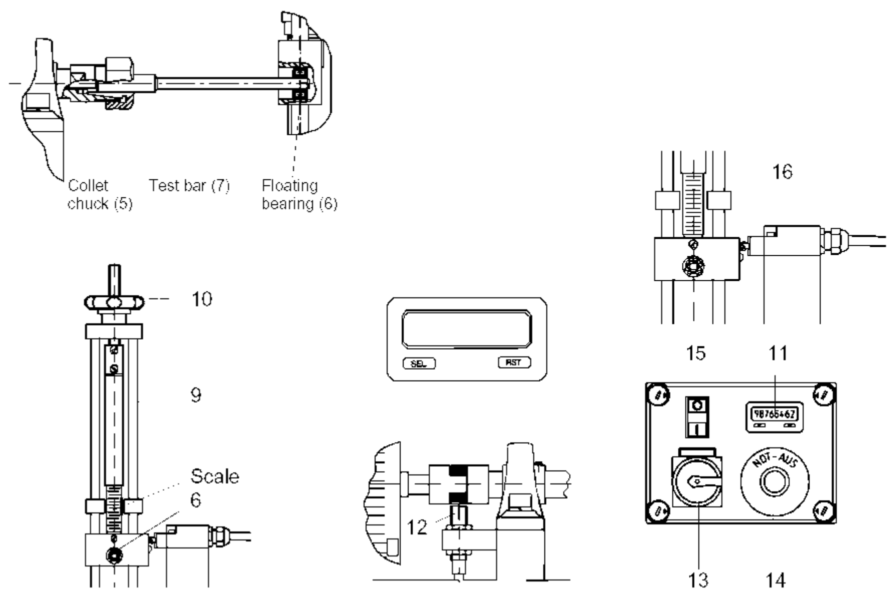
Apparatus:

In the revolving fatigue testing machine, a rotating sample which is clamped on one side is loaded with a concentrated force. As a result, an alternating bending stress is created in the cylindrical sample. Following a certain number of load cycles, the sample will rupture as a result of material fatigue. The revolving fatigue testing machine essentially consists of:

- Spindle with sample receptacle (1)
- Drive motor (2)
- Load device (3)
- Switch box with the electrical control and counter (4)
- Protective hood (8)



The spindle is mounted on two amply dimensioned rolling-contact bearings. The spindle is driven by a smooth running a.c. motor with a speed of approximately 2880 RPM.



The **test bar** (7) is clamped in the spindle on one side by a collet chuck (5) and guided on the other side in a floating bearing (6).

Loading of the sample is performed using a **spring balance** (9) and the floating bearing (6). Pre-stressing of the spring balance and hence adjustment of the load is performed via a threaded spindle with a hand wheel (10). The set load can be read from a scale on the spring balance.

A digital, 8-digit **counter** (11) records the number of load cycles. The counter may also be switched to **rotational speed measurement**. The rotational speed is then displayed in revolutions/minute.

The pulses for the counter are supplied by an **inductive proximity sensor** (12) on the motor coupling.

If the sample ruptures, the motor and the counter are halted automatically via the **stop switch** (16).

The master switch (13), emergency off switch (14), motor control switch (15) and counter (11) are housed in the **switch box** (4).

Procedure:

1. Relieve the load device using the hand wheel (the floating bearing must be at the height of the spindle).
2. First insert the test bar in the floating bearing of the load device.
3. Then insert the test bar in the collet chuck and push in as far as the end stop
4. Check concentricity of the sample by rotating the spindle by hand (correctly seated in the collet chuck, sample not deformed).
5. Mount the protective hood and lock with the knobs
6. Switch on the motor.
7. Swiftly apply the required load by rotating the hand wheel. Read off the load from the scale on the spring balance.
8. Reset the counter using the RST button in order to begin counting.
9. The motor halts automatically when the sample ruptures. Read off the number of load cycles from the counter and make a note of the number

Results & Analysis:

Number of load cycles for test bar under different loads			
No.	**Load F (N)**	**Endurance N (rpm)**	**Stress σ_a (N/mm^2)**
1	200	14030	
2	170	48800	
3	150	167000	
4	130	455000	
5	120	1280800	

1. Calculate the bending stress.
2. Plot stress against number of cycles (endurance).
3. Find the endurance limit and compare with the theoretical values.
4. Estimate the fatigue strength corresponding to $4*10^5$ cycles.
5. Estimate the expected fatigue life corresponding to a bending stress of 250 MPa.

Hardness Test

Objective:

This experiment will lead the student to proper understanding of the principals of hardness tests and measure the hardness of different metallic specimens using the available hardness tester.

Introduction:

The hardness test is a useful and rapid metallurgical non-destructive test, so it can serve as a check on heat treatment given to a metal. It also provides a quick and simple means of checking the tensile strength of ferrous materials since this property can be correlated with the hardness.

Apparatus:

Universal hardness tester includes a direct reading through an electronic digital display of hardness test results. The machine carries out Vickers, Rockwell and Brinell Hardness testing at different loads (see figure below).

Theory:

The hardness of any metal is its resistance to surface indentation under standard test conditions. Three main test methods are used: Brinell, Vickers & Rockwell.

The Brinell test:

In this test (figure 2) an indenter consisting of a hardened steel ball of a diameter **D**, mounted in a suitable holder, is forced into a prepared surface of the test piece using a suitable load **P**, which is maintained for 15 second. The diameter **d** of the circular indentation left in the surface after removal of the load is measured in two directions at right angles using a low power graduated microscope and the average diameter is taken. The Brinell harness number (BHN) maybe found from table relating hardness to the diameter (each table of such relationship refers to a specific load and ball diameter) or calculated from the formula given below:

$$BHN = \frac{\text{Load (kgf)}}{\text{Area of curved surface of indentation in } mm^2} = \frac{P\,(kgf)}{\frac{1}{2}\pi D[D - \sqrt{(D^2 - d^2)}]\ mm^2}$$

The larger the ball it is possible to use, the more accurate the result is likely to be. Balls of 10, 5, 2 and 1 mm diameter are available, enabling one of a suitable size for the thickness of the test piece to be chosen. Having decided on a suitable ball diameter, a load must now be chosen which will give an indentation of reasonable size. For different materials the ratio (**P/D^2**) has been standardized in order to obtain reliable and comparable results. Four standard values of (**P/D^2**) have been adopted, namely 30, 10, 5 and 1 as shown in table 1.

	Load (F kgf)			
Ball Diameter (D mm)	Steels & Cast Irons	Copper, Copper Alloys Aluminum Alloys	Aluminum	Tin, Lead & their Alloys
	$F/D^2 = 30$	$F/D^2 = 10$	$F/D^2 = 5$	$F/D^2 = 1$
1	30	10	5	1
2	120	40	20	4
5	750	250	125	25
10	3000	1000	500	100

Table 1: Standerd values of F/D^2 (Brinell test).

It is not advisable to apply Brinell tests to materials having a hardness, which exceeds (BHN) 450, since the ball maybe easily deformed and this will introduce errors into the test results. The hardness of the ball should be at least 1.7 times higher than the test specimen to prevent permanent set in the ball. By using special work hardened balls, the range of hardness can be extended to 630. For testing the harder steel carbon alloy (WC) balls are often used.

The Brinell test makes a relatively large indentation, which is desirable when it is necessary to obtain the average hardness of a heterogeneous material (e.g. gray cast iron), however large indentation maybe objectionable.

