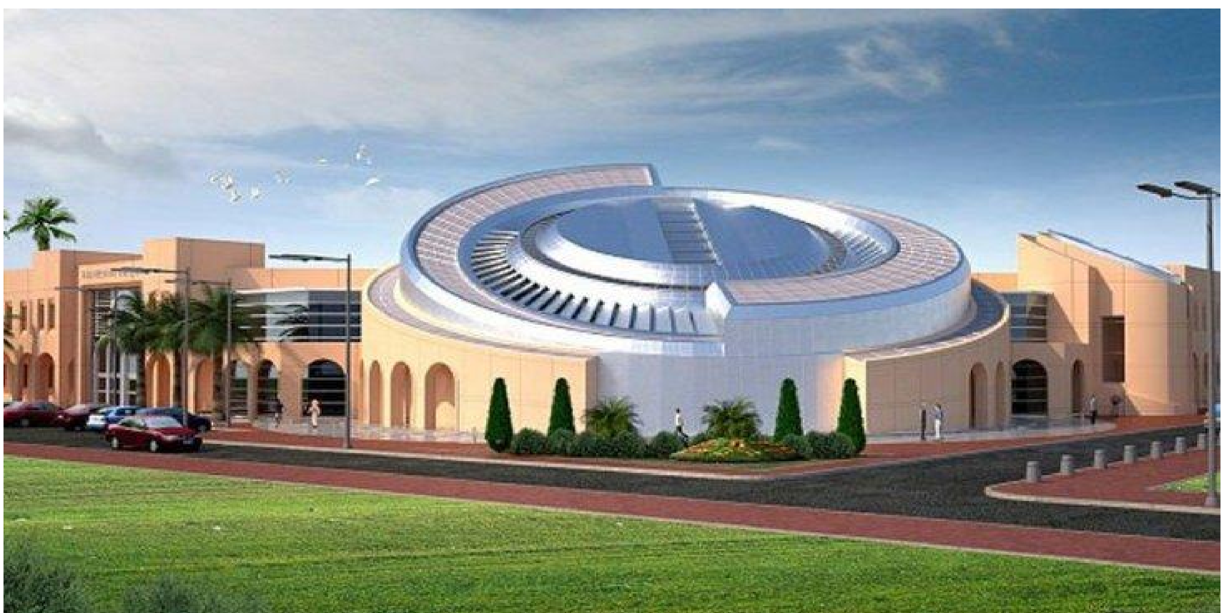
KING FAISAL UNIVERSITY

College Of Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

Engr209: Strength of materials

"Lab Manual"



Prepared By: Eng. Ziad Shatnawi

Major Topics covered and schedule in weeks:

Topic	Week #	Courses Covered
Introduction and Lab safety.	1	
Tensile Test	2	
Compression Test	3	
Torsion Test	4	
Deflection of Beams	5	
Buckling of Columns	7	
Fatigue Test	8	
Impact Test	9	
Creep Test	10	
Thin Wall Cyclinder	11	
Hardness Test	12	
Design Of Experiment	13-15	
Mid Term Exam	6	
Final Exam	16	

Specific Outcomes of Instruction (Lab Learning Outcomes):

A student who successfully fulfills the course requirements will have demonstrated:

Tensile and compression behavior using Universal Testing Machine
Torsion behavior using Testing Machine.
Hardness properties using Hardness Testing Machine
Fatigue mechanism of shafts using Fatigue Testing Machine
Impact behavior using Impact Testing Machine
Buckling behavior of columns using Buckling Testing Machine
Deflection behavior of beams using Deflection of Beams Apparatus
Stresses in thin walled pressure vessel using Thin Walled Pressure Vessel Apparatus.

Student Outcomes (SO) Addressed by the Lab:

z	Outcome Description General Engineering Student Outcomes	Contribution
1.	an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	M
2.	an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	H
3.	an ability to communicate effectively with a range of audiences	L
4.	an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	**L**
5.	an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	L
6.	an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	L
7.	an ability to acquire and apply new knowledge as needed, using appropriate learning strategies	M

Table of Content

Experiment 1: TENSILE TEST

I. Objective:

- Know which ASTM standards are used for the tensile test.
- Know how the tensile test is used to establish mechanical properties.
- Know how the tensile test is used to measure engineering and scientific data such as strain hardening rates, modulus of elasticity, 0.2% yield stress, tensile strength, fracture stress and energy to fracture a tensile specimen.
- Know how to compute engineering stress and strain and true stress and strain.
- Understand fracture types for tensile test

II. Test Standard

- ASTM E 8 and ASTM E 646.

III. Theory:

1- Introduction

The tensile test is one of the most frequently tests used to determine some mechanical properties by applying uniaxial load (static or quasi-static with very small rate) on a specimen until it breaks. The tensile machine is instrumented to read the applying force, and we know the cross- sectional area, so the stress at any load can be calculated. The gauge length of the test specimen should be at least five times its diameter, and the specimen must have a uniform cross-sectional area. The best way to represent the data is to plot a stress strain diagram. From the stress strain diagram many properties related to the material tested can be found. Also we can determine from this test whether the material is brittle or ductile, the brittle material shows a little amount of deformation and under a small load a fracture will be happened, on the other hand, the ductile material shows a considerable amount of deformation before fracture. Moreover, the yield point in the ductile material is clearly seen from the stress strain diagram, but in the brittle material the yield point is determined by the offset method. From another point of the ductile and brittle material classified according to the fracture strain as the following:

For ductile material $\varepsilon_f \geq 0.05$

For brittle material $\varepsilon_f < 0.05$

The following standards are used for Tensile test: ***ASTM E 8 and ASTM E 646.***

Stress Strain relations

- *Engineering Stress*: $\sigma = \frac{Applied\ Force}{Initial\ cross\ sectional\ area} = \frac{F}{A_o}$
- *Engineering Strain:* $\varepsilon = \frac{l_i - l_o}{l_o} = \frac{\Delta l}{l_o}$

Where: l_o is initial gauge length, and l_i is the instantaneous gauge length.

- *True Stress:* $\sigma_t = \frac{Applied\ force}{Instantaneous\ cross-sectioal\ area} = \frac{F}{A_i} = \sigma(1 + \varepsilon)$
- *True Strain:* $\varepsilon_t = ln\left(\frac{l_i}{l_o}\right) = ln(1 + \varepsilon)$

Stress - Strain diagram

Stress strain diagram is a plot of engineering stress (y-axis) versus engineering strain (x-axis). It is a very important plot, from which all mechanical properties for the test specimen can be found. Figure 2 shows a typical stress strain curve where all details, points and properties are illustrated

Elastic region:

- Stress and strain are linear proportionally
- Material returns to its original shape when load released
- Modulus of elasticity or Young's Modulus: it is a measure of a material's stiffness, and it is the slope of the linear part of the stress strain graph.

Proportional limit:

The end of the linear proportional between stress and strain

Elastic limit:

The end of the elastic region, for most materials proportional limit and elastic limit are coincide

Yield stress:

At this point, the material no longer exhibits elastic behavior and permanent deformation occurs. This onset of inelastic behavior is defined as the yield stress or yield strength.

Ductile materials will have a well-defined yield point that can be easily identified on the stress strain curve. Other materials will not have a discernable yield point and other methods must be employed to estimate the yield stress. One common method is the offset method, where a straight line is drawn parallel to the elastic slope and offset an arbitrary amount, most commonly for engineering metals, 0.2%

Ultimate tensile strength:

The highest stress the material is capable to withstand. It will be the highest measurable stress on the graph. This is termed the ultimate strength or tensile strength.

Fracture strength:

The point at which the material actually fractures is termed the fracture stress. For ductile materials, the Ultimate stress is greater than the fracture stress, but for brittle materials, the ultimate stress is equal the fracture stress.

Ductility:

Ductility is the materials ability to stretch or accommodate inelastic deformation without breaking. Another phenomenon that can be observed of a ductile material undergoing tensile testing is necking.

The ductility of the material can be measured by:

1- $Percent\ of\ elongation = \frac{\Delta L}{L} \times 100\%$

So the higher value the more ductile material.

2- $Percent\ of\ reduction\ of\ area = \frac{\Delta A}{A} \times 100\%$

Modulus of resilience Ur:

The amount of energy the material can absorb while still in the elastic region.

This is the area under the linear portion of the stress strain plot up to the yield point.

$$U_r = \frac{1}{2} \times \sigma_y \times \varepsilon_y = \frac{\sigma_y^2}{2E}$$

Where the strain (ε_y) and stress (σ_y) are measured at the yield point.

Modulus of toughness:

Toughness is the amount of energy the specimen can absorb until failure. This is the area under the stress-strain graph up to the failure point. This is easily done by counting the squares under the line on graph paper. If you have electronic data, it toughness is easy to calculate by numerical integration.

Poisson's ratio v

$\nu = \frac{lateral\ strain}{Axial\ strain}$ in the elastic region

At any point on diagram at elastic region

$lateral\ strain = \frac{\Delta D}{D_i}$ and $Axial\ strain = \frac{\Delta l}{l_o}$

Note: use constant volume principle $A \times L = A_o \times L_o$

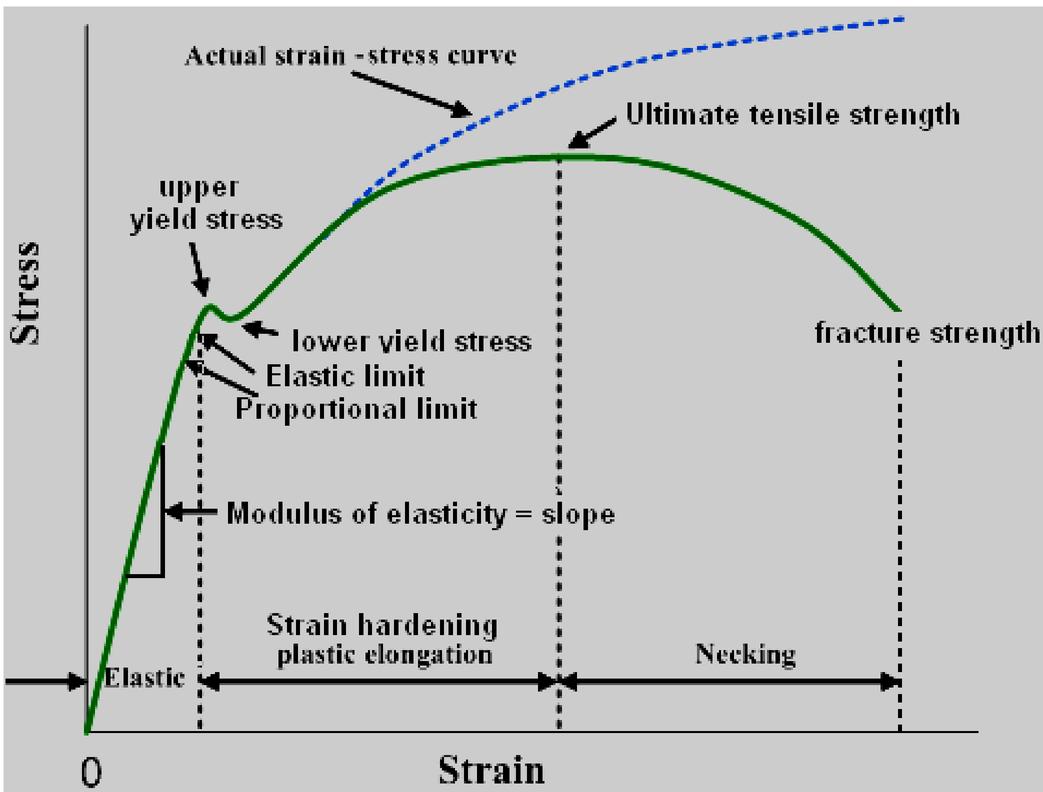


Figure 2: Typical Stress Strain diagram

Stress – strain diagram differs from ductile to brittle materials, figure 3 shows a typical stress strain diagram for different materials

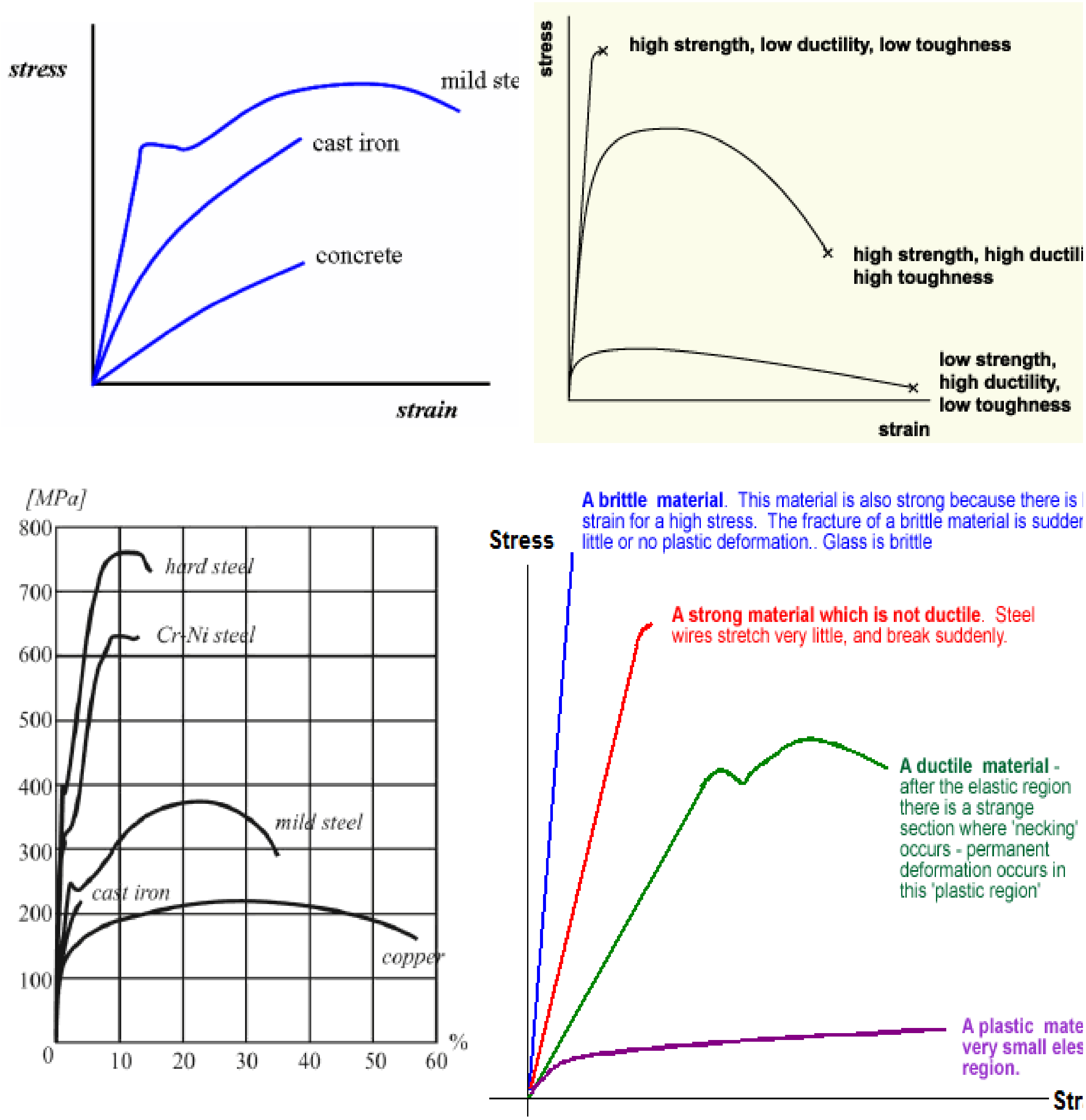


Figure 3: Stress Strain diagrams for different materials and cases

Types of fracture

In tensile test the state of stress is shown in figure 4 where maximum normal stress occurs at a plane perpendicular to the direction of applied load, but maximum shear stress occurs at a plane inclined 45o to the axis of specimen. Ductile materials are strong in carrying normal stress and weak in shear stress, on the contrary of brittle materials. So ductile material usually fail at angle 45o like cup and cone shape especially in circular specimens, but brittle materials fail at normal plane. See figure 5

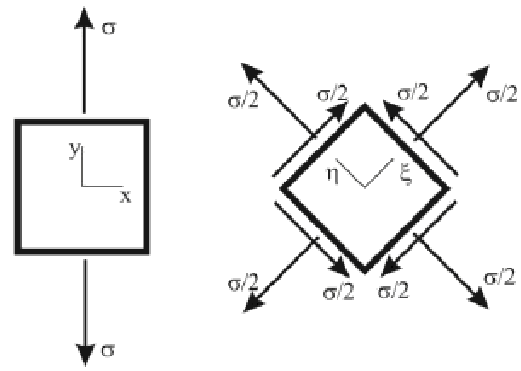
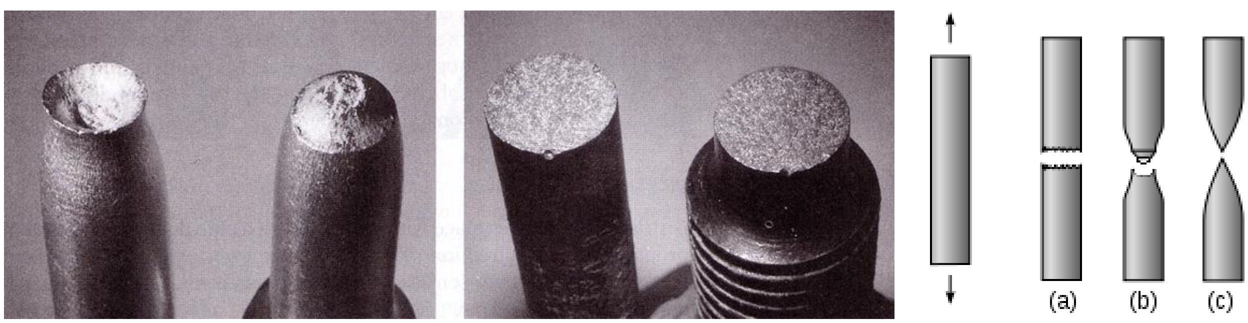


Figure 4: State of stress for tensile test



Ductile fracture

Brittle fracture

(a) Brittle fracture
(b) Ductile fracture
(c) Completely ductile fracture

Figure 5: types of fracture for tensile test

IV. Apparatus:

Figure 1 shows the Universal Testing Machine TM-300 with Dual Column, Stand Alone System with 300kN (65,000lbf) Maximum Capacity. The machine main components are grips/fixtures, load cells, and extensometer. It is designed to perform tensile, compression, flexural (bending) tests, and it is suitable for metals, composites, alloys, rigid plastics and films, textiles, paper, board and finished products. The machine was equipped with advanced software, the users can analyze the test data, have full control on processing, filing, and test management technical features

Figure 1: Universal Testing Machine

V. Procedure:

1. Using a micrometer, measure and record the diameter of the test specimen at its center.
2. Measure the exact gage length with a micrometer. Attach a extensometer to the specimen at two gage points.
3. Place the specimen in the threaded grips and load the specimen slowly to failure.
4. Record the load and deflection.
4. Remove the extensometer from the specimen before fracture occurs.
5. After the specimen has been broken, push the two broken pieces together by hand, and measure the distance between the two gage points by means of a micrometer to determine the total plastic deformation. Measure also the diameter of the reduced cross-section of the fractured specimen.
6. Sketch the fractured specimen.