In a Brinell test certain requirements must be met;

1. The depth of indentation, **t**, must not be too great relative to the thickness of the test piece **T**, otherwise the table supporting the test piece would be taking the load and not the test piece itself. For soft materials, **T/t** ≥ 15, whereas **T/t** ≥ 7 for hard materials.
2. It should not be used on work pieces less than 3.2 mm (1/8") thickness.
3. If several readings must be taken on the same specimen, they should be spaced away from each other and away from the edges of the work piece (figure 2).
4. The test maybe unreliable for hard or very soft materials.

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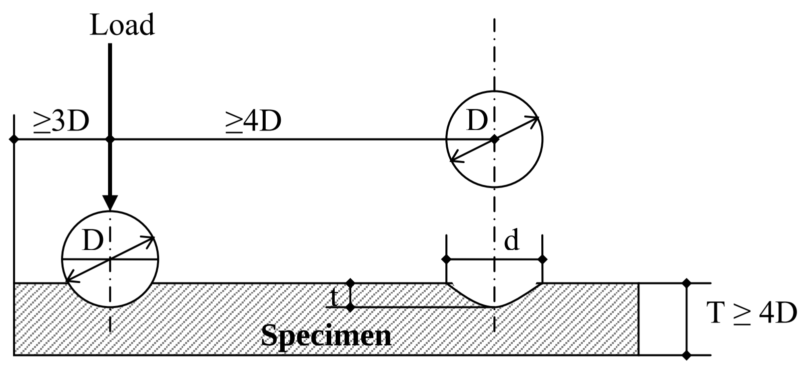


Figure 2

The Vickers test:

The Vickers Hardness test uses a square based diamond pyramid indenter. It gives geometrically similar indentations under different loads. Therefore, the accuracy of the result will not vary with the depth of indentation, through the relationship between the depth of the indentation and thickness of test piece must still be observed.

The diamond indenter, in the form of a right pyramid with a square base and an angle of 136^o between opposite faces, is forces into the prepared surface of the test material under a selected load; **P**. The diamond produces a square indentation and the average is taken of the diagonal lengths which are measured by means of a microscope with a variable slit built into the eye piece. The width of the slit is adjusted so that its edges coincide with the corners of the indentation, and the diagonal length (**d**) is then obtained from a revolution counter geared to the movement of the slit. The ocular reading obtained is converted to a Vickers Hardness number (VHN) by reference to tables. However, as with the Brinell test, the hardness is defined as:

$$VHN = \frac{\text{Load (kgf)}}{\textit{Surface area of indentation in } mm^2} = \frac{\text{P (kgf)}}{\text{d}^2 / 2 \sin \frac{1}{2}(136^\circ)} = 1.854\, P / d^2$$

Loads of 1, 2.5, 5, 10, 20, 30, 50 and 100 (kgf) can be used on the hardness and thickness of the material being tested.

Vickers Hardness test requires a smoother finish on the test material. Thus, it is more suitable than the Brinell test for testing finished components. The Vickers test provides a suitable hardness scale for materials ranging from the very soft to very hard material.

Up to hardness number of ≈ 300 the Brinell and Vickers Hardness values are nearly the same, but at higher values the Brinell results are the lower due to distortion of the ball indenter.

Rockwell test:

In Rockwell test the indentation depth is measured by the instrument and this is directly indicated as a hardness value. No subsequent measurement on the indentation is involved. The test piece is placed on the table of the machine and the indenter is brought into contact with the prepared surface under a minor load 10 kgf. The major load is then applied and when the reading on the indicator is steady the major load is taken off. The test piece remains under the minor load while the hardness value is read directly from the indicator.

Nine scales of the hardness are available (A to K inclusive) but the most commonly used are the B & C scales.

Approximate Hardness Conversions:

Hardness conversion data have been determined approximately and found to be dependent on material type and characteristics (see table 2).

Hardness is not a well defined material property, and because of the experimental dissimilarities among the various techniques, a comprehensive conversion scheme has not been devised. Therefore, care should be taken when conversions are used.

Determination of the tensile strength:

An approximate value of the tensile strength maybe deduced from the Brinell number according to the following relation:

Tensile strength (MPa) = 3.4 ~ 3.5 (BHN).

Brinell		Rockwell		Tensile Strength (kpsi) Approximately
Indentation Diameter Mm	No.	B	C	
2.25	745	-	65.3	-
2.3	712	-	-	-
2.35	682	-	61.7	-
2.4	653	-	60	-
2.45	627	-	58.7	-
2.5	601	-	57.3	-
2.55	578	-	56	-
2.6	555	-	54.7	298
2.65	534	-	53.5	288
2.7	514	-	52.1	274
2.75	495	-	51.6	269
2.8	477	-	50.3	258
2.85	461	-	48.8	244
2.9	444	-	47.2	231
2.95	429	-	45.7	219
3	415	-	44.5	212
3.05	401	-	43.1	202
3.1	388	-	41.8	193
3.15	375	-	40.4	184
3.2	363	-	39.1	177
3.25	352	(110.0)	37.9	171
3.3	341	(109.0)	36.6	164
3.35	331	(108.5)	35.5	159
3.4	321	(108.0)	34.3	154
3.45	311	(107.5)	33.1	149
3.5	302	(107.0)	32.1	146
3.55	293	(106.0)	30.9	141
3.6	285	(105.5)	29.9	138
3.65	277	(104.5)	28.8	134
3.7	269	(104.0)	27.6	130
3.75	262	(103.0)	26.6	127
3.8	255	(102.0)	25.4	123
3.85	248	(101.0)	24.2.	120
3.9	241	100.0	22.8	116
3.95	235	99.0	21.7	114
4	229	98.2	20.5	111
4.05	223	97.3	(18.8)	-
4.1	217	96.4	(17.5)	105
4.15	212	95.5	(16.0)	102
4.2	207	94.6	(15.2)	100
4.25	201	93.8	(13.8)	98
4.3	197	92.8	(12.7)	95
4.35	192	91.9	(11.5)	93
4.4	187	90.7	(10.0)	90
4.45	183	90.0	(9.0)	89
4.5	179	89.0	(8.0)	87
4.55	174	87.8	(6.4)	85
4.6	170	86.8	(5.4)	83
4.65	167	86.0	(4.4)	81
4.7	163	85.0	(3.3)	79
4.8	156	82.9	(0.9)	76
4.9	149	80.8	-	73
5	143	78.7	-	71
5.1	137	76.4	-	67
5.2	131	74.0	-	65
5.3	126	72.0	-	63
5.4	121	69.8	-	60
5.5	116	67.6	-	58
5.6	111	65.7	-	56

Note:
Values in ( ) are beyond normal range and are presented for information only.

VHN	BHN	RHB	RHC
20	19	-	-
40	38	-	-
60	57	-	-
80	76	31.9	-
100	95	52.5	-
120	114	66.3	-
140	133	67.1	-
160	152	83.4	-
180	171	89.2	-
200	190	93.8	14.0
220	209	97.5	18.0
240	228	-	21.8
260	247	-	25.1
280	266	-	28.2
300	285	-	30.0
320	304	-	33.4
340	323	-	35.7
360	342	-	37.8
380	361	-	39.8
400	380	-	41.7
420	399	-	43.5
440	418	-	45.1
460	437	-	46.7
480	452	-	48.2
500	467	-	49.7
520	482	-	51.1
540	497	-	52.4
560	512	-	53.7
580	527	-	54.8
600	542	-	55.7
620	555	-	56.7
640	568	-	57.6
660	580	-	58.5
680	592	-	59.3
700	602	-	60.1
720	-	-	60.9
740	-	-	61.7
760	-	-	62.5
780	-	-	63.3
800	-	-	64.0
820	-	-	64.8
840	-	-	65.5
860	-	-	66.3
880	-	-	67.0
900	-	-	67.7
920	-	-	-
940	-	-	-
960	-	-	-
980	-	-	-
1000	-	-	-

Table 2: Hardness and tensile strength comparison table.