VI. Experimental Work:

<u>Specimen</u>

Test specimens for tensile testing are generally either circular or rectangular with larger ends to facilitate gripping the sample. In this experiment the specimen is circular with the following details

Material	1018 steel	
Dimensions	Diameter D=	5.1 mm
	Initial test length l_o=	38.1mm

Force F(N)	Displacement Δl (mm)	Strain $\varepsilon = \frac{\Delta l}{l_o}$	Stress $\sigma = \frac{F}{A}$ (MPa)

I. Objective:

- To obtain load – displacement behavior of the materials.
- To determine mechanical properties of the material through compression test.
- To observe failure behavior of the materials subjected to compression load.
- To compare between tensile test and compression test.

II. Test Standard

- ASTM E 8 and ASTM E 646.

III. Theory:

Shape of stress stain diagram

Stress strain diagram for compression have different shapes from those for tesion.

a) Ductile materials: For ductile material such as mild steel, the load Vs compression diagram would be as follows (figure 1)

(1) The ductile materials such as steel, Aluminum, and copper have stress – strain diagrams similar to ones which we have for tensile test, there would be an elastic range which is then followed by a plastic region.

(2) The ductile materials have proportional limits in compression test are very much close to those in tension.

(3) The initial region of compression stress – strain diagrams are very similar to the tension diagrams, when yielding begins, the behavior is quite different. In tension test, the specimen is being stretched, necking may occur, and ultimately fracture fakes place. On the other hand when a small specimen of the ductile material is compressed, it begins to bulge on sides and becomes barrel shaped as shown in the figure above. With increasing load, the specimen is flattened out, thus offering increased resistance to further shortening (which means that the stress – strains curve goes upward) this effect is indicated in the diagram.

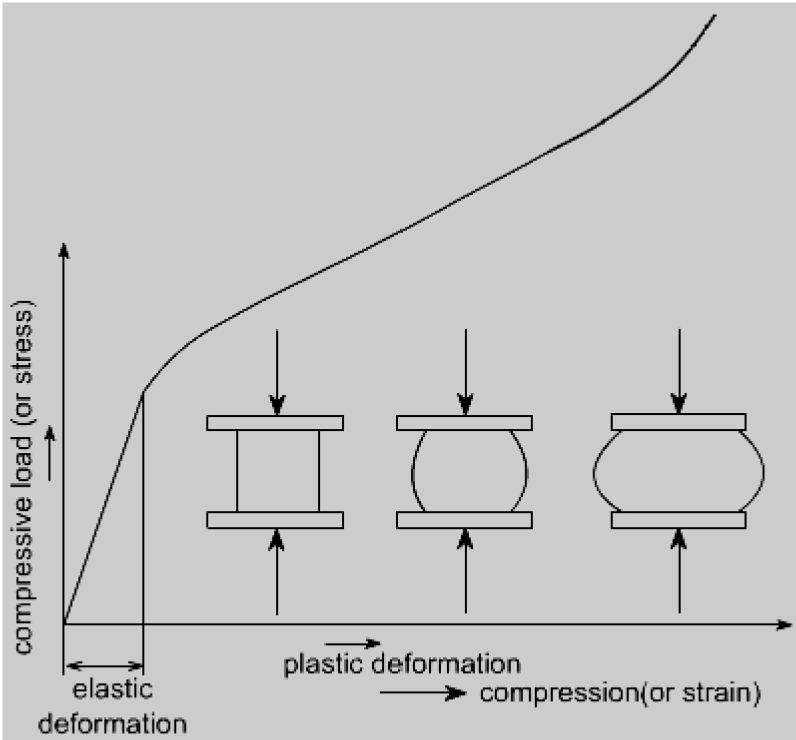


Figure 1: Ductile material under compression load

(b) Brittle materials

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. For cast iron, the shape may be as shown in figure 2.

Brittle materials in compression behave elastically up to certain load, and then fail suddenly by splitting or by cracking in the way as shown in figure. The brittle fracture is performed by separation and is not accompanied by noticeable plastic deformation.

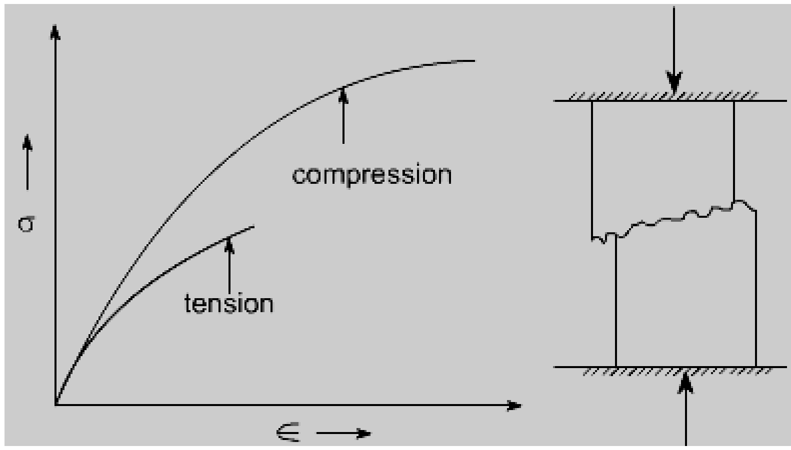


Figure 2: Brittle material under compression load

Shape of the specimen:

The shape of the specimen to be used for the different materials is as follows:

(i) For metals and certain plastics: The specimen may be in the form of a cylinder. The size of the specimen is determined by aspect ratio, which is defined as the ratio of the length of the specimen to its diameter (L/D), this aspect ratio must not exceed (3) to avoid buckling in the specimen.

(ii) For building materials: Such as concrete or stone the shape of the specimen may be in the form of a cube.

Stress Strain relations

- *Engineering Stress*: $\sigma = \frac{Applied\ Force}{Initial\ cross\ sectional\ area} = \frac{F}{A_o}$

Engineering Strain: $\varepsilon = \frac{l_i - l_o}{l_o} = \frac{\Delta l}{l_o}$

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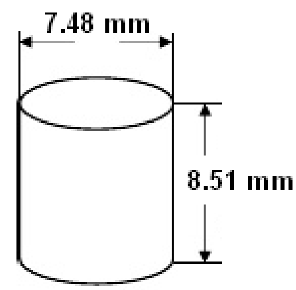
Figure 1: Universal Testing Machine

V. Procedure:

1. Measure the diameter and the length of the specimen.
2. Set the UTM for compression test.
3. Place the specimen in the lower compression anvil (make sure that the specimen at center of the anvil).
4. Put some lubrication oil on the lower and upper surfaces of the specimen and the anvils in order to reduce the barrel effect.
5. down the upper anvil manually until the upper unit just touches the specimen top surface.
6. Collect your data of applied load $\boldsymbol{F}$ and the displacement $\boldsymbol{\Delta l}$ by computer and software system.

VI. Experimental Work:

<u>Specimen</u>

<table>
<tr><td colspan="3">Test specimen for this experiment is cylindrical as shown</td><td rowspan="4">
</td></tr>
<tr><td>Material</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Dimensions</td><td>Diameter D=</td><td>7.48 mm</td></tr>
<tr><td>Initial test length l_o=</td><td>8.51 mm</td></tr>
</table>

Force F(N)	Displacement Δl (mm)	Strain $\varepsilon = \frac{\Delta l}{l_o}$	Stress $\sigma = \frac{F}{A}$ (MPa)

Analysis:

1. Calculate Engineering Stress and Engineering Strain
2. Plot the stress – strain Diagram
3. From your plot find the followings
   - Modulus of elasticity or Young’s Modulus E.
   - Yield stress, using 0.2% offset.
   - Ultimate tensile strength.
   - Fracture strength.
   - Ductility [$Percent\ of\ elongation\ and\ Percent\ of\ reduction\ of\ area$]
   - Poisson's ratio ν
4. Compare your experimental values with the standard one.
5. Explain the importance of these mechanical properties to engineering design.

Exp. # 3

Torsion Test

I. Objective:

- To investigate the behavior of materials when subjected to torsion loads.
- To obtain the mechanical properties of test material under torsion loads.
- To understand fracture mechanism in torsion.

II. Test Standard

- ASTM A938 Torsional Test of Wire
- ASTM D1043 Torsion Plastics Test Equipment
- ASTM D5279 Thermoset & Thermoplastic Dynamic Torsion Testing Machine
- ASTM E2207 Axial-Torsional Fatigue Thin-Walled Tubular Materials Test Equipment
- ASTM F383 Static Bend and Torsion Testing of Intramedullary Rods
- ASTM F543 Medical Bone Screw Torsion Test Equipment
- ISO 6475 Bone Screw Torsion Test Methods | Equipment
- ISO 7800 Metal Wire Torsion test
- ISO 80369-1 Axial Torsional Luer Connector Test Equipment

III. Theory:

1. Introduction:

Engineers need to know how different materials behave when stressed. They will then know how to use the right materials and material sizes for structures and parts in their designs. In many applications, such as axles, coil springs, and shafts that carries Torsional loads; an engineering material must have good resistance to the induced stresses.

The assumptions made in torsion test include but are not limited to the following:

1. The torque is applied along the center of axis of the shaft.
2. The material is tested at steady state (absence of strain rate effects).
3. Plane sections remain plane after twisting (the circular section conforms to this condition).

Consider a bar, or shafts, of circular cross-section twisted by Torque **T** acting at the end (figure 3).

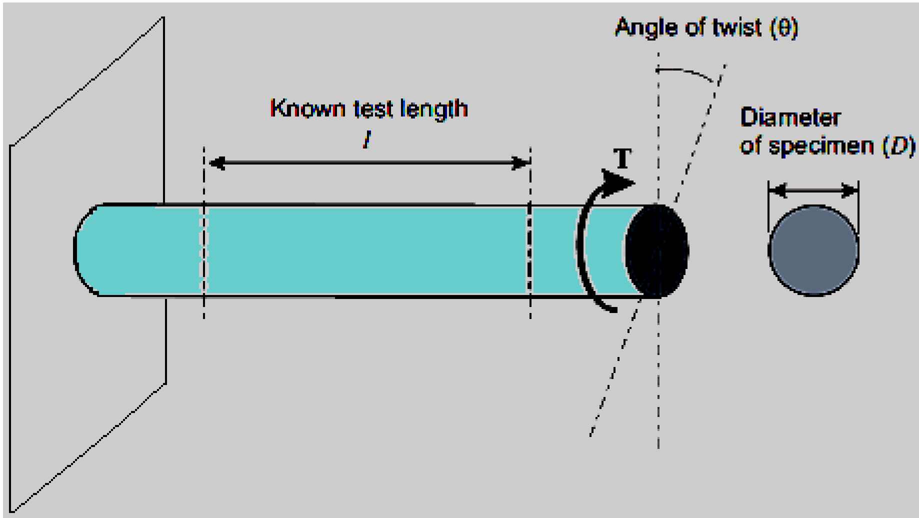


Figure 3: Torque load

During the twisting, there will be a rotation about the longitudinal axis of one end of the bar with respect to the other. The rotation angle θ is known as the angle of twist. The resulting shear stress τ, and shear strain γ should be calculated to construct the shear stress, shear strain diagram that can be used to obtain all Torsional properties of the testing material.

2. Torsional Stress and Strain

Elastic Region: The stress due to Torsional loading is shear stress τ is given by:

$$\tau = \frac{Tr}{J} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where: τ: Is the shear stress in N/m², or N/mm².

T: Is the Torque in N.m, or N.mm.

r: Is the radius of the shaft in m, or in mm

J: Is the polar moment of inertial given by:

$$J = \frac{\pi r^4}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The shear strain γ is given by:

$$\gamma = \frac{\theta \times r}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where: γ: Is the shear strain in m, or mm.

θ: Is the twisted angle in rad.

L: Is the specimen length in m or mm.

Plastic Region: The shear strain is given by the same eguation as in the Elastic region. But shear stress is given by:

$\tau = \frac{1}{2\pi r^3}\left[\theta' \frac{dT}{d\theta'} + 3T\right]$ ....(4)

Where:

θ' $is\ angle\ of\ twist\ per\ unit\ length\ = \frac{\theta}{L}$

Equation 4 can be evaluated at a point using diagram of ***T*** versus θ' then : (see the figure)

$\tau = \frac{1}{2\pi r^3}\left[AB\frac{BC}{AB} + 3CD\right]$

$\tau = \frac{1}{2\pi r^3}[BC + 3CD]$ ....(5)

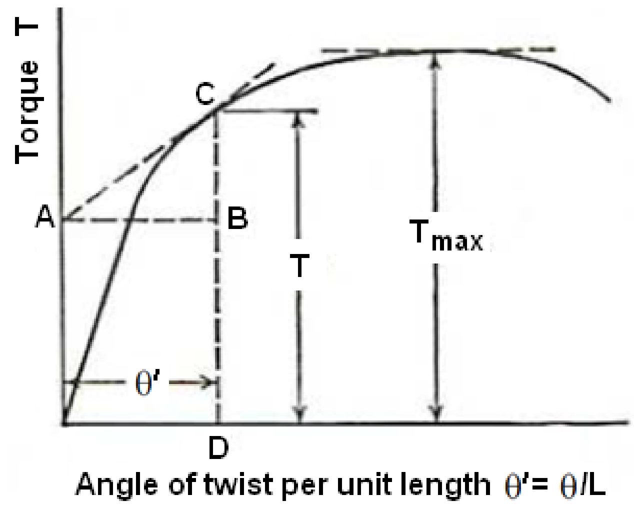


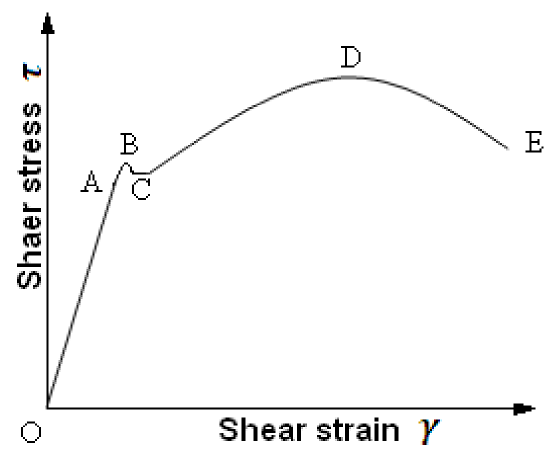
Figure 4: $T - \theta'$ ***Diagram***

Also at maximum point $\left[\frac{dT}{d\theta'} = 0\right]$, the ultimate shear stress or modulus of rupture the shear is

$\tau_U = \frac{3T_{max}}{2\pi r^3}$ ....(6)

The shear stress shear strain diagram for ductile material is shown in figure 5, where:

O-A: Elastic region, linear relation between τ and γ
A: Elastic limit
B: Upper yield point
C: Lower yield point
C-E: Plastic region
D: Ultimate shear stress
E: Fracture point

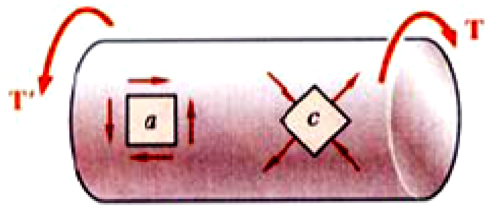


Main mechanical properties

1- Yield shear stress
2- Shear Modulus of elasticity or Modulus of rigidity G = slop of elastic region line
3- Modulus of rupture = Ultimate shear stress

Torsional Failure Modes

The state of stress due to torsion is shown in figure 6 element ***a,*** and the principal stresses occurs at angle 45 element ***c***. Ductile materials weaker in shear than tension, but brittle materials are weaker in tension than shear.



$$\tau_{max} = \frac{Tc}{J} \qquad \sigma_{45} = \pm\frac{Tc}{J}$$

Figure 6: State of stress

• When subjected to torsion, a ductile specimen breaks along a plane of maximum shear, i.e., a plane perpendicular to the shaft axis.

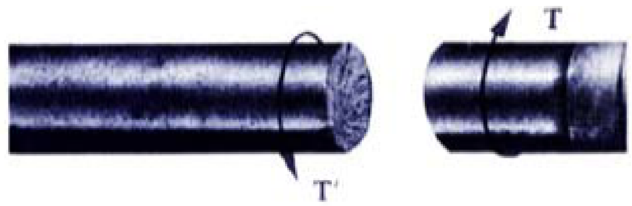


Figure 7: Ductile failure

• When subjected to torsion, a brittle specimen breaks along planes of maximum tensile stress, i.e., along surfaces at 45o to the shaft axis.

Figure 8: Brittle failure

IV. Apparatus:

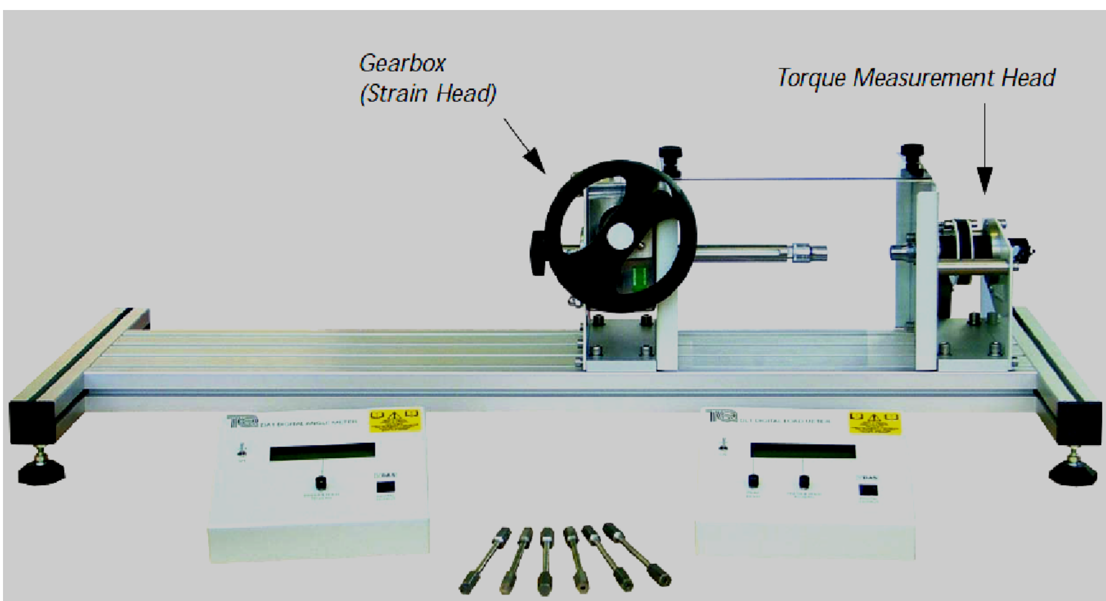


Figure 1: Torsional Test Apparatus

The torsional test apparatus consists of the following main parts

- **The Base**
- **The Gearbox (Strain Head):** Manually turned, with a 60:1 reduction ratio and a sliding output shaft. A transducer measures the number of turns of the Gearbox. The Gearbox can turns clockwise and anticlockwise to apply clockwise and anticlockwise torsion. ***The normal direction for tests is clockwise***.
- **The Torque Measurement Head:** It has a moment (torque) arm and industrial force sensor. Its torque value is a product of the length of the moment arm and the force on the force sensor.
- **Digital Meters:** Two meters, one shows the angle of twist in degrees and the other one show the torque
- **Versatile Data Acquisition System:** consists of two parts (Hardware and Software) connect and installed to a PC. It log experiments, calculate data, create charts and tables, export your data for processing in other software.
- **Specimens:** The dimensions of the specimens used are shown in figure below. Carbon steel, cast iron, and brass specimens are available.

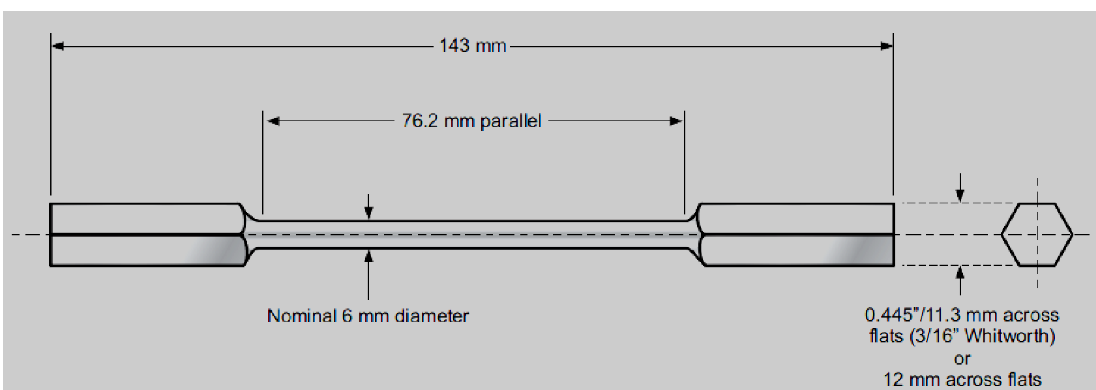


Figure 2: Specimen details

V. Procedure:

1. Accurately measure and record the dimensions of your specimen.
2. Fit the sockets to the torque head and the gearbox output.
3. Fit the specimen to the sockets. Slide the gearbox output shaft along so that the specimen's ends fit fully into each socket.
4. Switch on both Digital Meters, and press their 'Press to zero' buttons.
5. Fit the clear guard around the specimen.

6. To remove any mechanical error (or ‘backlash’), slowly turn the Gearbox Hand Wheel until the load display starts to show a small value of torque, then use the ‘Press to zero’ buttons to set all displays
7. At the beginning of the experiment the specimen will be stressed in its elastic region, increase the angle of twist in small steps of 1 degree.
8. At each angle, record the angle and the torque value. If you are to use VDAS®, press the ‘record.
9. After approximately 10 degrees, the specimen has passed its upper yield point. You can now increase the angle size between measurements to larger increments. Continue to increase the angle until the specimen breaks.
10. Save the data on the PC and turn off your apparatus.

VI. Experimental Work:

Specimen material				
Specimen dimensions	**Length**		**Diameter**	

Other results of Torque and twist angle will be taken from data acquisition-PC system

Analysis:

1. Calculate angle of twist per unit length
2. Plot a chart of torque (vertical axis) against angle of twist per unit length (horizontal axis). $T - \theta'$ curve.
3. Calculate shear stress τ and the shear strain γ for both elastic and plastic regions.
4. Plot the stress strain diagram [shear stress τ on vertical axis, and shear strain γ on horizontal axis].
5. On your shear stress τ and the shear strain γ diagram find the following properties:

✔ **Modulus of Rigidity or Shear Modulus (G):-**

G is the slope of the τ - γ curve in the elastic range

✔ **Yield Shear Strength:**

Mark the yield point on stress strain diagram and find the yield stress. If the yield is not clear use offset of 0.1 as shown in the figure 9

✔ **Modulus of rupture:**

The maximum shear stress or using equation 6.

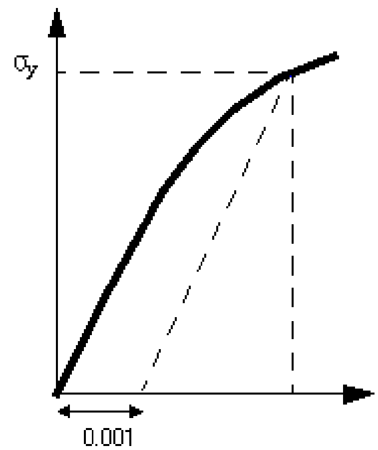


Figure 9: Yield strength at 0.1% offset

Discussion and Conclusions:

- Compare your results with typical ones.
- What can you state about the ‘nominal stress’ assumption?

Exp. # 4

Deflection of beams

I. Objective:

To study deflection of simply supported and cantilever beams.

II. Test Standard

ASTM Standards

D618 Practice for Conditioning Plastics for Testing

D638 Test Method for Tensile Properties of Plastics

D883 Terminology Relating to Plastics

D4000 Classification System for Specifying Plastic Materials

D4101 Specification for Polypropylene Injection and Extrusion Materials

D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

D6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending

E4 Practices for Force Verification of Testing Machines

E83 Practice for Verification and Classification of Extensometer Systems

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E2309 Practices for Verification of Displacement Measuring Systems and Devices Used in Material Testing Machines

III. Theory:

In Engineering beam is defined as any rigid member or structure that is loaded transversely.

The types of beams based on the manner in which they are supported are shown in figure 2

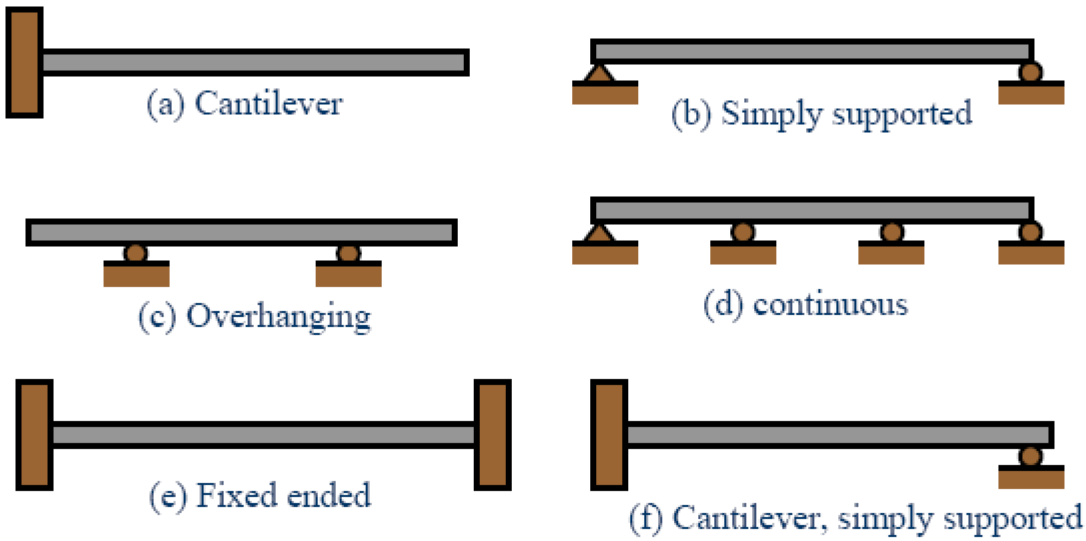


Figure 2: Types of beams

Simply-supported Beams

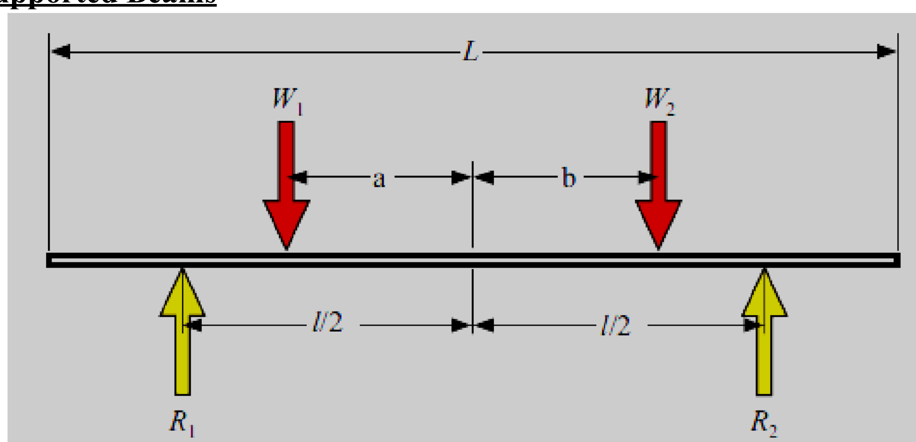


Figure 3: simply supported beam

For the beam shown in figure 3:

$$\sum F_y = 0 \quad \rightarrow \quad R_1 + R_2 = W_1 + W_2 \quad \ldots\ldots(1)$$

$$\sum M_{R_2} = 0 \quad \rightarrow \quad R_1 l = W_1\left(\frac{l}{2} + a\right) + W_2\left(\frac{l}{2} - b\right) \quad \ldots\ldots(2)$$

Solve 1 and 2 for R_1 and R_2

$$R_1 = \frac{\left(W_1 + W_2\right)}{2} + \frac{W_1 a}{l} - \frac{W_2 b}{l} \quad \ldots\ldots (3)$$

$$R_2 = \frac{(W_1+W_2)}{2} - \frac{W_1 a}{l} + \frac{W_2 b}{l} \quad \text{......(4)}$$

Pure (Elastic) Bending

The theory of pure (elastic) bending of a beam shows that when a beam is loaded in such a way that it bends only in the plane of the applied moment, the theory of pure (elastic) bending shows that the stress distribution and curvature of the beam are related by:

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R} \quad \text{......(5)}$$

The curvature of a beam $1/R$ is given, to a close approximation, by the second derivative of the deflection. If z is the deflection of the beam at distance x from a chosen origin then:

$$\frac{d^2z}{dx^2} = \frac{1}{R} = \frac{M}{EI} \quad \text{......(6)}$$

For the beam shown in figure 4, the deflection z at distance x from R_1 can be determined by double integrating equation 6

At section a-a $M = -\frac{W}{2}x$, Substitute M into equation 6

$$\frac{d^2z}{dx^2} = \frac{-Wx}{2EI}$$
……………………………..(7)

Integrate both sides of equation 7

$$\frac{dz}{dx} = \frac{-W}{2EI}\frac{x^2}{2} + C = \frac{-W}{4EI}x^2 + C$$
…………..(8)

Equation 8 defines the slope of the deflection curve of the beam, for this configuration of load the slop at midpoint is zero i.e.

$\frac{dz}{dx} = 0 \quad at\ x = \frac{l}{2}$ sub this condition at equation 8:

$$0 = \frac{-W}{4EI}\frac{l^2}{4} + C \quad \rightarrow \quad C = \frac{Wl^2}{16EI}$$
…………..…(9)

Sub. C into equation 8

$$\frac{dz}{dx} = \frac{-W}{4EI}x^2 + \frac{Wl^2}{16EI}$$
……………………..…(10)

Now integrate equation 10 to get the deflection z at any position x from the left reaction.

$$z = \frac{-W}{4EI}\frac{x^3}{3} + \frac{Wl^2}{16EI}x + C$$

$$z = \frac{-Wx^3}{12EI} + \frac{Wl^2x}{16EI} + C$$
………………..…(11)

At $x = 0 \quad z = 0 \quad \rightarrow C = 0$

$$z = \frac{-Wx^3}{12EI} + \frac{Wl^2x}{16EI}$$
………………………(12)

Maximum deflection occurs at $x = \frac{l}{2}$

$$z_{max} = \frac{-W}{12EI}\frac{l^3}{8} + \frac{Wl^2}{16EI}\frac{l}{2}$$

$$z_{max} = \frac{-Wl^3}{96EI} + \frac{Wl^3}{32EI}$$

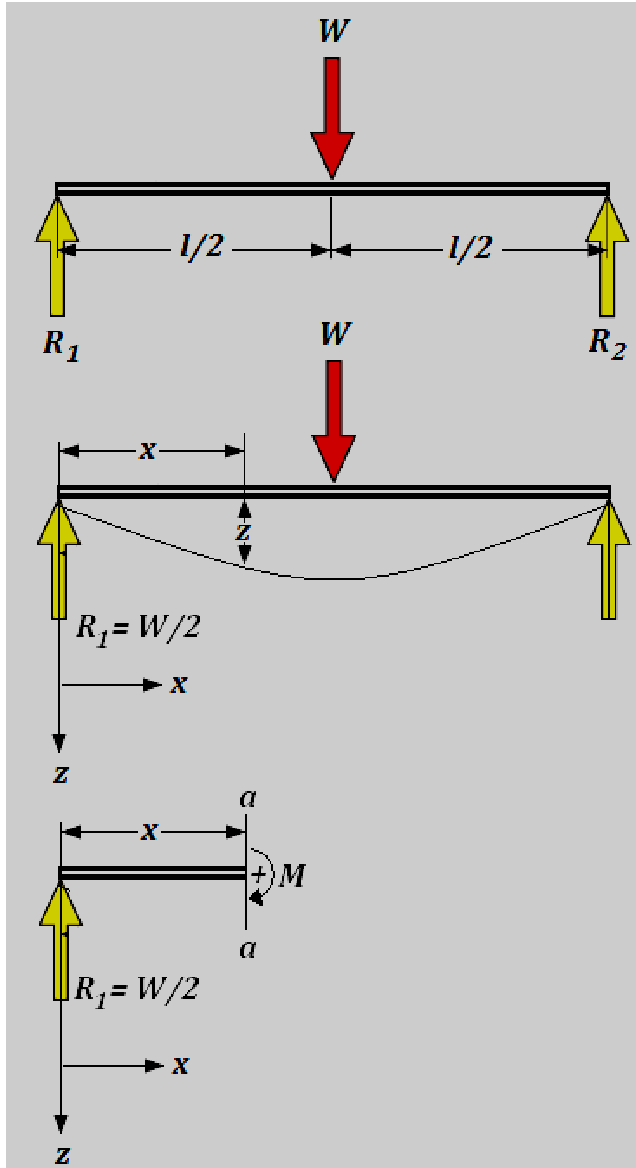


Figure 4:Deflection of simply supported beam

$$z_{max} = \frac{Wl^3}{48EI} \quad \text{...}(13)$$

Cantilever Beam

For the cantilever beam shown in figure 5, same procedure can be followed using equation 6 to show that for the a cantilever of length l, the deflection of free end where a point load W applied is given by:

$$z = \frac{Wl^3}{3EI} \quad \text{....................................}(14)$$

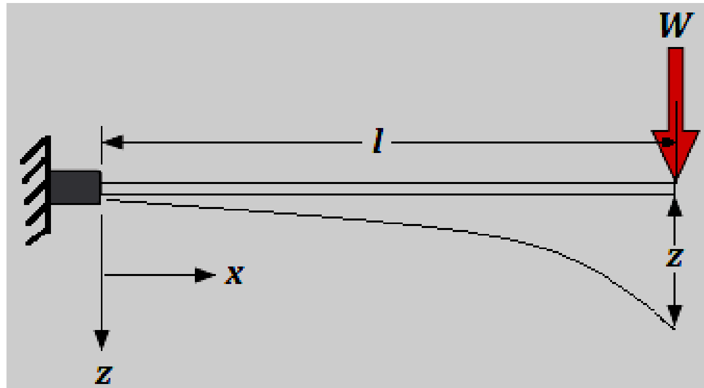


Figure 5:Deflection of cantilever beam

IV. Apparatus:

Figure 1 shows the Beam Apparatus. It is a sturdy steel frame that holds fully movable digital deflection indicators, Load Cell supports, the beam and the cantilever support.