Procedure:

1. Set the Universal hardness testing machine as shown in table (3).
2. Switch on display by the main switch at the back.
3. Select the desired hardness test by cycling using the RANGE cycle key (*) button on the electronic display.
4. Set the upper limit to 999.9 then ENTER (#) and the lower limit to 19.9 then ENTER (#).
5. Ensure that the main load is unloaded.
6. Recheck the selection of the indenter, main load, pre-load, test specimen and the proper hardness test from table 3.
7. Rise the test specimen gradually against the indenter by means of the hand wheel to apply the preload until a reading between 100 to130 is reached on the digital display and wait till you observe a PASS green led on.
8. Load the specimen by moving the main load operating handle to the load position.
9. Wait till the system is stabilized; normally 5 – 8 seconds.
10. Unload the specimen by moving the main load operating handle to the unload position.
11. Wait 5-8 seconds the read the digital display for the hardness test value.
12. Repeat from step 5 to step 11 when testing other specimens.
13. Press the RESET button (4) for other hardness tests.
14. Repeat from step 5 to step 12 when using other hardness tests.

Universal hardness testing machine settings:

Test / Setting	Brinell Hardness Test (HB)	Vickers Hardness Test (HV)		Rockwell Hardness Test (HRC)	Rockwell Hardness Test (HRB)
		10	30		
Indenter	Ball 2.5 mm	Pyramid	Pyramid	Cone	Ball (1/16")
Preload	3	3	3	10	10
Main Load	187.5	10	30	150	100

Table 3: Universal hardness testing machine settings

Hardness test Data Sheet

Test / Material	Brinell Hardness Test (HB)	Vickers Hardness Test (HV)		Rockwell Hardness Test (HRC)	Rockwell Hardness Test (HRB)	Ultimate Tensile Strength	Theoretical Tensile Strength	%Error
		10	30					
Mild Steel			X	X				
High Speed Steel	X	X			X			
Aluminum			X	X		X	X	X
Brass			X	X		X	X	X

X: test is out of range for the selected specimen.

Analysis:

1. Find the Ultimate tensile strength based on the hardness test.
2. Find the theoretical tensile strength and compare your results.
3. Compare types of hardness tests together and state the advantages of each test over the other (Vickers, Brinell, and Rockwell).
4. Check from conversion tables the validity of the experiment results.

Creep Test of Metallic Materials

Objective:

In this test the student will inspect the property of creep in metals..

Introduction

When a material like steel is plastically deformed at ambient temperatures, its strength is increased due to work hardening .This work hardening effectively prevents any further deformation from taking place if the stress remains approximately constant. Annealing the deformed steel at an elevated temperature removes the work and restores the steel to its original condition. However, if the steel is plastically deformed at an elevated temperature, then both work hardening and annealing take place simultaneously. A consequence of this is that steel under a constant stress at an elevated temperature will continuously deform with time, which is creep.

Creep in steel is important only at elevated temperatures. In general creep becomes significant at temperatures above about 0.4 $\mathbf{T_m}$ where $\mathbf{T_m}$ is the absolute melting temperature. However, materials having low melting temperatures will exhibit creep at ambient temperatures. Good examples are lead and various types of plastic. For example, lead has a melting temperature of 326°C (599K), and at 20°C (293K or about 0.5 $\mathbf{T_m}$), it exhibits similar creep characteristics to those of iron at 650°C.

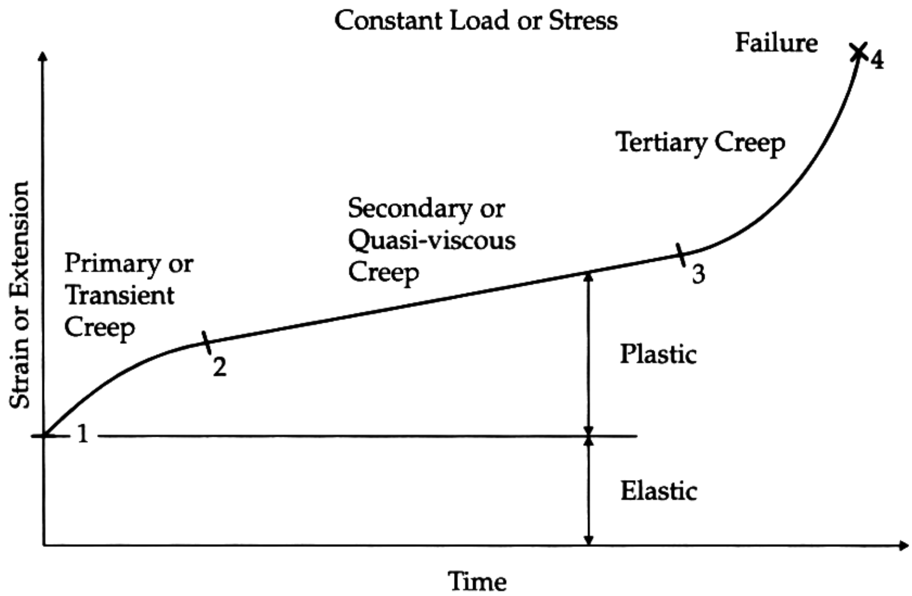


Figure 1 Typical Extension-Time Curve

Creep in Metals

A creep test is carried out by applying a constant load to a specimen and observing the increase in strain (or extension) with time. A typical extension- time curve is shown in Figure 1. Three regions can be readily identified on the curve:

1 to 2 Primary Creep:

Creep proceeds at a diminishing rate due to work hardening of the metal.

2 to 3 Secondary Creep:

Creep proceeds at a constant rate because a balance is achieved between the work hardening and annealing (thermal softening) processes.

3 to 4 Tertiary Creep:

The creep rate increases due to necking of the specimen and the associated increase in local stress. Failure occurs at point 4.

In terms of dislocation theory, dislocations are being generated continuously in the primary stage of creep. With increasing time, more and more dislocations are present and they produce increasing interference with each others movement, thus causing the creep rate to decrease. In the secondary stage, a situation arises where the number of dislocations being generated is exactly equal to the number of dislocations being annealed out. This dynamic equilibrium causes the metal to creep at a constant rate. Eventually, however, the creep rate increases due to localized necking of the specimen (or component); void and micro crack formation at the grain boundaries, and various metallurgical effects such as coarsening of precipitates.

When in service, an engineering component should never enter the tertiary stage of creep. It is therefore the secondary creep stage which is of prime importance as a design criterion. Components which are subject to creep spend most of their lives in the secondary stage, so it follows that the metals or alloys chosen for such components should have as small a secondary creep rate as possible. In general it is the secondary creep rate which determines the life of a given component.