For cantilever experiments, the cantilever support holds the beam at one end. A weight hanger holds weights (a mass) to load the beam at any place along its length. Digital (deflection) Indicators measure the deflection of the beam at any point along its length.

In simply supported beam experiments, the Load Cells support the beam and measure any reaction force if needed or just work as support props. The Weight Hanger loads the beam at a fixed place. The deflection indicator measures how much the beam bends at a given point.

A graduated scale at the top of the apparatus helps students to apply loads and measure deflections and reactions at known and repeatable distances.

The Load Cells measure distance moved, but has a support spring, calibrated so that each 10 N of downward force moves the indicator by 1 mm.

Beams with different metals and of different sizes are available.

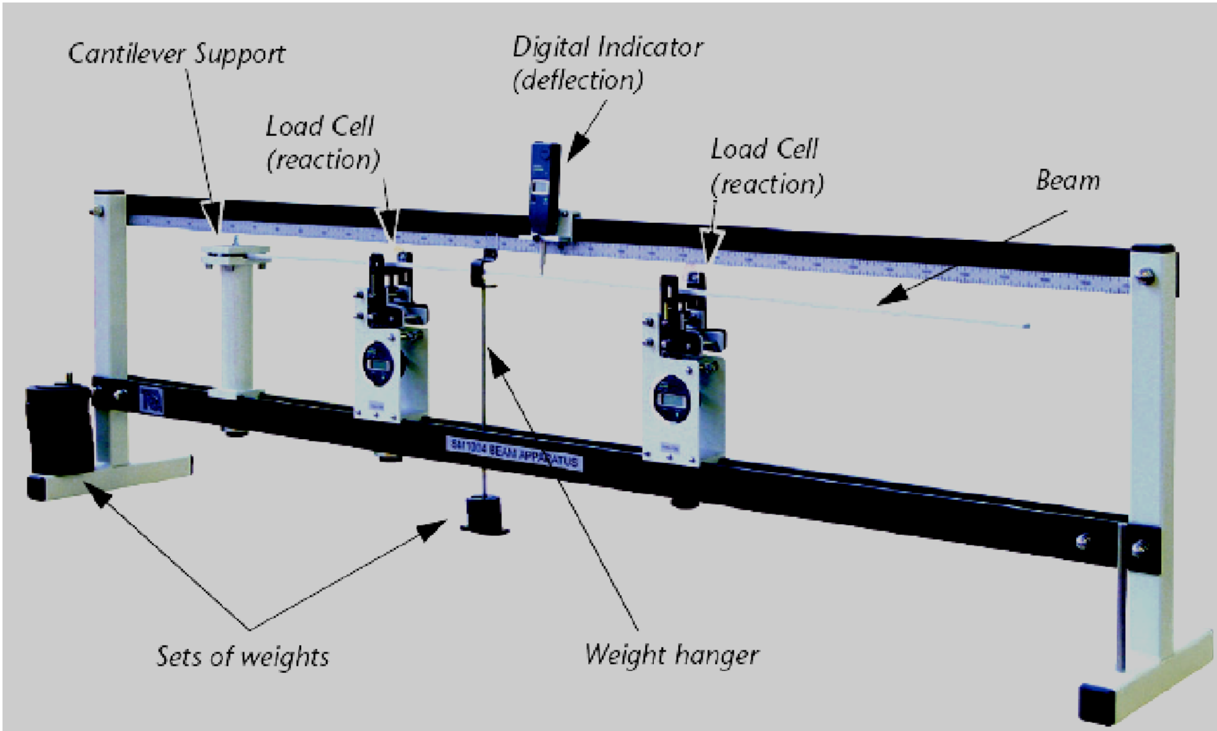


Figure 1

V. Procedure:

Part 1: Support Reactions for a Point-loaded, Simply- Supported Beam

1. Set up the beam with the two Load Cells and the two weight hangers as shown on figure 2.
2. Put a digital indicator on the upper cross member so that its contact rests on the centre-line of the beam immediately above the left-hand Load Cell. Check that the stem is vertical and there is enough travel in the downward direction. Zero the indicator.
3. Move the digital indicator to a position above the right-hand support, and check its reading is still zero to check that the beam is parallel to the cross member. If it is not, then adjust the height of the knife-edge of the right - hand Load Cell so that the digital indicator reads zero.
4. Remove the digital indicator and unlock both Load Cell knife-edges. Zero the Load Cell indicators.
5. Apply loads to the hangers in increments shown in Table 1. Each time you add a load, tap the apparatus very gently and take readings of the reaction forces (*R1* and *R2*) measured by the Load Cells.

Part 2: Deflection of a Simply-supported Beam

1. Set up the beam with the two Load Cells, one digital indicator, and one weight hanger at mid span as shown on figure 4.
2. Apply load of 20 N to the hanger, and measure the deflection at different positions from left load cell as shown in table 2.
3. Repeat for load of 30N.
4. Repeat for different beams.

Part 3: Deflection of a Cantilever Beam

1. Set up the beam apparatus with one digital indicator and one weight hanger at free end as shown on figure 5.
2. Apply load of 20 N to the hanger, and measure the deflection at different positions from left load cell as shown in table 3.
3. Repeat for load of 30N.
4. Repeat for different beams.

VI. Experimental Work:

Analysis:

Part 1: Support Reactions for a Point-loaded, Simply- Supported Beam

1. Calculate R_1 *and* R_2 theoretically and compare with experimental values.
2. Calculate % Error for both R_1 *and* R_2 where

$$\%Error = \frac{|R_{Theo} - R_{Exp}|}{R_{Theo}} \times 100\%$$

3. Comment on your results.

Part 2: Deflection of a Simply-supported Beam

1. Calculate the deflection z theoretically and compare with experimental values.
2. Calculate the % Error.
3. Plot deflection (y axis) versus distance (x axis).
4. Comment on your results.
5. What is the effect of increasing the load? Does it agree with theory?
6. Drive equation No. 14

Part 3: Deflection of a Cantilever Beam

1. Calculate the deflection z theoretically and compare with experimental values.
2. Calculate the % Error.
3. Plot deflection (y axis) versus beam length l (x axis).
4. Comment on your results. Does it agree with theory?

L= **l=** **a=**

W_1(N)	W_2(N)	$R_{1,Exp}(N)$	$R_{1,Theo}(N)$	% Error	$R_{2,Exp}(N)$	$R_{2,Theo}(N)$	% Error
10	0						
20	0						
30	0						
0	10						
0	20						
0	30						
10	10						
20	20						
30	30						

Part 1: Support Reactions for a Simply- Supported Beam

Beam material	Modulus of Elasticity	Working length l	Cross section	
			B(mm)	H(mm)

Distance from left reaction (mm)	Load W = 20 N			Load W = 30 N		
	Deflection		% Error	Deflection		% Error
	z_{Exp}(mm)	z_{Theo}(mm)		z_{Exp}(mm)	z_{Theo}(mm)	
100						
200						
300						
400						
500						

Part 2: Deflection of a Simply-supported Beam

Beam material	Modulus of Elasticity	Cross section	
		b(mm)	h(mm)

L (mm)	200			400			600		
W (N)	Deflection z (mm)								
	z_{Exp}	z_{Theo}	% Error	z_{Exp}	z_{Theo}	% Error	z_{Exp}	z_{Theo}	% Error
4									
6									
8									

Part 3: Deflection of a Cantilever Beam

Buckling of column

I. Objective:

To find the buckling load of a strut experimentally and compare it with the theoretical value calculated from Euler's equation, and to prove the theory and show its limits.

II. Test Standard

ASTM Standards

D198 Test Methods of Static Tests of Lumber in Structural Sizes

D883 Terminology Relating to Plastics

D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products

D3878 Terminology for Composite Materials

D6108 Test Method for Compressive Properties of Plastic Lumber and Shapes

E4 Practices for Force Verification of Testing Machines

E6 Terminology Relating to Methods of Mechanical Testing

E83 Practice for Verification and Classification of Extensometer Systems

E575 Practice for Reporting Data from Structural Tests of Building Constructions, Elements, Connections, and Assemblies

E631 Terminology of Building Constructions

III. Apparatus:

Figure 1 shows the main part of the Loading and Buckling of Struts apparatus. It consists of frame that has slots to hold the loading end and the load measuring end.

The loading end has a hand wheel that turns a thread to give a compression force on the end of a strut. The load measuring end has a load sensor connected with a unique mechanism. This mechanism allows the sensor to measure the axial force (buckling load) on the strut, but ignores any bending (rotating) forces.

The load sensor connects to a separate Load Meter (Display) that shows the axial force on the strut. The Load Display has two buttons. Press one button to zero the load display before you take any readings. The other button sets the display to hold a peak value of the force. Columns with different metals and of different sizes are available.

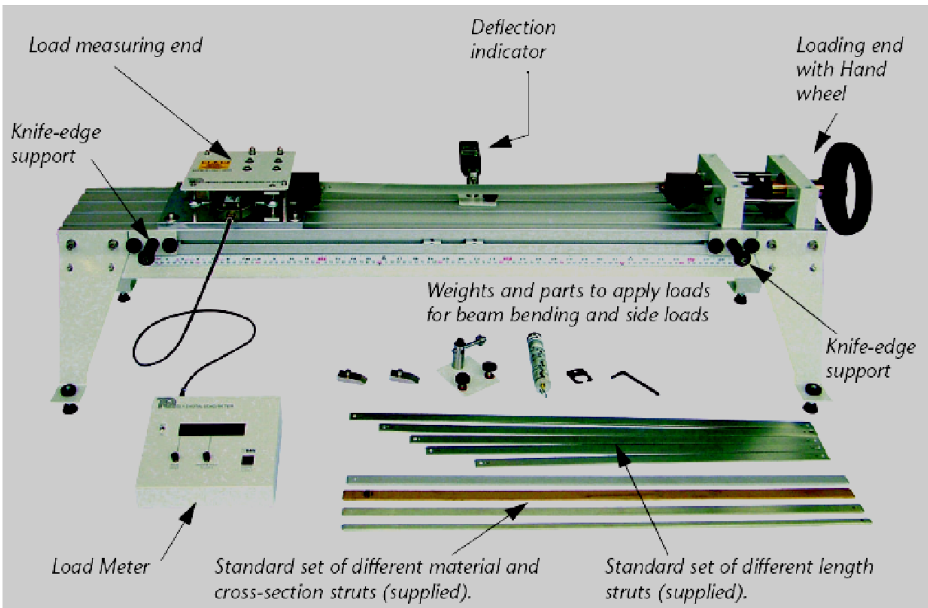


Figure 1: Buckling of columns Apparatus

IV. Theory:

Columns are parts of structures that resist compressive axial loads (usually vertical loads). **Stanchions** are upright (usually metal) columns in buildings. **Struts** are the smaller parts (members) that resist compression in trusses and frames.

Columns can be either long (slender) or short (fat) (see Figure 2). When compressed by too much axial load, long, slender columns fail by suddenly bending out of line (for example - a plastic ruler). They become 'unstable' and 'buckle' at a maximum or 'critical (buckling) load'. Short, fat columns fail in several ways, mostly determined by the material they are made from (for example - concrete crushes and mild steel yields).

In reality, most columns are 'intermediate' - they fail by a combination of effects, where bending starts a material failure. However, this experiment examines a single effect - how slender struts or columns fail by buckling

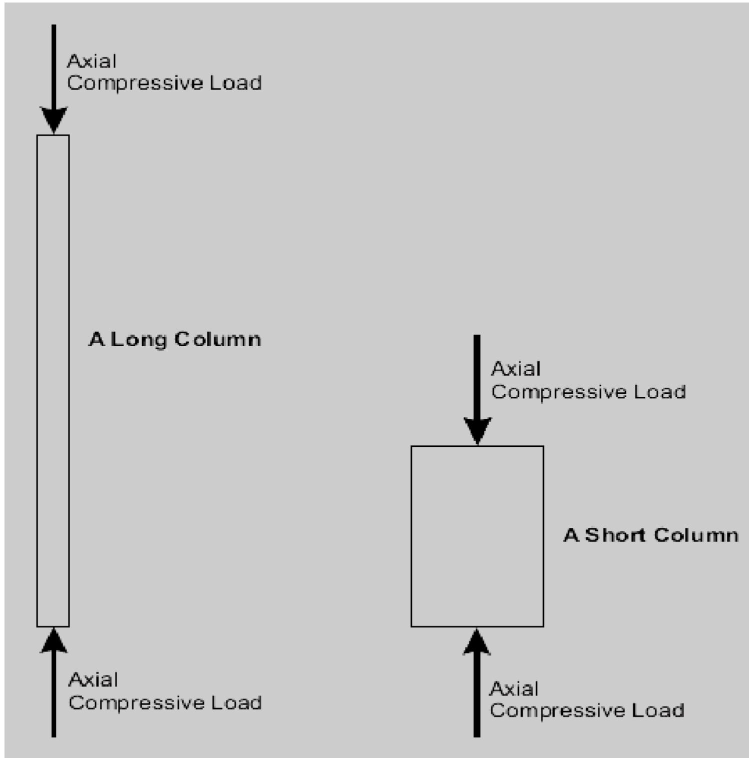


Figure 2: Long and short columns

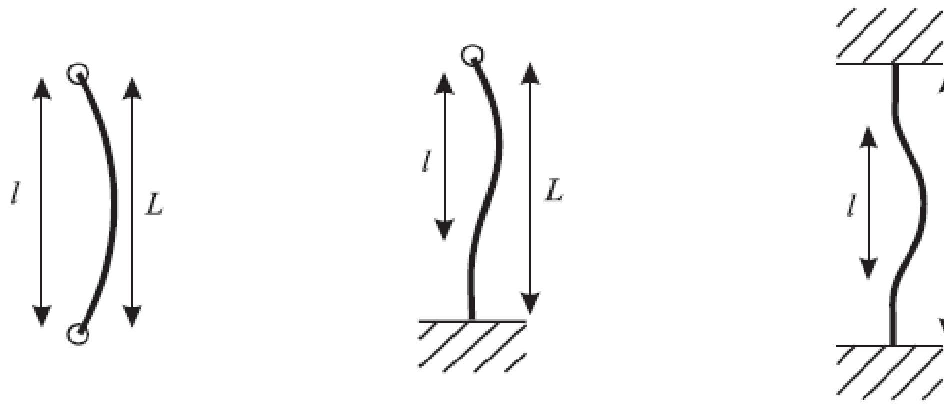
Euler's Maximum (Critical) Buckling Load

A Swiss mathematician - Leonhard Euler, created a formula that predicts the maximum (critical) axial buckling load (P_{cr}) of a strut.

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} \quad \ldots\ldots(1)$$

Where K is an 'effective length factor' - determined by how you fix the ends of the strut. It is the ratio of the 'effective length' (l) between two points, to the overall length (L) of the strut. The equation shows that the Young's Modulus (E) and cross-sectional dimensions (second moment of area (I)) affect the maximum buckling load. It also shows that the buckling load varies linearly with these quantities. This allows you to see that, for example, a steel strut with an E value of 200 GPa should buckle at twenty times the load of an equivalent wooden strut, if the wood has an E value of only10 GPa.

Figure 3 show that the way you fix a strut decides its effective length. A strut with one fixed end has an effective length of 0.7 of its total length. A strut with two fixed ends has an effective length of 0.5 of its total length.



Simple Pinned Ends	One end pinned, the other end fixed	Both ends fixed
$l = L,\ so\ K = 1$	$l = 0.7L,\ so\ K = 0.7$	$l = 0.5L,\ so\ K = 0.5$
$P_{cr} = \frac{\pi^2 EI}{L^2}$	$P_{cr} = \frac{\pi^2 EI}{(0.7L)^2} = \frac{2\pi^2 EI}{L^2}$	$P_{cr} = \frac{\pi^2 EI}{(0.5L)^2} = \frac{4\pi^2 EI}{L^2}$

Figure 3: Euler's Equations for Different Strut End Conditions

MATERIAL STRENGTH LIMITATIONS

Considering the case of a pin-ended column again, the critical load is given by

$$P_{cr} = \frac{\pi^2 EI}{L^2} \quad \text{...(2)}$$

Mean stress at $\boldsymbol{P_{cr}}$, $\sigma_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 E(\frac{I}{A})}{L^2}$ ....(3)

But $\frac{I}{A} = r^2$, r is the radius of gyration

So $\sigma_{cr} = \frac{\pi^2 E}{(L/r)^2}$ ....(4)

L/r is known as the "slenderness ratio" and a plot of $\boldsymbol{\sigma_{cr}}$ against ***L/r*** will appear as Shown in figure 4-a. This suggests that as ***L/r*** gets smaller the critical (buckling) stress increases without limit. However, all real materials will yield or fail as their stress increases. Columns with a sufficiently small slenderness ratio (***L/r***) will fail by yielding, whereas more slender columns will fail (at least initially) by elastic buckling.

The dividing line between 'short' and 'long' columns depends on yield stress and elastic modulus. The transition from short (yielding) columns to long (buckling) ones is not sharply defined in practice. There is a transition zone in which failure involves a mix of buckling and yielding. For example, a slight tendency to buckle may cause yielding and further deflection. Similarly buckling may be precipitated by the first hint of yielding on one side of a column.

Actual failure loads (or the corresponding stresses) if plotted will follow a pattern as shown in figure 4-b

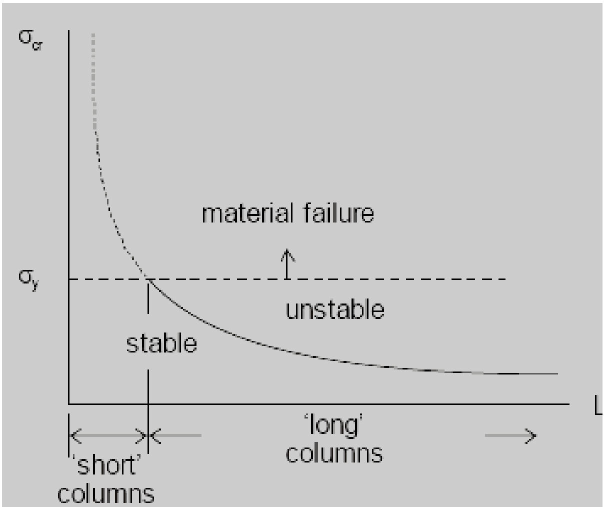


Figure 4-a

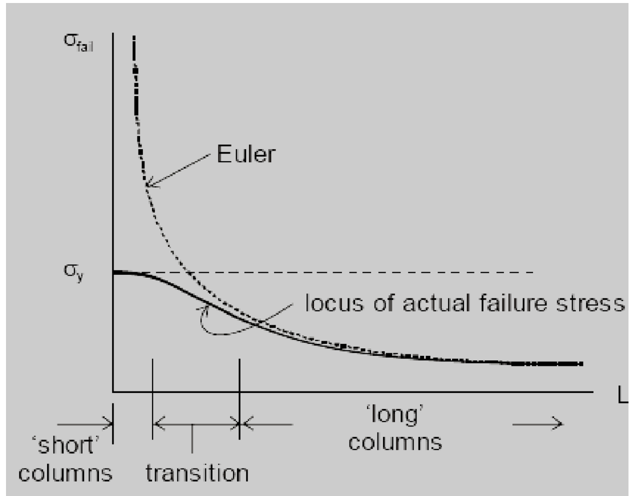


Figure 4-b

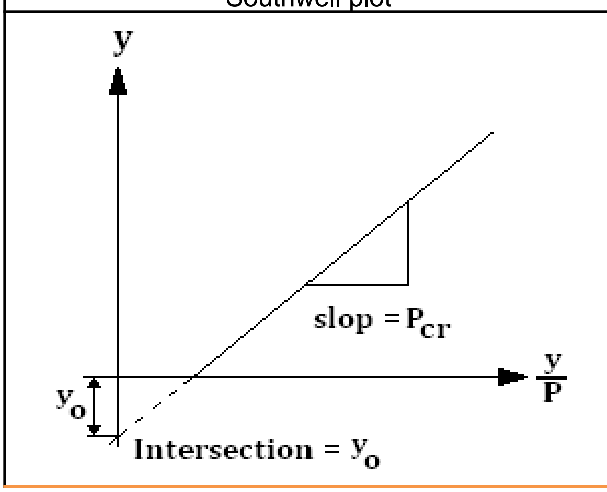
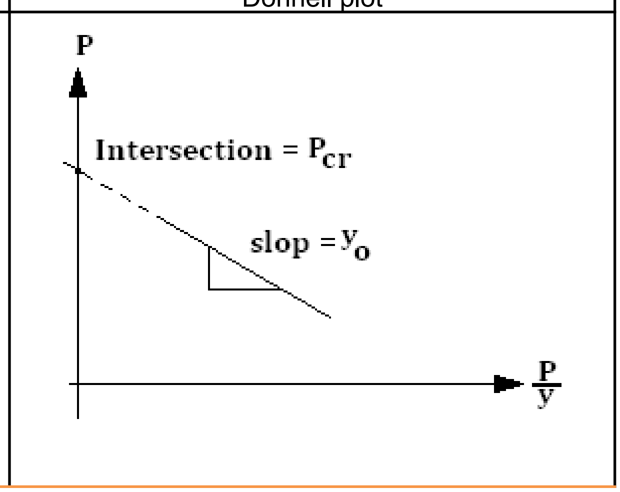
Experimental determination of buckling loads

Southwell finds a linear relationship between deflection (y) and $\left(\frac{y}{P}\right)$ given by:

$$y = P_{cr}\left(\frac{y}{P}\right) - y_o$$

Donnell suggest an alternative presentation of southwell equation given by:

$$P = -y_o\left(\frac{P}{y}\right) + P_{cr}$$

Southwell plot	Donnell plot
	

V. Procedure:

1. Find the strut you need for your test and make a pencil mark at its mid-point.
2. Write the type, properties, and the dimensions of the strut.
3. Connect and switch on the Load Display. Allow a few minutes for the display and the load cell of the measuring end to warm up. Tap the load measuring end to remove any effects of friction, and then zero the display.
4. Turn the hand wheel of the loading end and use the hexagon tool supplied, to loosen the four screws securing the loading end and slide it along the base until your strut fits into each chuck for the end condition you need. Re-tighten the four screws.
5. Fit the deflection indicator on its L-shaped holder, to the top of the base.
6. Adjust it so its tip touches your pencil mark, half-way along the strut.
7. Use the large hand wheel to apply a small force to the strut. Check that its bends away from the deflection indicator. If not, reduce the force and turn the strut around.
8. Zero the deflection indicator reading.
9. Use the large hand wheel to load the strut slowly to get a deflection of 1 mm. As you turn the hand wheel, gently tap the base to help remove any friction in the deflection indicator. Watch the load reading and the deflection of the strut. Record the deflection and load at approximately 1 mm intervals until you reach 10 mm deflection. Release the load. [Note: Maximum deflection allowed is 10 mm].

VI. Experimental Work:

Analysis:

1. Calculate $\left(\frac{y}{P}\right)$, and $\left(\frac{P}{y}\right)$
2. Create Southwell Plot and find the slop $P_{cr,\,Exp} = slop$
3. Create Donnell Plot and find the intersection with P axis $P_{cr,\,Exp} = intersection$
4. Calculate the theoretical maximum (critical) buckling load using Euler's equation.
5. Calculate the % Error for both Southwell and Donnell.
6. Comment on your results.
7. Refer to Euler's equation; write the four factors that affecting buckling of columns, and the effect of each one on the critical buckling load.
8. Drive Euler's equation for pinned end conditions [equation No 2]

Results:

Beam material	Modulus of elasticity	Length L	Cross section	
			b	h

P (N)	y (mm)	$\frac{y}{P}$	$\frac{P}{y}$

Fatigue Test

I. Objective:

To investigate the failure of metals due to fatigue loading

To plot S-N curve and use it to find Endurance limit, Fatigue strength, and fatigue life.

II. Test Standard:

- ASTM **E466**

III. Apparatus:

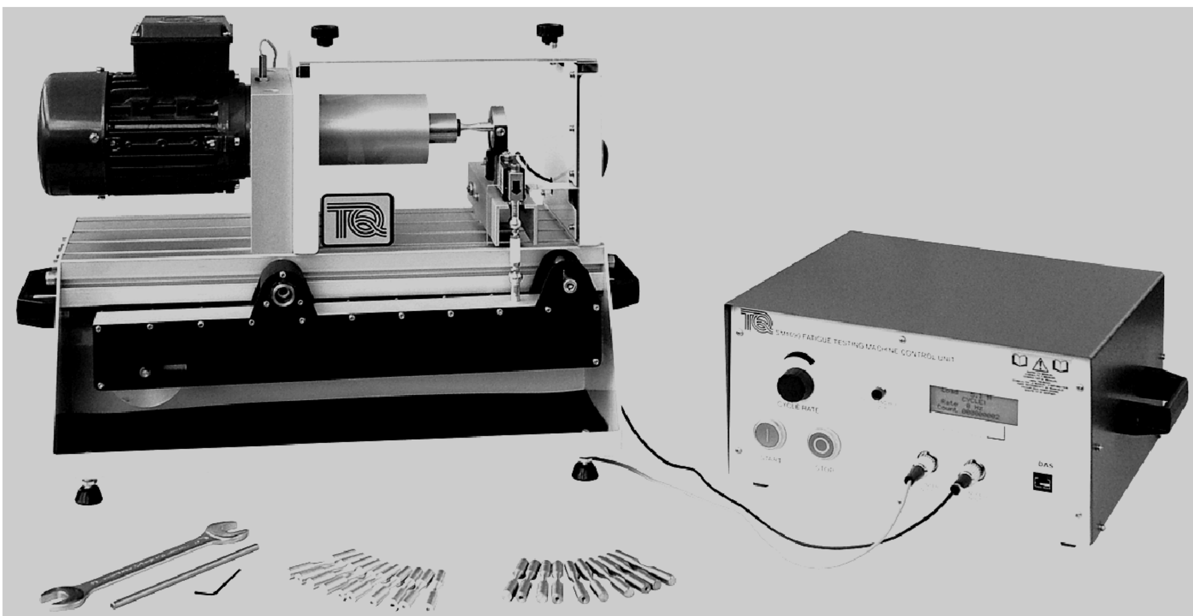


Figure 1: Fatigue Apparatus

Figure 1 shows the Rotating Fatigue Machine. It has two main parts: a main unit and a separate Control and Instrumentation Unit. The main unit has a motor that rotates a test specimen under constant load (stress). At the ‘loading end’ of the specimen, an adjustable ‘dead weight’ applies a vertical (downwards) load on the specimen.

The driven end and loading end make the specimen an axially rotating cantilever with a point load near its end.

A sensor counts the rotations (cycles) of the specimen and a load cell measures the force that you apply to the specimen (determined by the dead weight position). A separate control box contains an electronic motor drive and a display that shows the load, speed of rotations (cycle rate) and the number of rotations (cycle count) since the start of the test. A transparent safety guard protects the user in case small parts of the specimen fly off when it fractures.

When the specimen breaks, a switch at the loading end switches off the motor power and the display stops counting so you know how many cycles the specimen has done up to the point of failure.

The Fatigue machine can be connected to a Data Acquisition System, so all data can be logged automatically

Specimens

A set of mild steel test specimens and a set of aluminum specimens are available. The details of the specimen are shown in figure 2 below.

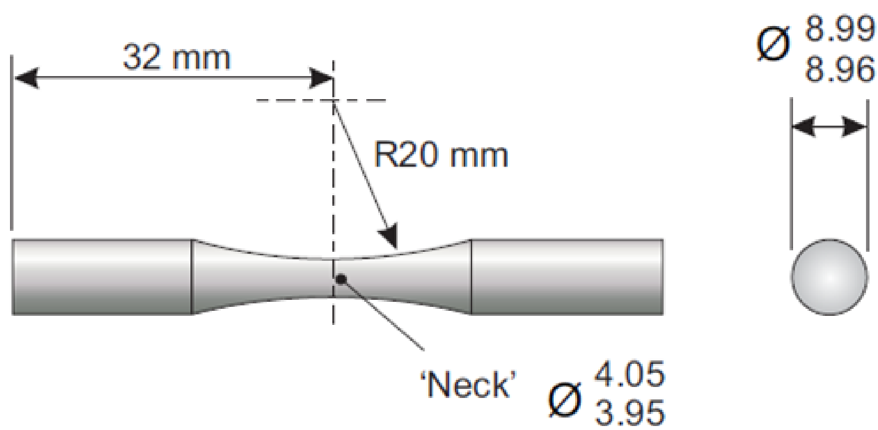


Figure 2: Specimen Details

IV. Theory:

Introduction

Fatigue is the condition whereby a material cracks or fails as a result of repeated (cyclic) stresses applied below the yield stress of the material.

Fatigue failures occurs suddenly with catastrophic (disastrous) results, and it is responsible for a large percentage of failures in connecting rods and crankshafts of engines; steam or gas turbine blades; connections or supports for bridges, railroad wheels, and axles; and other parts subjected to cyclic loading.

Fatigue failures generally involve three stages:

1.) Crack Initiation,

2.) Crack Propagation, and

3.) Fast Fracture

Fatigue causes brittle like failures even in normally ductile materials with little gross plastic deformation occurring prior to fracture. The process occurs by the initiation and propagation of cracks and, ordinarily, the fracture surface is close to perpendicular to the direction of maximum tensile stress.

Applied stresses may be axial (tension-compression), flexural (bending) or torsional (twisting) in nature. The simplest is completely reversed alternating stress varies from a maximum tensile stress to a minimum compressive stress of equal magnitude. This is occurs when a rotating cantilever beam subjected to constant load at its free end.

Rotating Cantilever

Figure 3 shows a rotating cantilever, the load on its free end creates tension on the upper half of the specimen and compression on the lower half. Because it rotates, it has alternate compressive and tensile stress on any given part along the unsupported length of the test specimen.

Figure 4 shows a cross section through the specimen as it rotates. A point on the outside of its diameter at any length moves through one cycle of compression and tension. In each cycle the stress at that point moves from a zero stress point (at the neutral axis) to maximum tension (+σ),

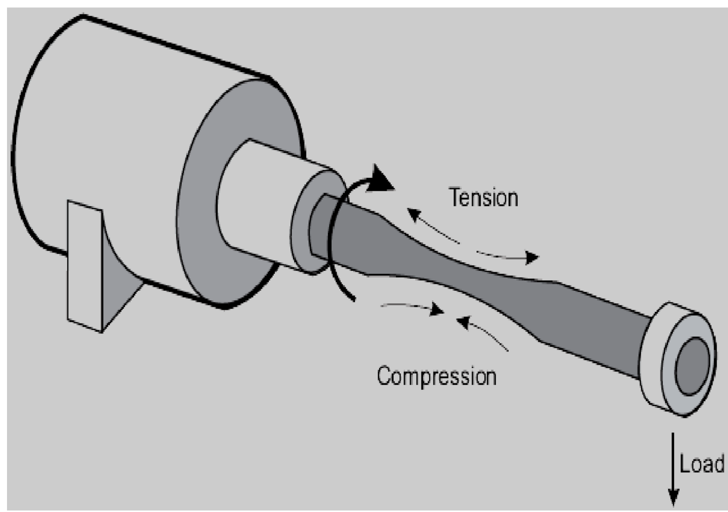


Figure 3: The Rotating Cantilever

back through zero stress and to a maximum compression (-σ) point. It then moves back to zero stress and repeats the cycle. As the stress fully reverses (from positive to negative or negative to positive stress), this is called a reversal. Each cycle has two reversals

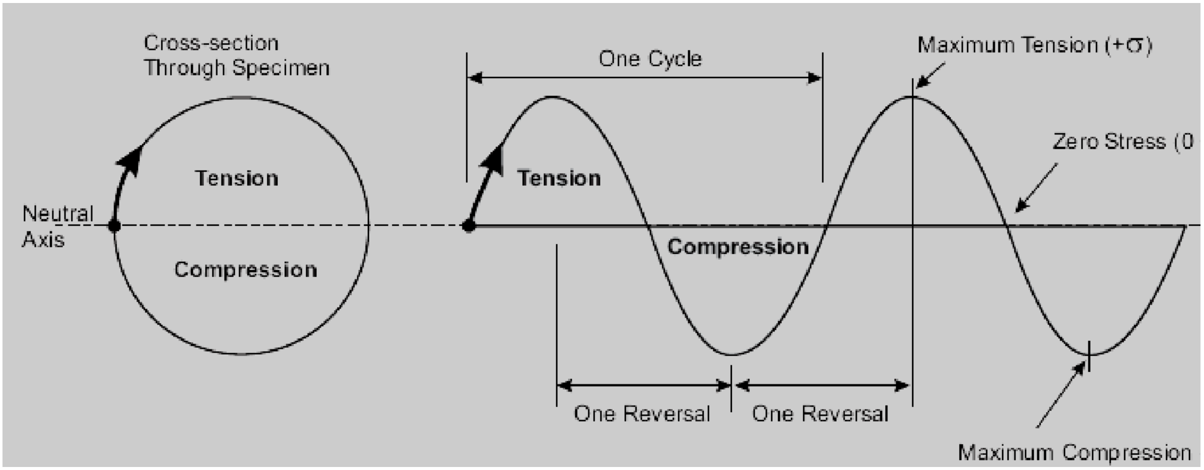


Figure 4: Cycles and Reversals

Stress along the cantilever

The stress at any point along the cantilever beam (in elastic bending) is:

$\sigma = \frac{My}{I_x}$ ....(1)

Where y in this case is D/2,

D is the diameter of the specimen

I_x is the second moment of area $= \frac{\pi D^4}{64}$

M is the bending moment

$M = Fl$ ....(2)

For test setup $l = 28\ mm$ (see figure 5)

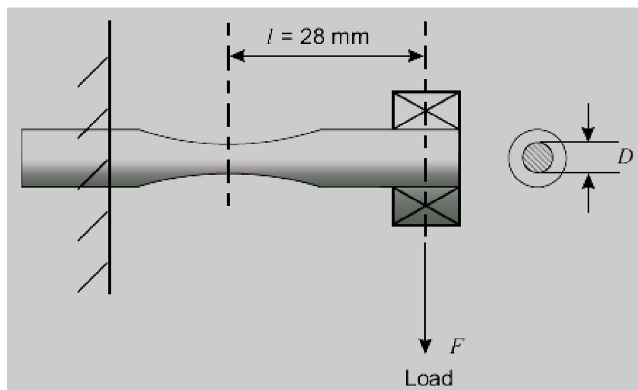


Figure 5: Distance to Load in a Standard Specimen

the stress can be calculated for given load and diameter.