Secondary creep rate for a particular metal or alloy depends on several variables, the most important of which are stress and temperature. The most commonly used expression for relating secondary creep rate **ε** to stress **σ** and absolute temperature **T** has the form:

$$\varepsilon = A\sigma^n e^{-E/RT} \quad \text{……… (1)}$$

The equation shows that the creep rate is increased by raising either the stress or the temperature. Taking natural logarithms gives:

$$Ln\,\varepsilon = Ln\,A + n\,Ln\,\sigma - \frac{E}{RT} \quad \text{……… (2)}$$

Where:

ε is the creep rate.
n is constants and equals to 10
R is the universal gas constant (8.31 J/mol.K)
E is the activation energy for creep in metals (120 kJ/mol).
σ is the stress.
A and **B** are constants.
α is a constant and approximately equals to 0.85

Most metals have a stress exponent of about (**n** = 5) and this value is also applicable in the case of lead, but only when the stress is below about 5 N/mm. At higher stress levels the exponent **n** increases to about 10, and eventually the simple power law of Equation 2 ceases to apply. Instead an exponential expression more adequately fits the experimental data:

$$\varepsilon = B\,e^{\alpha\sigma} e^{-E/RT} \quad \text{……… (3)}$$

Where:

ε is the creep rate.
n is constants and equals to 10
R is the universal gas constant (8.31 J/mol.K)
E is the activation energy for creep in metals (120 kJ/mol).
σ is the stress.
A and **B** are constants.
α is a constant and approximately equals to 0.85

A plot of Ln **ε** against σ will therefore yield a straight line of slope α. If the stress is in units on N/mm^2 (or MN/m^2) the value of α is approximately 0.8 to 0.9 and also varies somehow with stress level.

Apparatus

The SM106 MkII Creep Measurement Apparatus, illustrated in Figure 3.1, uses a simple lever to apply a steady load to the specimen. The specimen is attached at one end to the lever mechanism by a steel pin and fixed at the other end to the bearing block by another steel pin.

Loads are applied to the lever arm by placing weights on the weight hanger, which is pinned to the lever arm. The weight hanger has two pinning positions:

1. The uppermost is used to pin the hanger in the rest position.
2. The lower hole is used to pin the hanger in the loaded position.

The lever arm has a mechanical advantage of 8. The mass of the arm is 0.367 kg, the weight hanger mass is 0.16 kg, and the pins used for pinning the weight hanger and specimen are 0.04 kg each. The load on specimen can be found by taking moments about the pivot bearing as illustrated in Figure 3.

If a mass m is added to the weight hanger then the tensile pull on the specimen (F) is:

$$F = (2.84 + 8m)g \quad (N) \qquad (4)$$

Where

g = acceleration due to gravity

Figure 2 Components of the SM106 Mk II Apparatus

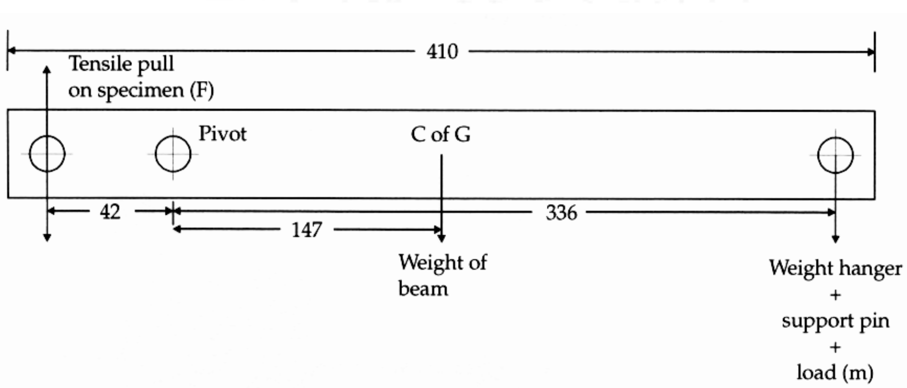


Figure 3 Details of the Lever Arm

Note: The mass m does not include the mass of the hanger: this is included in the constant 2.84.

The specimen extension is measured by a dial test indicator (DTI). A tube fixed to the bearing block is the housing for the DTI and a nylon pinch screw is used to restrain the DTI under steady load conditions. The top of the DTI is attached to the lever mechanism by means of a grooved plate which is bolted to the lever arm. The arrangement is such that the groove in this plate is twice the distance from the pivot than that of the centre of the specimen. Therefore the extension given by the DTI is twice the extension of the specimen.

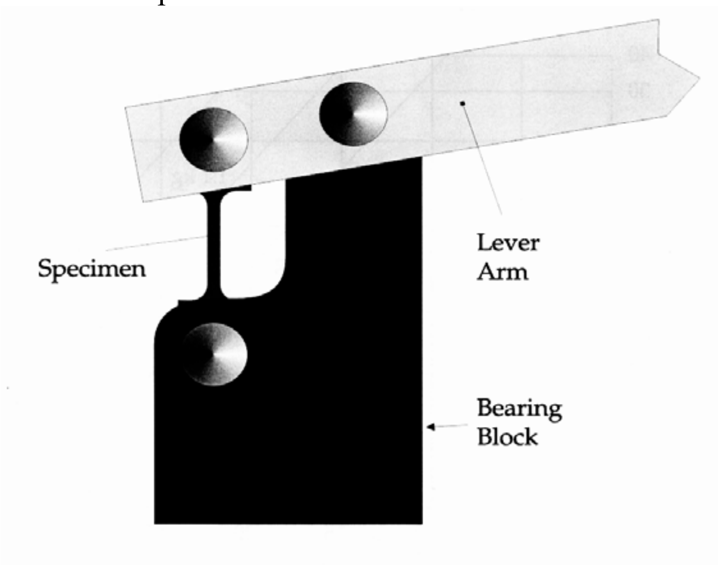


Figure 4 Details of Specimen Loading Arrangement

Procedure

Lead Specimens at Room Temperature

1. Gently raise the lever arm and pin in the rest position.
2. Remove the thumb nut retaining the grooved plate on the lever arm and slacken the nylon pinch screw retaining the Dial Test Indicator (DTI) in the tube.
3. Using both hands, gently lift the DTI and the grooved plate clear of the apparatus. Separate the plate from the DTI and stow in a safe place.
4. Remove the specimen retaining pins from the lever arm and bearing block.
5. Measure and record the thickness and width of the gauge length of the specimen.
6. Fit the top of the specimen into the lever arm and replace the specimen retaining pin.
7. Fit the bottom of the specimen into the bearing block and replace the specimen retaining pin (it may be necessary to remove the rest pin to allow some movement of the lever arm; if this is done, then replace the rest pin when the specimen has been fitted).
8. Refit the DTI and grooved plate but do not tighten up the nylon pinch screw.
9. Remove the rest pin and gently lower the lever arm to take up any free movement. Zero the DTI and turn the nylon pinch screw until it is finger tight.
10. Refit the rest pin.
11. Record the ambient temperature and reset the stop watch to zero ready to start the test.
12. Load the weight hanger with the required load, remove the rest pin and gently lower the lever arm to take up any slack.
13. Raise the hanger to the load position and refit the pin. Gently release the load and start the stop watch.
14. Record extension readings from the DII every 15 seconds for the primary stage of creep. When the extension rate slows down then record readings every minute. As the test approaches the tertiary stage record readings every 15 seconds until fracture occurs or the weight hanger bottoms.

Data and results sheet:

Specimen type : ....

Specimen Dimensions:

- Thickness : ....
- Width : ....
- Gage length : ....

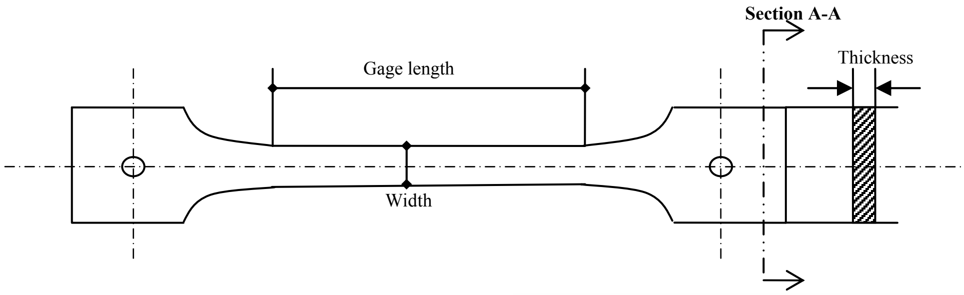
Tensile force (F) : ....

Stress (N/mm^2) : ....

Ambient temperature (^oC) : ....

Time (minutes)	Extension (mm)*	Time (minutes)	Extension (mm)*

Note: * Extension = (dial test indicator reading)/2.



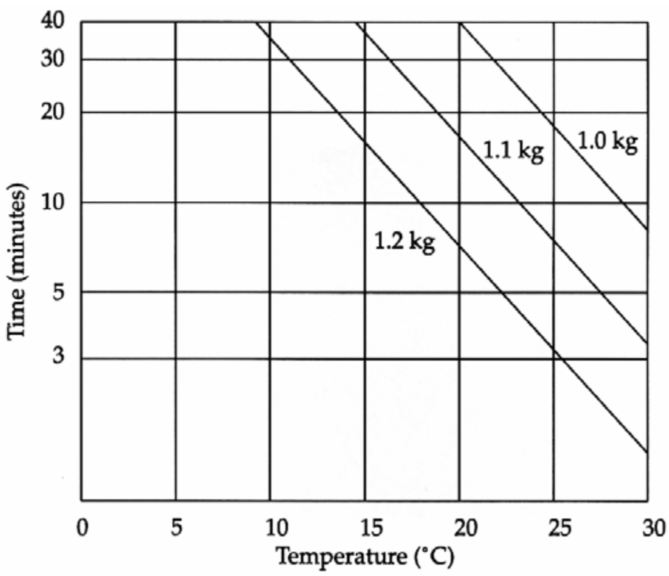


Figure 4: Typical test times for lead specimens at various loads (m) and temperatures.

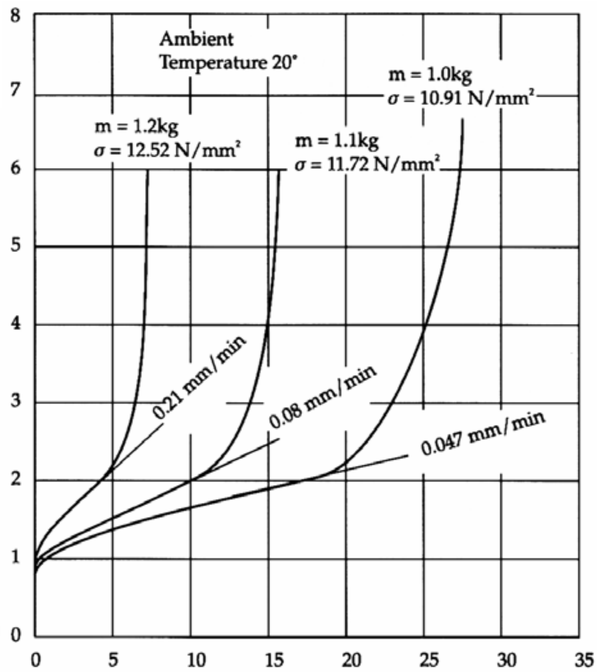


Figure 5: Creep curves for lead specimens at various stress levels.

Analysis:

Time (min)	Extension (mm)
0.25	0.975
0.50	1.060
0.75	1.128
1.00	1.195
1.25	1.220
1.50	1.255
1.75	1.290
2.00	1.320
2.25	1.345
2.50	1.373
2.75	1.395
3.00	1.418
4.00	1.500
5.00	1.580
6.00	1.658
7.00	1.783
8.00	1.825
9.00	1.898
10.00	2.043
11.00	2.160
11.50	2.235
12.00	2.355
12.25	2.398
12.50	2.423
12.75	2.470
13.00	2.575
13.25	-
13.50	2.735
13.75	2.840
14.00	3.085
14.25	3.300
14.50	3.510
14.75	3.705
15.00	3.900
15.25	4.125
15.50	4.475
15.75	4.900
16.00	6.000

Table: Typical results for lead specimens.

1. Plot the results obtained from the test using the graph paper and obtain a curve similar to that shown in **figure 1.**

$$Extension = \frac{reading}{100 * 2 * web\ length} \quad \text{….. (Why?)}$$

2. Plot Extension against time, the slope of the curve at the secondary region is the creep rate **ε**.
3. from the plot obtained, find:
   - The time required for the secondary creep and the tertiary creep.
   - Find the value of the constant **B** from equation 3 for the specimen.
4. Discuss the advantages that can form obtained by the plot.
5. State 3 applications where the creep test is essential in elements and members design.

Exp. # 2

Strain Measurement with Strain Gauges

Objective:

To learn and practice the techniques of strain gauge measurement by applying strain gages to a beam which is simply supported, and to calculate the state of stress at two different points, Poisson's ratio and modulus of elasticity E of the tested beam.

Theory:

The electrical strain gauge is a tool which translates small changes in dimensions and consequent electrical resistance into an equivalent change of strain.

A strain indicator is usually provided in order to give accurate measurements of such a strain. Due to their small size, strain gauges can be used on small surface in any direction.

The electrical strain gauge measurement is based on the simple fact that the electrical resistance of a conductor changes once the length of the conductor changes. If the resistance of a conductor is (R_o) when its length is (l_o), then its resistance will change by (ΔR) when its length changes by (Δl).

The physical relationship between strain and the change of resistance is linear. See figure 1.

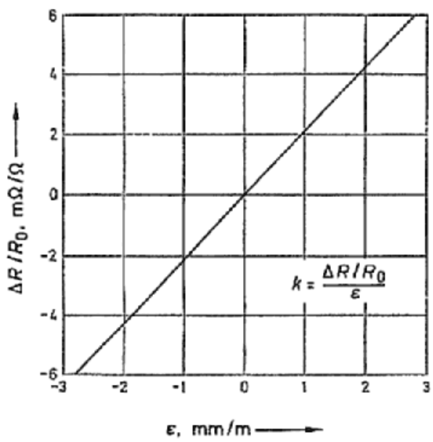


Figure 1: Characteristic for a metal strain gage and the definition of the gage factor k.

A strain gage's sensitivity is expressed by the ratio of the relative change of resistance to the strain and it is represented by the symbol k:

$$k = \frac{\Delta R/R_o}{\Delta l/l_o} = \frac{\Delta R/R_o}{\varepsilon} = \frac{\Omega/\Omega}{m/m} \qquad \text{.......................... [1]}$$

And it is a unit less quantity.

The circuit diagram of the *Wheatstone Bridge*:

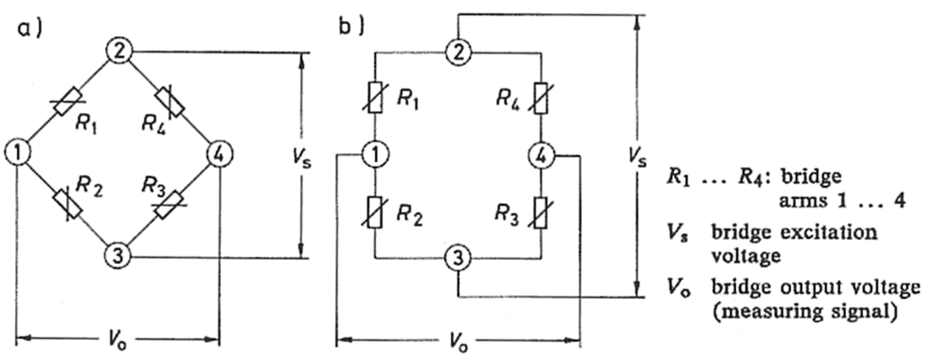


Figure 2: Different representations of the Wheatstone Bridge circuit.