S-N Curve

Fatigue Tests are conducted to determine the behavior of materials under fluctuating loads. An alternating load is applied to a specimen and the number of cycles required to produce failure (fatigue life N) is recorded. Generally, the test is repeated with identical specimens and various fluctuating loads. Data from fatigue testing are plotted in a semi log S-N diagram which is a plot of the number of cycles required to cause failure in a specimen against the amplitude of the cyclical stress developed. The cyclical stress represented may be stress amplitude, maximum stress or minimum stress.

The most important part of the curve is the **Endurance Limit** or the **Fatigue Limit**. The **Endurance Limit** defines the stress level below which the material will not fail due to fatigue.

Figure 6 show S-N curves for steel and aluminum. Steel has a **fatigue limit**. So, designers would normally make sure that any parts made of steel do not have repeated applied stress above its **fatigue limit**.

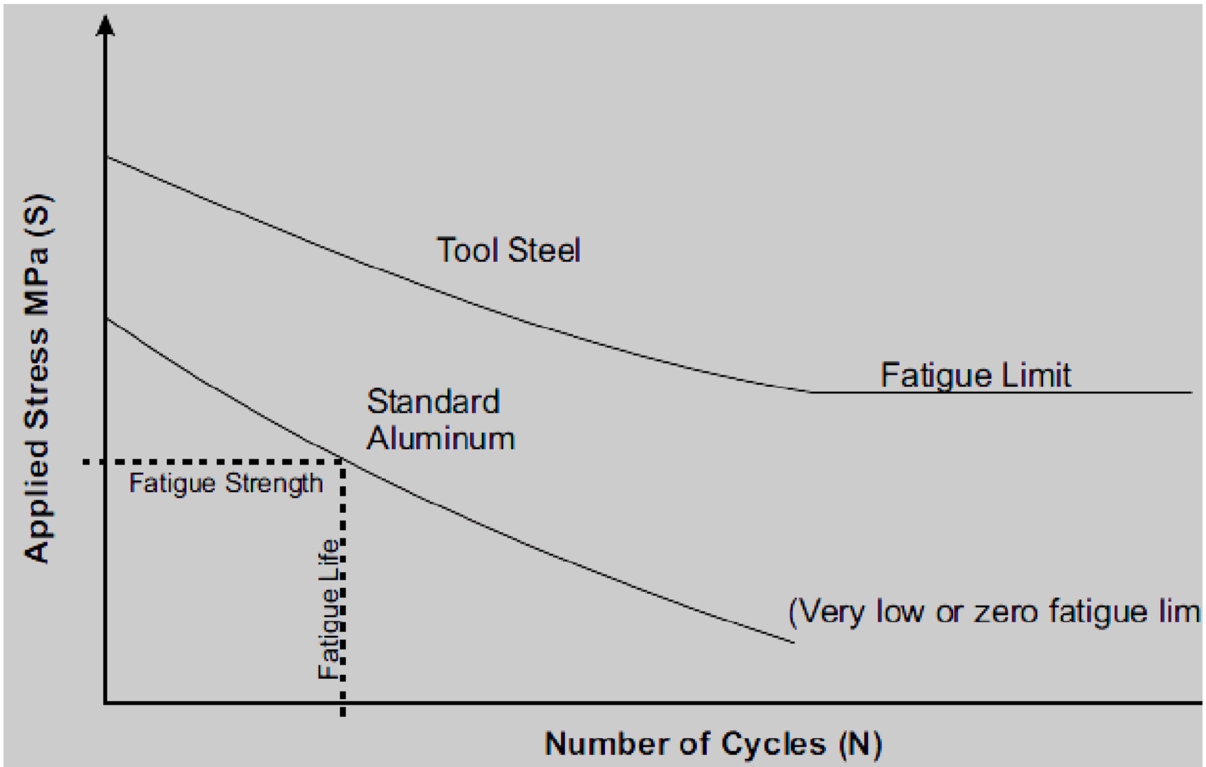


Figure 6: Typical S-N (stress - number of cycles) curves for Steel and Aluminum

Aluminum will fail due to fatigue even at low repeated stress levels. It has a zero or a very small **fatigue limit**. So, if designers use aluminum and it is under repeated stress, they can use the curves to find a **fatigue life** for a given applied stress (its **fatigue strength**). Because some metals (including aluminum) have no **fatigue limit**, specifications for these metals show **fatigue strength**. This is the maximum stress you can use for a given number of cycles. The dotted lines under the aluminum curve in Figure 5 shows this. Textbooks and other sources of specifications normally approximate **fatigue strength** based on a given number of cycles (for example, 5×10^7 or 5×10^8 cycles) to be the **endurance limit** or **fatigue limit**

Engineers often use **fatigue ratio** to compare materials. This is the ratio of the **fatigue limit** to the tensile strength of the material. Fatigue ratio is normally approximately 0.5 for most iron based (ferrous) materials, because its fatigue limit is usually approximately half its tensile strength.

<u>Fatigue and Temperature</u>

Temperature affects fatigue resistance in most materials. As they get hotter, they also get weaker and their fatigue life decreases.

Fatigue and Stress Concentrations

Fatigue tests use ideal specimens tested in ideal conditions. The fatigue fracture occurs at the known point of highest stress. In reality, many parts may have localized points of stress concentration, which will cause premature fatigue failure. Sharp corners and rough or scratched surfaces cause stress concentration at the corner or scratch. So, smooth or rounded surfaces give a better stress distribution and help to reduce fatigue fracture. Also, surface corrosion of the material causes an uneven surface and will cause premature fatigue fracture.

V. Procedure:

1. Choose a test specimen
2. Accurately measure the neck dimensions of your specimen and write the details of the specimen.
3. Move the dead weight along to the furthest left position (lowest or neutral stress position)
4. Switch off the Control and Instrumentation Unit and remove the safety guard from the Main Unit.
5. Fit the specimen to the machine
6. Adjust the dead weight to the position on the load arm to give the required load.
7. Start and run the motor.
8. Note the cycle count when the specimen breaks.

VI. Experimental Work:

Results:

1045 STEEL	
Load F(N)	**No of cycles**
111	1×10^4
101	5×10^4

2014-T6 ALUMINUM ALLOY	
Load F(N)	**No of cycles**
80	1×10^4
69	5×10^4

91	1×10^5
85	2.5×10^5
80	5×10^5
75	7.5×10^5
70	1×10^6
69	5×10^6
69	1×10^7
69	1×10^8

60	1×10^5
56	2.5×10^5
52	5×10^5
49	7.5×10^5
45	1×10^6
41	5×10^6
36	1×10^7
29	1×10^8

Analysis:

1- Calculate the bending stress

2- Plot (**S - Log N**) diagram for both steel and aluminum

3- Find the Endurance limit σ_{EL} for both steel and aluminum and compare with the following theoretical values

$\sigma_{EL}(steel) = 305\ MPa$

$\sigma_{EL}(AL) = 131\ MPa$

4- Estimate the fatigue strength corresponding to **6×10^5** cycles for both steel and aluminum

5- Estimate the expected fatigue life (in cycles) corresponding to stress of **320 MPa** for both steel and aluminum.

Impact Test

I. Objective:

- To determine the behavior of metals under impact stresses.
- To measure the energy absorbing capacity of the material subjected to sudden loading.

- To evaluate the toughness and notch sensitivity of engineering materials.

II. Test Standard

- ASTM E23 - 18 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials.

III. Apparatus:

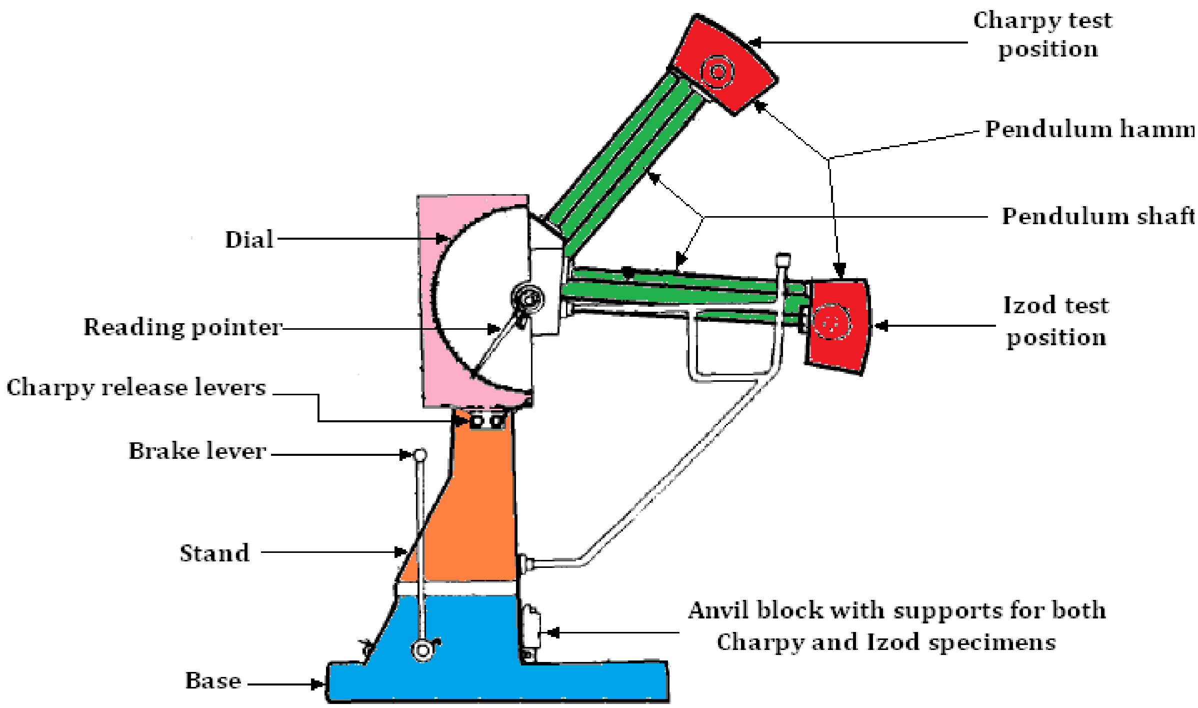


Figure 1: Pendulum Impact Tester

Figure 1 show a Universal Pendulum Impact Tester that can be used to carries out Charpy and Izod tests. The machine frame consists of an anvil block and two stands. The pendulum is mounted between the stands on anti-friction ball bearings, the use of which ensures frictional loss within the permissible limit of 0.5% of the maximum impact energy.

IV. Theory:

<u>Introduction</u>

The impact test provides information about the resistance of the material to a sudden fracture and gives a means for testing materials under conditions of shock loading at fixed temperature. So, impact test are useful in measuring the toughness of materials which is depends primarily on the strength and ductility of a metal since the toughness is the total strain energy per unit volume of metal.

Impact test are not intended to simulate shock loading in service, but are used to indicate differences in metals that are not indicated by other tests. The tests are particularly sensitive to variation in the structure of the metal caused by the following:

- Heat treatment
- Compositions that cause brittleness
- Sulfur and phosphorus content.

Although, there is not direct relationship between impact tests and shock loading in service these tests are goods for comparing materials and for supplying additional information regarding failure of structural members during earthquakes floods, tornadoes and other disaster but they don't give quantitative data that can be used directly in design.

The term brittle fracture is used to describe rapid propagation of cracks without any excessive plastic deformation at a stress level below the yield stress of the material. Metals that show ductile behavior usually can, under certain circumstances, behave in a brittle fashion. The stress needed to cause yield rises as the temperature falls. At very low temperatures, fracture is brittle and occurs before yielding.(see figure 2)

Impact test conditions were chosen to represent those most severe relative to the potential for fracture, namely, (1) deformation at a relatively low temperature, (2) a high strain rate (i.e., rate of deformation), and (3) a triaxial stress state (which may be introduced by the presence of a notch).

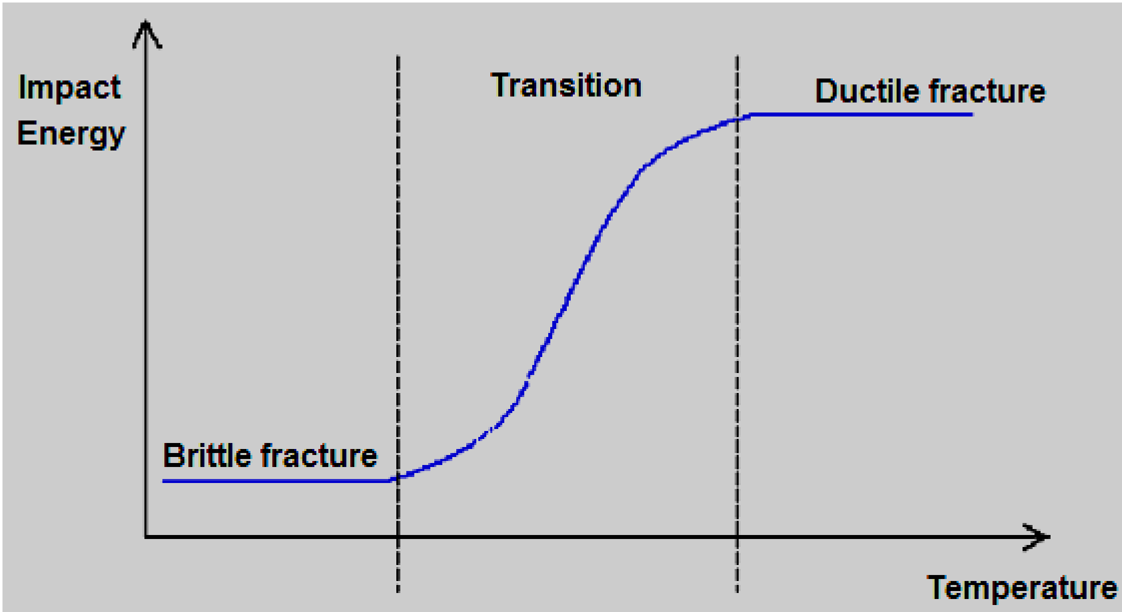


Figure 2: Relation between impact energy , fracture and temperature

Two standardized tests, the Charpy and Izod, are commonly used to measure Impact Energy (sometimes referred to as Notch Toughness). For both Charpy and Izod, a V-notch is machined into a bar specimen with a square cross section.

The primary difference between the Charpy and Izod techniques can be summarized and clarified in table 1.

	Charpy	**Izod**
Maximum Impact Energy of pendulum	300 Joules	160 Joules
Angle of drop of pendulum	140^{o}	85^{o}
Effective weight of pendulum	21.0 Kgs	21.675 Kgs.
striking velocity of pendulum	5.35 m/sec	3.86 m/sec.
Specimen & Notch	55mm long and 10mm square section, with 'V' or 'U' notch in the centre.	75mm long and 10mm square section with a single "V" notch 28 mm from the (top) end. Other configurations with up to three notches on different faces may also be used.
Specimen Support	Simply supported, horizontally	Cantilever, vertically

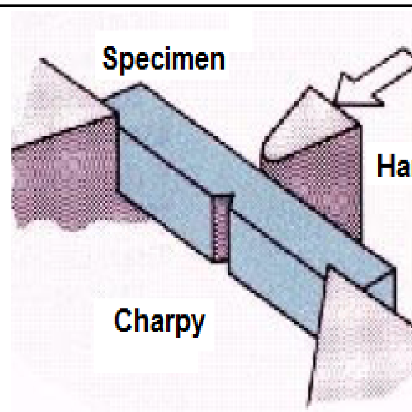
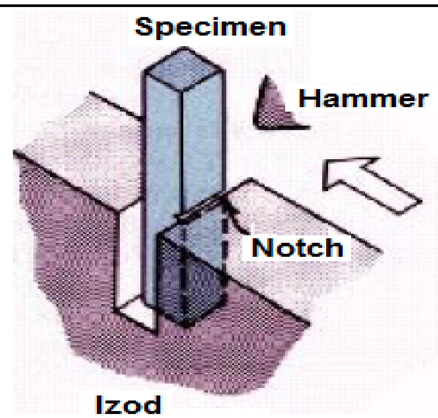
Striking direction	On the face opposite to the notch by a vertical striker.	On the same face as the notch and at a fixed height above it (22mm) by a horizontal striker.
Illustration figures		

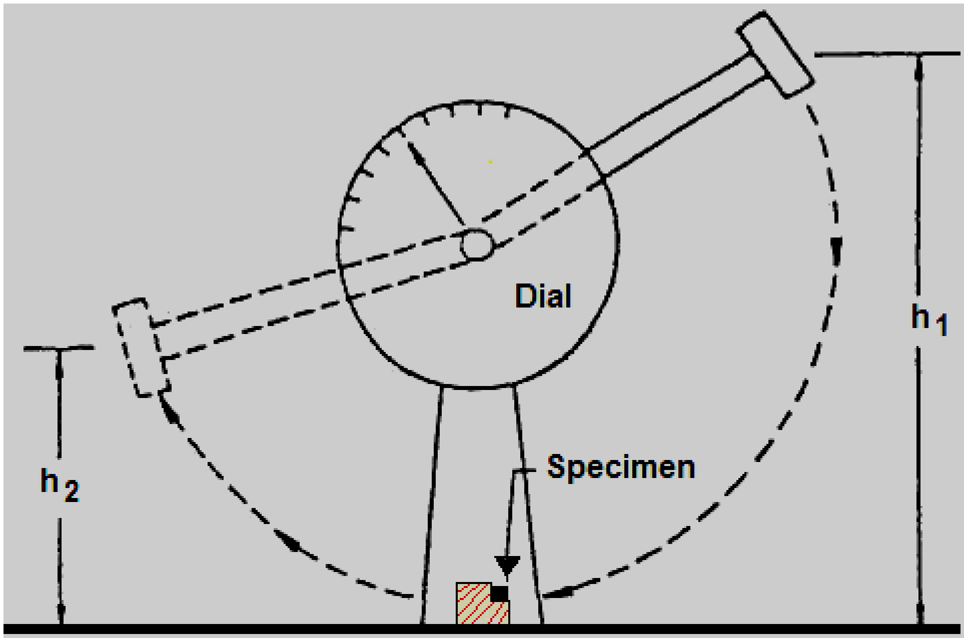
Table 1: difference between the Charpy and Izod tests

Pendulum impact test theory

In its elevated position the pendulum possesses a definite potential energy which is converted to kinetic energy during its swing. The pendulum achieves maximum kinetic energy at the lowest point of its swing just before it comes in contact with the test specimen mounted in its support on the machine base (see figure). The impact energy absorbed by the specimen during rupture is measured directly on the dial scale which can be computed based on the difference between the height of drop before rupture and the height of rise after breaking the test specimen.

$$The\ impact\ Energy = mg\left(h_1 - h_2\right)$$

The losses due to friction are permissible within a limit of 0.5% of the maximum impact energy.