Figure 2 shows two different illustrations of the Wheatstone bridge which are however electrically identical; Figure 2-a shows the usual rhombus type of representation which Wheatstone used; Figure 2-b is a representation of the same circuit which is more clear for the electrically untrained person.

The four arms or branches of the bridge circuit are formed by the resistances R_1 to R_4, the corner points 2 and 3 of the bridge designate the connections for the bridge excitation voltage V_s; the bridge output voltage V_o, the measurement signal, is available on the corner points 1 and 4.

The bridge excitation is usually an applied, stabilized direct or alternating voltage V_s. Sometimes a current supply is used.

The principle of the *Wheatstone Bridge* Circuit:

If a supply voltage V_s is applied to the two bridge supply points 2 and 3 then this is divided up in the two halves of the bridge R_1, R_2 and R_4, R_3 as a ratio of the corresponding bridge resistances, i.e. each half of the bridge forms a voltage divider, see figure 3.

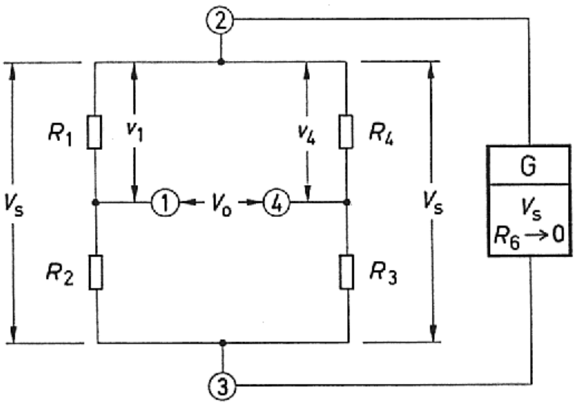


Figure 3: Principle of the voltage-fed Wheatstone bridge circuit.

The following treatment of the bridge circuit assumes that the source resistance R_6 of the voltage supply is negligibly small and that the internal resistance of the instrument for measuring the bridge output voltage is very high and does not cause any load on the bridge circuit. This method of treatment is acceptable.

The partial voltage v_1 on bridge node 1 can be calculated as:

$$v_1 = \frac{R_1}{R_1 + R_2}.V_s \qquad \text{[2]}$$

And the partial voltage v4 on bridge node 4 is:

$$v_4 = \frac{R_4}{R_3 + R_4}.V_s \qquad \text{[3]}$$

The difference between the two partial voltages are the bridge output voltage V_o:

$$V_o = V_s\left(\frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4}\right) = V_s(v_1 - v_4) \qquad \text{[4]}$$

If the unbalance in the bridge is defined as the relative output voltage Vo/Vs, then equation (4) appears in the form

$$\frac{V_o}{V_s} = \frac{R_1}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \qquad \text{[5-a]}$$

Or

$$\frac{V_o}{V_s} = \frac{R_1.R_3 - R_2.R_4}{(R_1 + R_2).(R_3 + R_4)} \qquad \text{[5-b]}$$

There are two conditions where $V_o = 0$;

- When all bridge resistors are equal value, $R_1 = R_2 = R_3 = R_4 = R$
- When the resistor ratios in the two halves of the bridge are the same, $\left(\frac{R_1}{R_2} = \frac{R_4}{R_3}\right)$, in this case $\left(\frac{V_o}{V_s} = 0\right)$ and the bridge circuit is balanced.

If the bridge resistors R_1 to R_4 change their value by an amount ΔR, then the bridge circuit becomes unbalanced, and an output voltage is present between points 1 and 4. Equation (5-a) becomes:

$$\frac{V_o}{V_s} = \frac{R_1 + \Delta R_1}{R_1 + \Delta R_1 + R_2 + \Delta R_2} - \frac{R_4 + \Delta R_4}{R_3 + \Delta R_3 + R_4 + \Delta R_4} \qquad \text{……………………. [6]}$$

All bridge conditions can be calculated with equation 6, irrespective of the basic resistance R that the individual arms of the bridge possess. However, in strain gage techniques all the arms of the bridge should have the same resistance; at least the two halves of the bridge R_1, R_2, R_3 and R_4 must have the same resistances. Variations due to the tolerance on the strain gage resistance do not affect the measurement accuracy. Even differences of 5% in the resistances of R_1 and R_2 produce errors of less than 0.1%.

In strain-gauge techniques the amounts by which the resistance changes in the metal strain gages are very small and of the order of about 10^{-3}. It is therefore usual to use the approximation below, which provides sufficiently accurate results for practical requirements, instead of equation 6.

$$\frac{V_o}{V_s} = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) \qquad \text{……………………. [7]}$$

The approximate formula also shows that the relative change of resistance of each arm of the bridge is the governing factor in balancing the bridge and not the absolute change of resistance.

Also

$$\frac{\Delta R}{R} = k.\varepsilon \qquad \text{……………………. [8]}$$

Where equation 7 in the form:

$$\frac{V_o}{V_s} = \frac{k}{4}\left(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4\right) \qquad \text{……………………. [9]}$$

The equations 7 & 9 assume that all the resistances in the bridge change. This situation occurs for example in transducers or with test objects performing a similar function. In experimental stress analysis this is hardly ever the case and usually only some of the arms of the bridge contain active strain gages, the remainder being made up of bridge completion resistors. Designations for the various forms such as Quarter Bridge, Half Bridge, Double Quarter or Diagonal Bridge and full bridge are commonplace. Figure 4 illustrates the different forms.

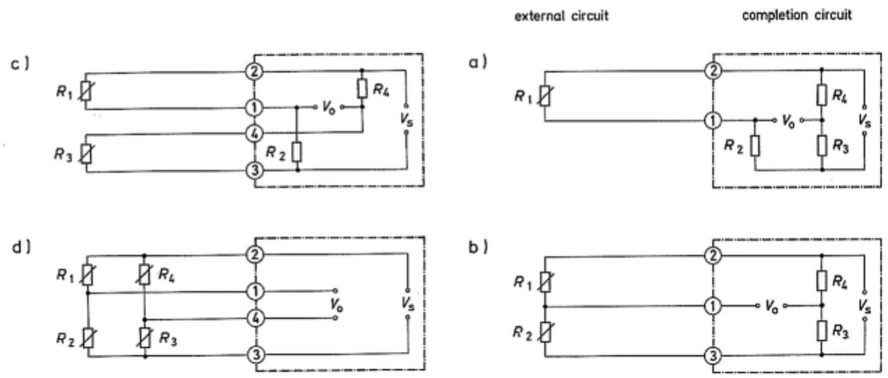


Figure 4:
Forms of the Wheatstone bridge circuit used in strain gauge techniques:
a) Quarter Bridge.
b) Half Bridge.
c) Bouble Quarter or Diagonal Bridge.
d) Full bridge.

The measurement system:

The strains measured with strain gauges are normally very small. Consequently the changes of resistance are also very small and cannot be measured directly, say with an ohmmeter. The strain gauge must therefore be included in a measurement system where precise determination of the strain gauge's change of resistance is possible.