V. Procedure:

1. Fit Charpy or Izod striker in its appropriate position according to which test to be performed, ensuring that the fastening screws are fully tightened.
2. The Anvil for the Charpy or Izod test should be securely fastened on the base by the socket head screws. Correct positioning of the striker against the specimen
3. Check that the release mechanism is operating correctly.
4. Set the pointer to 300J for Charpy and 150 J for Izod on the Dial Scale and in contact with its carrier.
5. Raise the pendulum to its release position and ensure it is securely latched. The pointer carrier should have rotated with the pendulum. Now move the pointer itself to be in contact with the carrier
6. Release the pendulum by pressing down the lever. This test is run without specimen to measure the energy loss due to friction.
8. Wait until the pendulum has completed its initial swing, before applying the pendulum brake to slow down the pendulum and bring stop read the energy absorbed.
9. Place the specimen on the support. The specimen should be placed in such a way related to test (Charpy or Izod).
10. Repeat steps 4 to 8.

VI. Experimental Work:

Energy losses =   N.m

Charpy Test			Izod Test		
Material	**Notch type (V,U)**	**Energy Absorbed (N.m)**	**Material**	**Notch type (V,U)**	**Energy Absorbed (N.m)**
Mild steel			**Mild steel**		
Brass			**Brass**		
Aluminum			**Aluminum**		

Analysis:

- Compare between impact energy values of different specimens tested?
- Why we use the notch in the specimens?
- For the same conditions, where would the impact absorbed energy be greater, at the case of V-notch or U-notch specimens? And why?
- What are the uses and the applications of the impact energy.
- What are the factors affecting the impact energy

Creep in metals

I. Objective:

- To demonstrate and investigate creep in metals
- To construct creep curve and understand stages of creep
- To be able to explain the causes of creep in metals, creep deformation and be able to indicate factors influencing creep behavior in metals.
- To analyze the obtained creep data and how use it for the selection of appropriate engineering materials to prevent creep failures.
- To derive the creep constants from experimental data.

II. Test Standard

- **ASTM** E139

III. Apparatus:

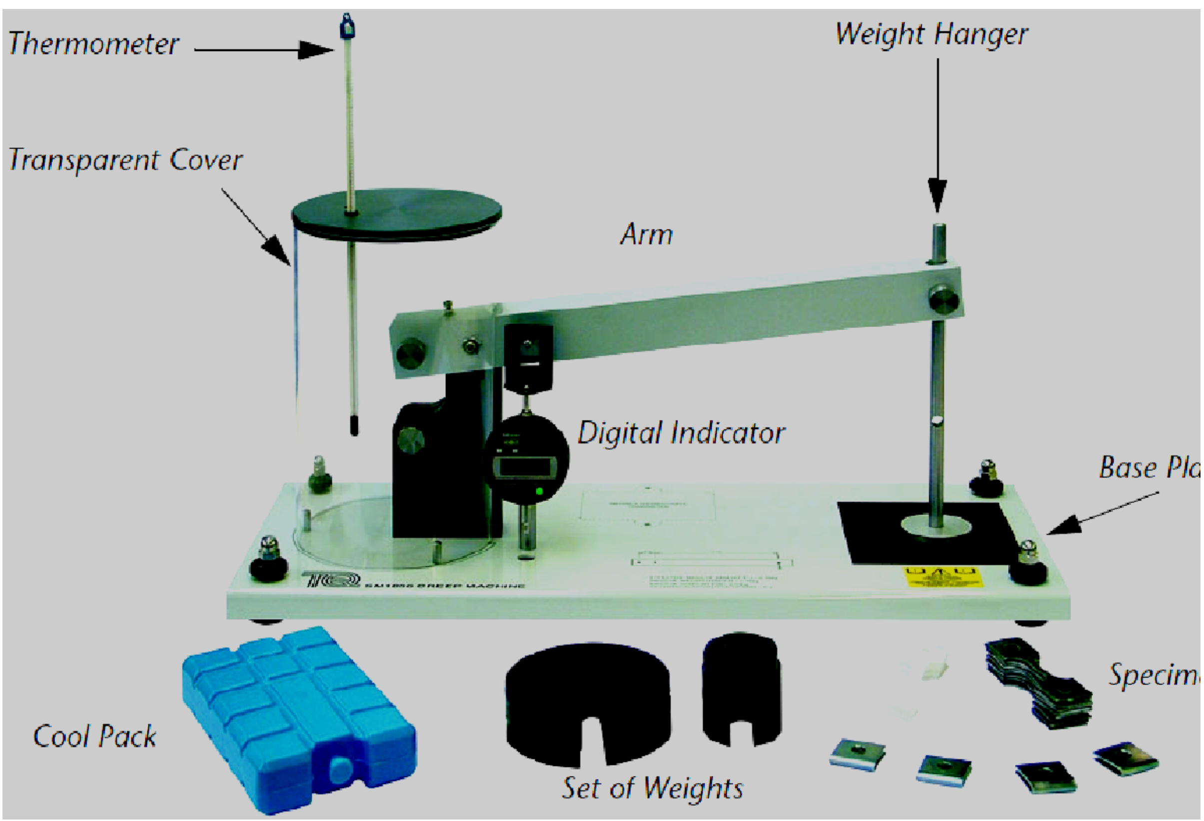


Figure 1: Creep Apparatus

The Creep Apparatus uses a simple lever to apply a steady tensile load to a specimen (see Fig. 1). The specimen is fixed at one end of lever and loads are applied by hanging weights on the other end of the lever arm. A rest pin is provided to support the weight of the lever arm when loading the specimen prior to a test.

A digital displacement indicator measures the change in length (extension) of the specimen during the experiments.

A thermometer measures the ambient temperature around the specimen.

A clear enclosure fits around the specimen area to help keep the temperature constant and provide some protection when specimens are tested to fracture.

<u>Specimen</u>

Lead specimen with dimensions shown in figure 2

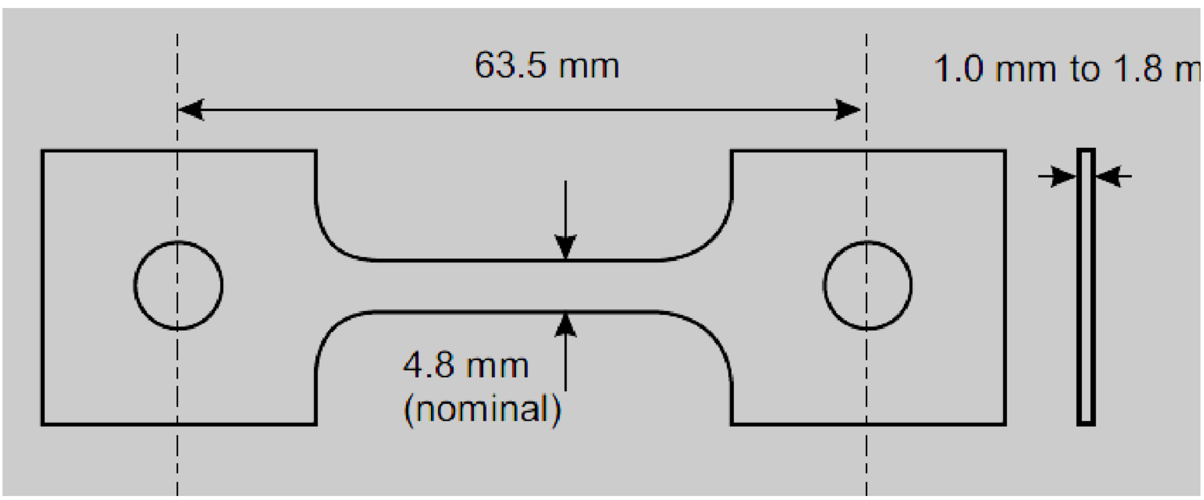


Figure 2 Key Dimension of the Specimens

Data Acquisition System (VDAS)

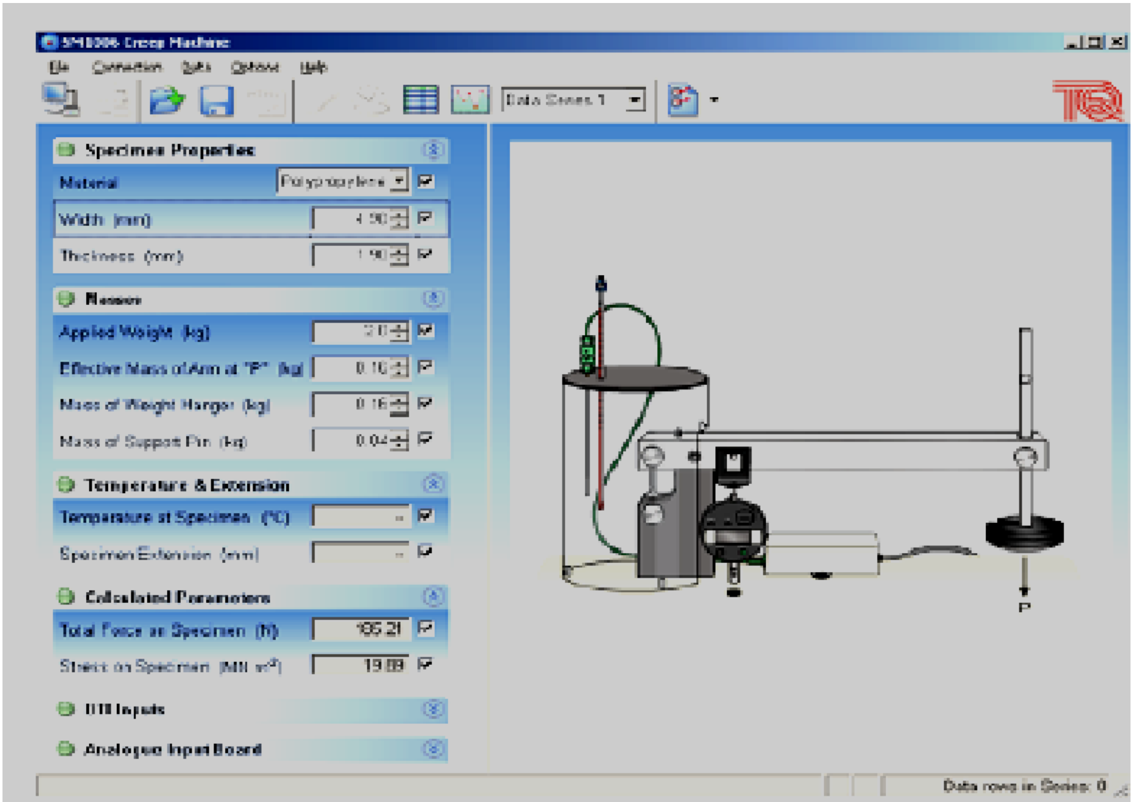


Figure 3 Software interface

The apparatus can be connected to a data Acquisition System with software installed on the PC, so that data can be collected automatically from the experiment. Figure 3 show the software interface.

IV. Theory:

Elastic and Plastic Deformation

When a material is stressed so that it compresses or stretches (deforms), then returns to its original shape when the stress is removed, the material is **perfectly elastic**. The atoms in the material have not moved, but the bonds between them have stretched, then returned to their original position.

When a material is stressed so that it compresses or stretches (deforms), then does not return to its original shape when the stress is removed, the material is **perfectly plastic**. The atoms have actually moved and will not return.

Most materials have both elastic and plastic properties. When stressed by a small amount, they behave like an elastic material, up to their elastic limit. When stressed by a large amount (that takes them past their elastic limit), they behave like a plastic material. Rubber and soft plastic materials usually have more elasticity than more brittle materials like metal or ceramics. (see figure 4)

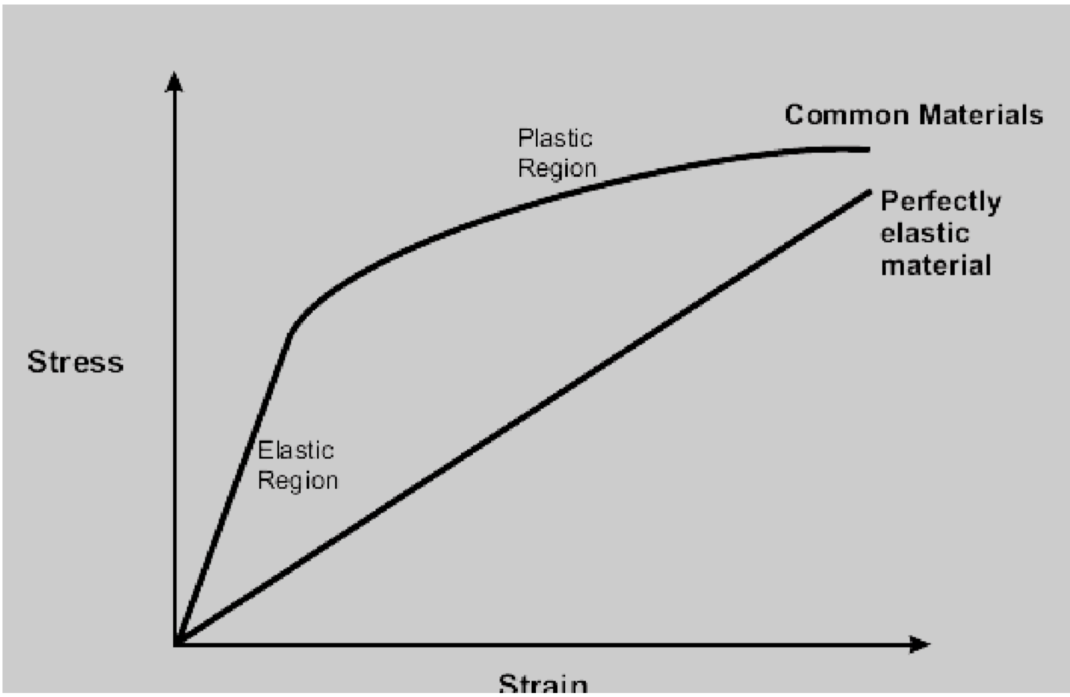


Figure 4 Stress/Strain Curves

Creep

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 hardening 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, that is, it is said to "creep".

Creep in steel is important only at elevated temperatures. In general, creep becomes significant at temperatures above about 0.4Tm where Tm 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 0.5Tm) it exhibits similar creep characteristics to those of iron at 650°C.

Four main things determine the speed and amount of creep:

- Applied load - higher loads give higher stresses that increase the speed of creep
- Type of material - softer materials creep more quickly for the same value of stress
- Dimensions of the material - thinner materials take higher stresses for the same value of load
- Temperature of the material - higher temperatures encourage faster creep

The applied load and the dimensions of the material determine the stress, so you could say that three main things determine creep: Stress, material and temperature.

Figure 5 show Creep at Different Temperatures and Stress.

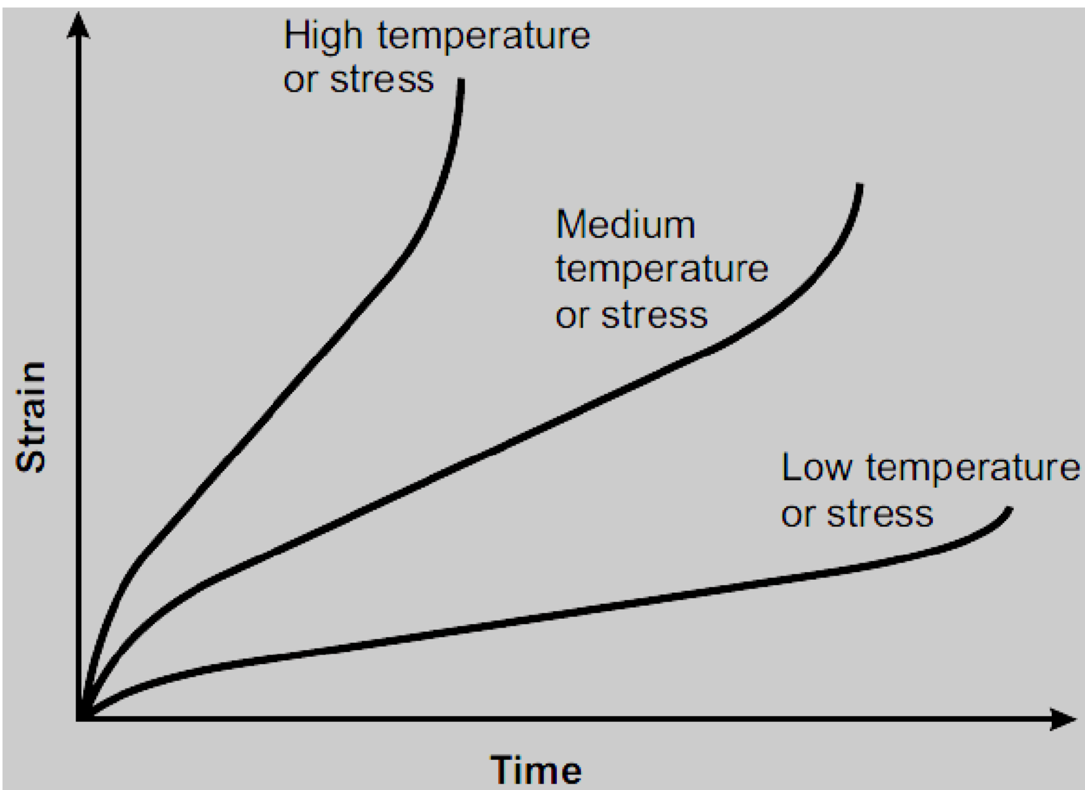


Figure 5 Creep at Different Temperatures and Stress.