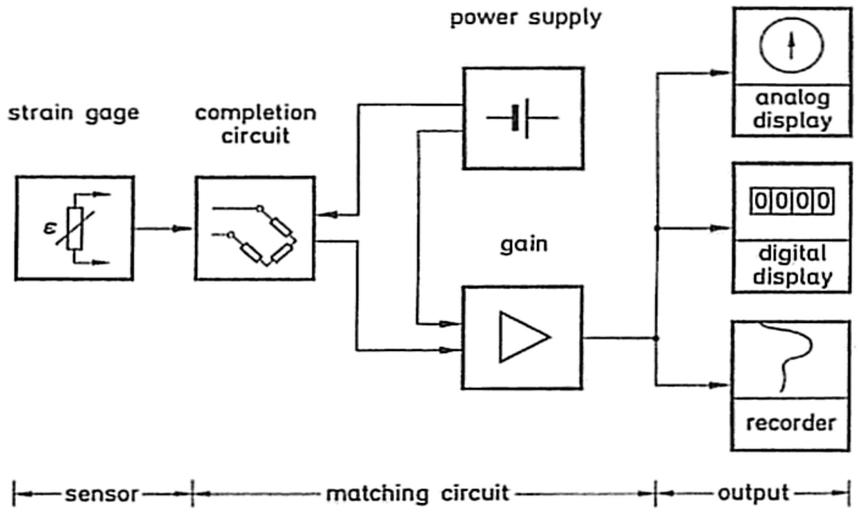


Figure 5: Diagram of a measurement system for measuring strains with a strain gage.

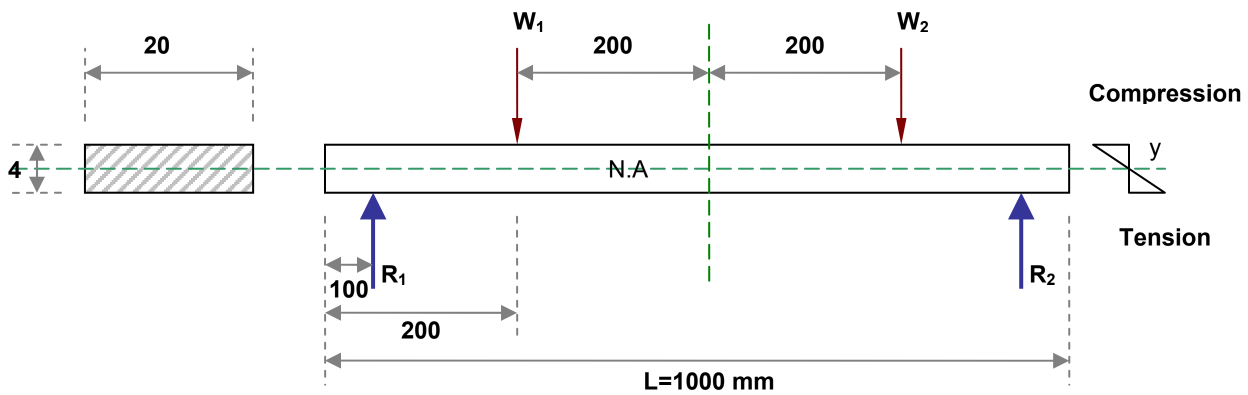


Figure 6: Free body diagram.

The relation for the normal bending stresses in beams is very well developed. As for shown in figure 6 the bending stress σ is directly proportional to the distance y from the neutral axis and the bending moment M.

$$\sigma = -\frac{My}{I} \qquad \text{.......................... [10]}$$

Where I is the second moment of area about the z - axis. It is customary to designate c = y_{max}. to omit the negative sign, and to write:

$$\sigma = -\frac{Mc}{I} \qquad \text{.......................... [11]}$$

Where it is understood that the above equation gives the maximum stress.

If the strain gauge techniques are used to measure strain. Then using Hook's law, the stress state at a point can be calculated after the state of strain has been measured. We define the principal strains as the strains in the direction of the principal stresses. The general form of Hook's law is

$$\sigma_1 = E\varepsilon_1(1-\nu) + \nu E(\varepsilon_2 + \varepsilon_3)/1-\nu-2\nu^2$$
$$\sigma_2 = E\varepsilon_2(1-\nu) + \nu E(\varepsilon_1 + \varepsilon_3)/1-\nu-2\nu^2$$
$$\sigma_3 = E\varepsilon_3(1-\nu) + \nu E(\varepsilon_1 + \varepsilon_2)/1-\nu-2\nu^2$$

where σ_1, σ_2, σ_3 are the principal stresses, ε_1, ε_2, ε_3, are the principal strains, E is the modulas of elasticity and v is the Poison's ratio.

For the case of uniaxial type of stress, Hook's Law reduces to the form:

$$\sigma_1 = E\varepsilon_1$$
$$\sigma_2 = 0$$
$$\sigma_3 = 0$$

And the Poisson's ratio for the beam is given by:

$$\nu = \frac{Lateral\ Strain}{Axial\ Strain}$$

Strain Measurement:

The governing Equations of the strain reading, in a half bridge setup, of the indicator is given by:

$$\text{Voltage read in mV} = \frac{Ge}{k_R} = \frac{G}{k_R}.\frac{V}{4}.\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2}\right) = \frac{GV}{4}.\frac{k}{k_R}\left(\varepsilon_1^J - \varepsilon_2^J\right) \qquad \text{.......................... [12]}$$

Where:

- **k** is the real gauge factor of the gauges.
- $\mathbf{k_R}$ is the value of the dividing factor set as gauge factor on the bridge.
- (**GV/4**) = 1000 for the EI 616 Bridge.

Note that we set k_R = k in the experiment, consequently all readings are in terms of 10^{-6}.

See figure 7 for comparison of half bridge with full bridge setup.

Apparatus & equipments needed:

- Beam Apparatus.
- Two half bridge Strain Gauges fixed on lower & upper faces of the beam.
- Digital strain indicator as shown in the figure below (EI 616 STRAIN BRIDGE).

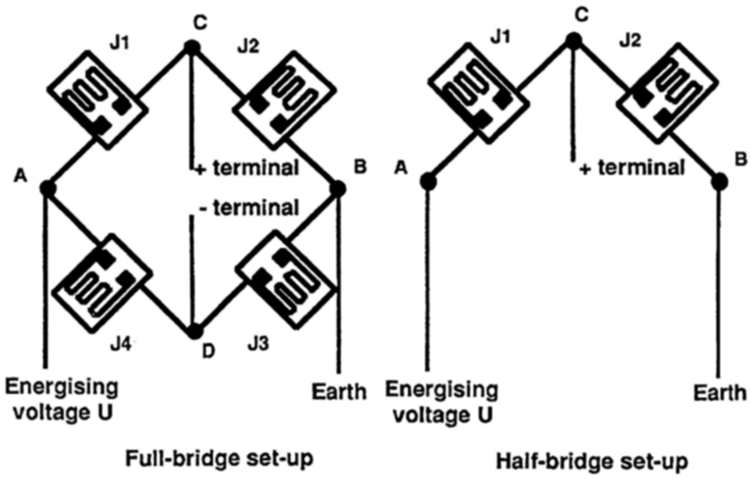


Figure 7: for comparison of half bridge with full bridge setup.

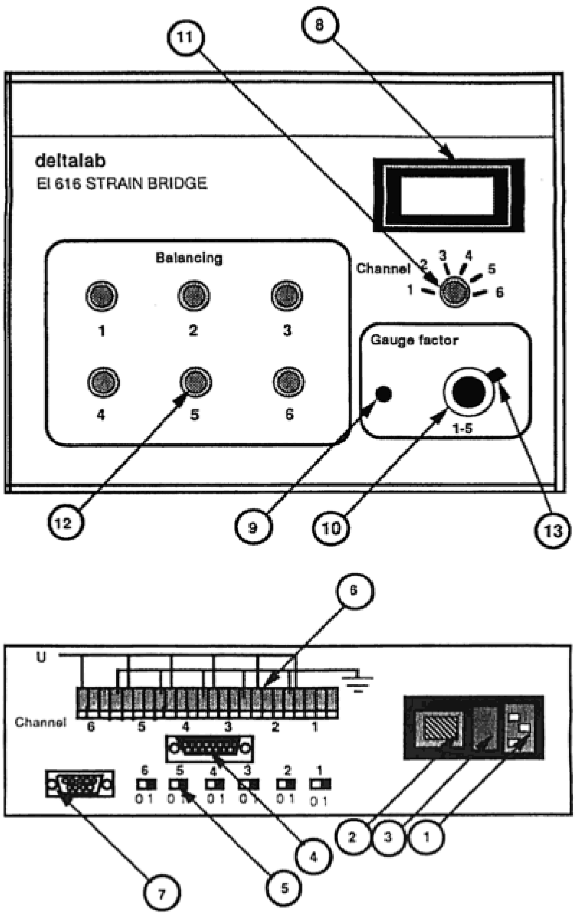


Figure 8: Digital strain indicator, EI 616 STRAIN BRIDGE. The first figure for the front panel and the second one is for the rear panel. Illustration of the function of each component is indicated as follows:

1. Mains Power socket.
2. On-Off switch.
3. Fuse.
4. 15-pin cannon socket for gauge bridge connection.
5. Half Bridge- Full Bridge selector for each measurement channel.
6. Pressure contacts for connecting individual strain bridges.
7. Analogue output via 9-pin cannon socket.
8. 20 000-point digital display.
9. Push-button for setting gauge factor.
10. Gauge factor adjustment potentiometer.
11. Channel selector switch.
12. Potentiometers for initial balancing of bridge gauges.
13. Gauge factor potentiometer lock.

Procedure

1. Set up the beam apparatus with two load hangers.
2. Two linear, half circuits strain gauges to be connected on the top and bottom of the beam at midspan.
3. Insert the gauge factor, and zero the gauge readings.
4. Apply loads to the hangers, and take readings of the channels of the strain gauges indicator.
5. Repeat the experiment at different applied loads.

Results and analysis:

1. Fill the experimental results at table below.
2. Calculate the bending moment (M) at the midspan.
3. Calculate the axial stress (σ).
4. Plot (σ) against (ε_{axial}), find E and compare it with the theoretical value.
5. Plot ε_{axial} against $\varepsilon_{lateral}$, find ν and compare it with the theoretical value obtained from 6.
6. Obtain the value of Poison's ratio ν for the type of steel beam from strength of material and books.
7. State 5 applications of strain measurement using strain gauges.
8. State 5 specific sources of error in this experiment.

Rod material:	....	Cross section dimensions:	....
Length:	....	Distance of W from center:	....
Cross Section Type:	....	Ends condition:	....

Table 1: experiment parameters.

No.	W_1 (N)	W_2 (N)	Channel 1 reading $\varepsilon_{lateral}$	Channel 2 reading ε_{axial}	Bending moment (M)	Stress (σ)
1	*0*	*5*				
2	*5*	*5*				
3	*5*	*10*				
4	*10*	*10*				
5	*10*	*15*				
6	*15*	*15*				

Table 2: experiment data and results.

THIN WALL CYLINDER

1. OBJECTIVE:

1. To study the stress and strain developed in a thin wall cylinder under internal pressure.
2. To determine the Poisson's ratio (ν) and the Young's modulus of elasticity (E) for the cylinder material.

2. APPARATUS:

Fig. 1 shows a thin walled cylinder of aluminum containing a freely supported piston. The piston can move in or out to alter the end conditions by use of the adjustment screw. A pressure gauge fits onto the cylinder. Six strain gauges are positioned onto the cylinder at different angels to measure the strain.(see fig.2) The apparatus is connected to P.C. so that all readings of the stain gauges can be taken out from the computer. Cylinder contains way of relieving cylinder of all longitudinal stress (open end condition).

3. THEORY:

In a thin cylinder, where the ratio of wall thickness to internal diameter is less than about (1/20), the value of stress may be assumed to be constant throughout the wall thickness, so the radial stress will be ignored.

The two principal stresses, circumferential (hoop) and longitudinal see (fig. 3) will be given by the following equations:

$$\sigma_H = \frac{pd}{2t} \quad \text{and} \quad \sigma_L = \frac{pd}{4t}$$

$$\varepsilon_H = \frac{\sigma_H}{E} - \upsilon \frac{\sigma_L}{E}$$

$$\varepsilon_L = \frac{\sigma_L}{E} - \upsilon \frac{\sigma_H}{E}$$

For open end conditions ($\sigma_L = 0$)

$$\varepsilon_H = \frac{\sigma_H}{E} \quad \text{and} \quad \varepsilon_L = -\upsilon \frac{\sigma_H}{E}$$

$$\upsilon = \frac{-\varepsilon_L}{\varepsilon_H}$$

4. PROCEDURE:

I:YOUNG'S MODULUSE EXPERIMENT:

1. Verify the open end condition:
   a- Return valve shall be fully unscrewed.
   b- Screw the adjustment screw until it reaches the stop.
2. From the main menu select experiments, then select Young's modulus.
3. From the tools menu select calibrate, this will set zero to all the transducers.
4. Close the return valve; take reading at no pressure by pressing F5.
5. Increase the pressure slowly (using the hand pump), then take readings with F5 every 0.5 MPa steps.

Π:POISSON'S RATIO EXPERIMENT:

1. Repeat steps 1 to 4.
2. Increase the pressure using the hand pump to 3 Mpa.
3. Press F5 to store the strain gauge and pressure readings.
4. Fill the results into tables 1 and 2.

5. RESULTS:

I:YOUNG'S MODULUSE EXPERIMENT:

Cylinder pressure (MN/m^2)	Hoop stress σ_H (MN/m^2)	Measured hoop strain ε_H ($\mu\varepsilon$)	
		Gauge No. 1	Gauge No. 6

II:POISSON'S RATIO EXPERIMENT:

P= MN/m^2

Gauge No.	Actual strain ($\mu\varepsilon$)	Theoretical strain ($\mu\varepsilon$)	Error
1			
2			
3			
4			
5			
6			

6. ANALYSIS:

1. Plot the hoop stress σ_H against the hoop strain ε_H

Where: $$\sigma_H = \frac{pd}{2t}$$ and $$\varepsilon_H = \frac{\varepsilon_{gage1} + \varepsilon_{gage6}}{2}$$

2. Determine the modulus of elasticity (E) from the above graph and compare your results with the theoretical value.

3. Calculate the Poisson's ratio for open end conditions using the following equation.

$$\upsilon = \frac{-\varepsilon_{L1}}{\varepsilon_{H1}}$$

Where ε_{L1} = Actual strain reading of gauge 2.
ε_{H1} = Average actual strain readings of gauges 1&6.

4. Calculate the theoretical principal hoop and longitudinal strains for Poisson's experiment and compare your results with the experimental values.