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 6.

Three stages can be identified on the curve:

Primary Creep -creep proceeds at a diminishing rate due to work hardening of the metal. Primary creep does not start until the material has passed its elastic limit.

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

Tertiary Creep - the creep rate increases due to necking of the specimen and the associated increase in local stress until failure occurs.

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 other's 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 and the specimen fails due to localized necking of the specimen.

When in service, an engineering component should never enter the tertiary stage of creep. It is therefore the secondary creep rate, 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.

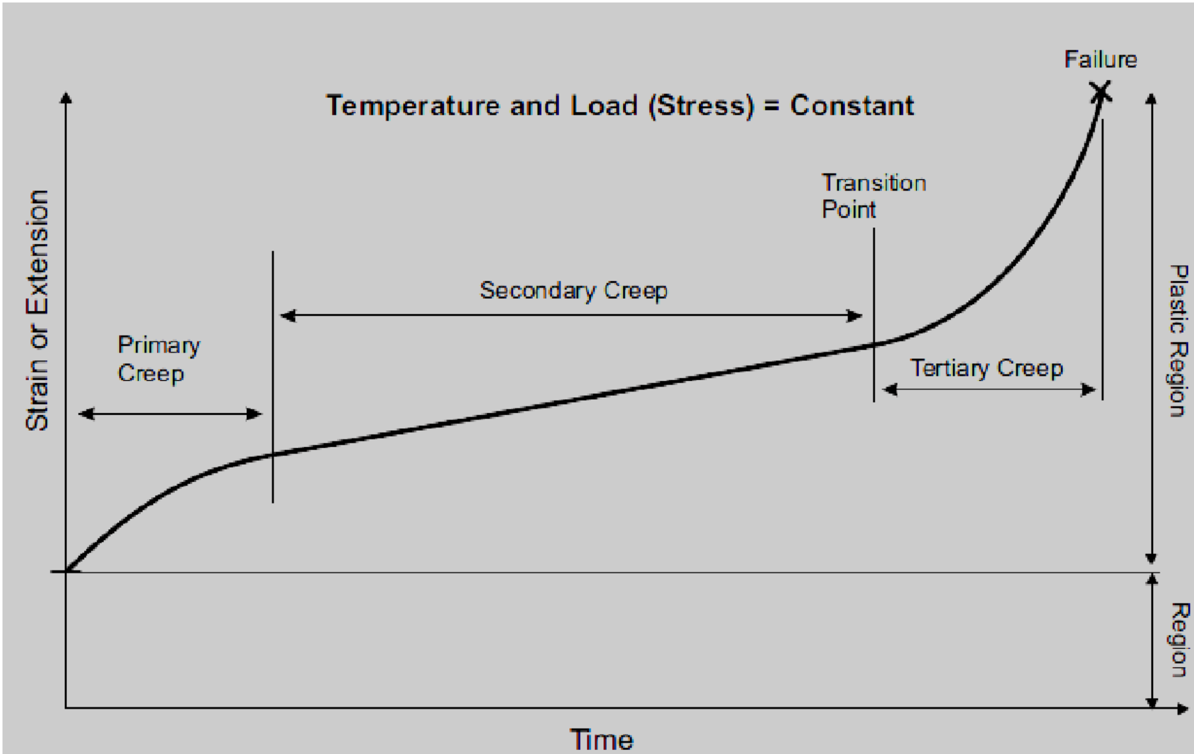


Figure 6 Creep Curve

<u>Calculation of Creep Rate (secondary creep)</u>

Secondary creep rate is linear, so experimentally is equal to the slop of the line in secondary stage.

$$\dot{\varepsilon} = \frac{\Delta\varepsilon}{\Delta t} \quad \text{...}(1)$$

To most common equation used to predict creep rate in metals and alloys is:

$$\dot{\varepsilon} = A\sigma^{n} e^{-Q/RT} \quad \text{...}(2)$$

Where A and n are constants, Q is the activation energy and R is the universal gas constant (8.31 J/mol K).

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

$$ln\dot{\varepsilon} = lnA + nln\sigma - \frac{Q}{RT} \quad \text{...}(3)$$

So for tests at constant temperature and varying stress, a plot of $ln\dot{\varepsilon}$ against $ln\sigma$ gives n

Also, for tests at constant stress and varying temperature, a plot of $ln\dot{\varepsilon}$ against $\frac{1}{T}$ can produce the activation energy Q.

The fact that the exponent n varies with stress demonstrates the inadequacy of simple laws for correlation of data over a wide range of stress levels. In practice, more complicated equations are used to correlate experimental data. For our purposes, it is sufficient to use the equation 2.

V. Procedure:

1. Accurately measure and record the width and thickness of the specimen
2. Put the weight hanger in position and fit its support pin in its highest hole to hold the arm up and ready for the test specimen.
3. Fit the steel specimen support clips to the specimen.
4. Fit the specimen into place between the black support block.
5. Put the transparent cover into place around the specimen. Make sure that the thermometer is in its hole in the top of the cover and its tip is near to the specimen.
6. Fit a suitable weight to the Weight Hanger, to give a stress needed.
7. Set the digital indicator in its place and connect it to data logger.
8. Carefully remove the Weight Hanger support pin from the highest hole in the Weight Hanger
9. Switch on the digital indicator and press its origin button to set its display to zero.
10. Run the software for sampling every 30 sec.
11. Apply the load by fix the hanger and weights at lower hole. Try to load the specimen and sampling data at same time.

VI. Experimental Work:

Results:

Specimen dimensions	Width	
	Thickness	
	Gage length	
Temperature		
weight add to the Weight Hanger		
The Effective mass of the Arm at 'P'		
Mass of the Weight Hanger		
Mass of the Support Pin		

Note: table of results of time and extension will be supplied from software.

Analysis:

1. Calculate of the Stress on a Specimen

a. Calculate the total mass at the end of the Arm (point 'P'). To do this, add together:

- The value of the weight you are to add to the Weight Hanger
- The Effective mass of the Arm at 'P'
- Mass of the Weight Hanger
- Mass of the Support Pin

b. Multiply the total mass by 8 (the mechanical advantage of the Arm), and then by 9.81 (acceleration due to gravity). This will give the total force on the specimen in Newtons.
c. Calculate the cross sectional area of the specimen (width x thickness) in m^2.
d. Divide the total force (Newtons) by the cross sectional area (m^2) to find the stress on the specimen (in N/m^2).

2. Calculation of the Strain on a Specimen

$$Strain = \frac{Extension}{Gage\ length} = \frac{\Delta l}{L}$$

3. Plot the creep curve, and show on curve the three stages and fracture point.

4. Find the slope of the second stage which is the creep rate.

5. Find the time required for each stage.

6. State the importance of creep and its application in real life

Thin wall cylinder

I. Objective:

To study the stress and strain developed in a thin wall cylinder under internal pressure.

To determine the Poisson's ratio and modulus of elasticity for the cylinder material.
To plot Mohr’s circle and use it to find strains at different directions.

III. Apparatus:

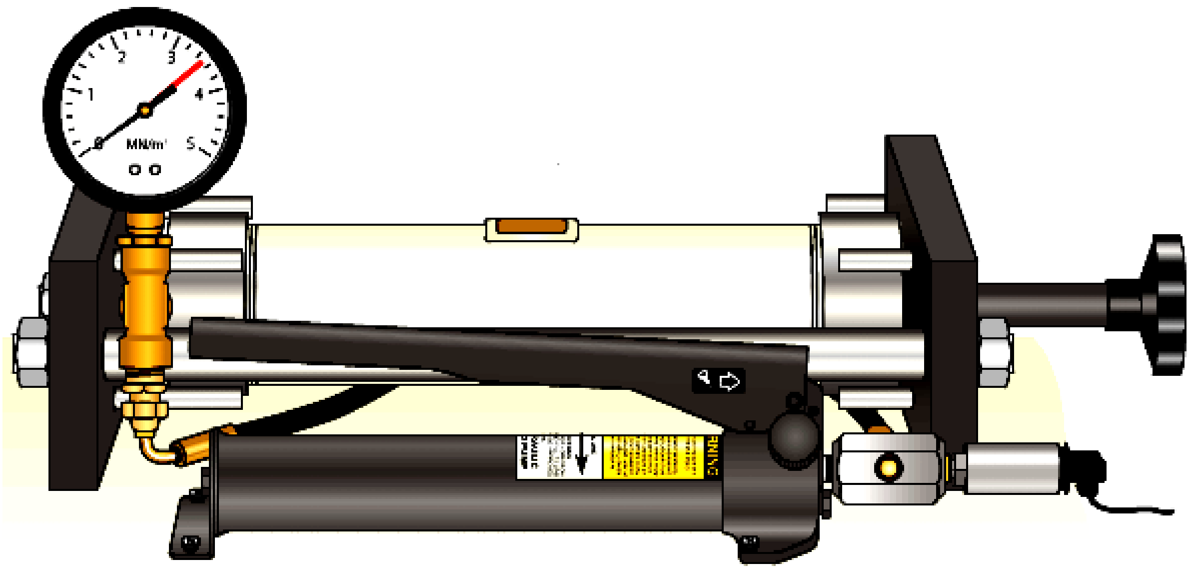
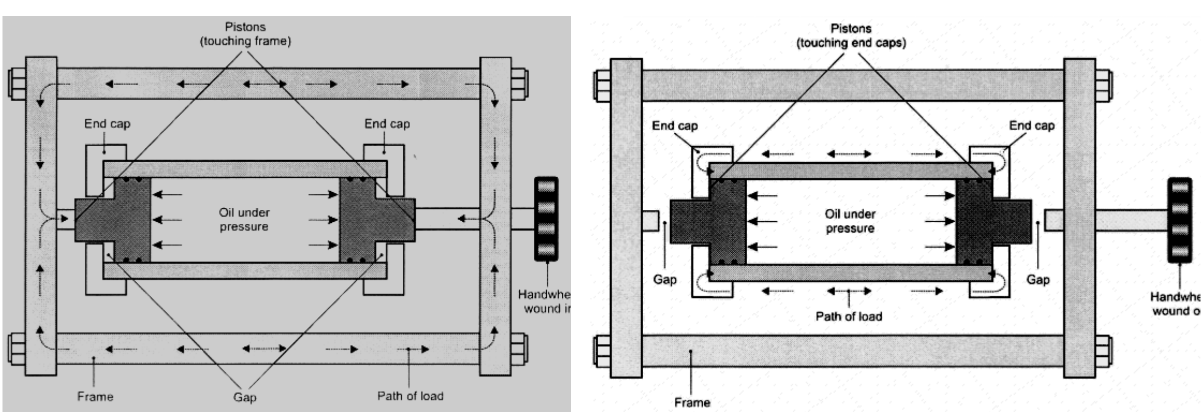


Figure 1: Thin cylinder apparatus

Figure 1 shows a thin-walled cylinder of Aluminum containing a freely supported piston. A hand pump is fitted with a pressure relief valve, to pressurize the cylinder up to approximately 4 MN/m^2. A bleed nipple is fitted to the right-hand end of the cylinder. The piston can move in or out to alter the end conditions by use of the adjustment screw. A frame supports the cylinder unit, which rests on four dowels, and is located axially by the locking screw and the adjustment screw. When the adjustment screw is screwed out, the pressurized oil in the cylinder forces the piston against an end plate. This gives the ***close end conditions***. Screwing in the adjustment screw forces the piston away from the end plate. This places the entire axial load on the frame, thus relieving the cylinder of all longitudinal stress (***open end condition***).



Open end condition **Closed end condition**

Figure 2: End conditions

Six active strain gauges cemented onto the cylinder. These are used to measure the strain at different directions as shown in figure 3.

The characteristics of Aluminum cylinder

- Cylinder material Aged aluminum alloy 6063
- 80 mm internal diameter
- 3 mm wall thickness
- Young's Modulus (E) = 69 GN/m2
- Poisson's ratio 0.33

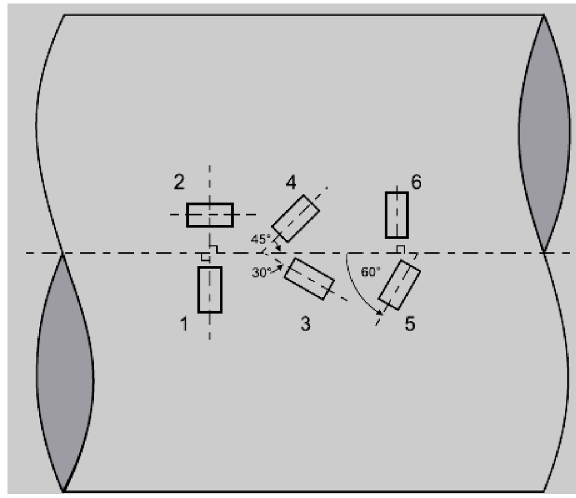


Figure 3: Strain gauges

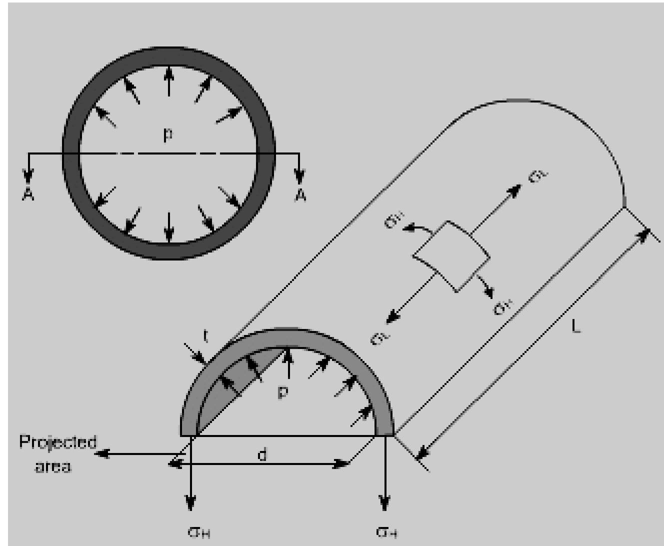
IV. Theory:

A cylinder is considered thin wall if the ratio of wall thickness to internal diameter is less than about 1/20. When a thin wall cylindrical vessel is pressurized two kinds of stress are caused: hoop (circumferential) stress σ_H and axial (longitudinal) stress σ_L.

The value of σ_H and σ_L may be assumed reasonably constant over the area, i.e. throughout the wall thickness. In the subsequent theory the radial stress, which is small, will be ignored.

<u>Hoop or circumferential stress:</u>

This is the stress which is set up in resisting the bursting effect of the applied pressure and can be most conveniently treated by considering the equilibrium of the cylinder.
In the figure we have shown a one half of the cylinder. This cylinder is subjected to an internal pressure P. Total force on one half of the cylinder due to the internal pressure is



$F = PdL$

Where P = internal pressure
d = inside diameter
L = Length of the cylinder

The cross-section area of material which sustains the pressure force is given by:

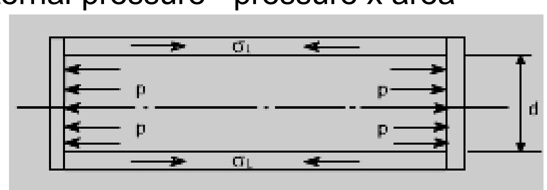
$A = 2tL$

Where t = thickness of the wall. Therefore the Hoop stress is given by:

$\sigma_H = \frac{F}{A} = \frac{Pd}{2t}$

Longitudinal Stress:

Consider the vessel have closed ends and under an internal pressure P. Then the walls of the cylinder will have a longitudinal stress as well as a circumferential stress. The force on the end of the cylinder due to internal pressure= pressure x area



$F = P \times \frac{\pi d^2}{4}$

The area of metal resisting this force $= \pi dt$ (approximately) because πd is the circumference and this is multiplied by the wall thickness t

Therefore the Longitudinal stress is given by:

$\sigma_L = \frac{F}{A} = \frac{Pd}{4t}$

Note that $\sigma_L = \frac{1}{2}\sigma_H$

Open Ends Condition

The cylinder in this condition has no end constraint and so the longitudinal component of stress σ_L will be zero. However, there will be some strain in this direction due to the Poisson effect. Consider an element of material; σ_H will cause strains of:

$\varepsilon_H = \frac{\sigma_H}{E}$ and $\varepsilon_L = -\frac{\nu\sigma_H}{E}$

Where E is the modulus of elasticity, and ν is Poisson ratio, given by

$$\nu = \frac{lateral\ strain}{axial\ srain} = -\frac{\varepsilon_L}{\varepsilon_H}$$

ε_H and ε_L are the two principal strains. ε_L is negative, indicating that the cylinder in the longitudinal direction will be in compression.

Closed Ends Condition

By constraining the ends, a longitudinal as well as circumferential stress is imposed upon the cylinder. Consider an element of material; σ_H will cause strains of:

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

σ_L will cause strains of:

$$\varepsilon_L = \frac{\sigma_L}{E} \quad \text{and} \quad \varepsilon_H = -\frac{\nu\sigma_L}{E}$$

The principal strains are a combination of these values i.e

$$\varepsilon_H = \frac{1}{E}\left(\sigma_H - \nu\sigma_L\right) \quad \text{and} \quad \varepsilon_L = \frac{1}{E}\left(\sigma_L - \nu\sigma_H\right)$$

The principal strains can be evaluated and a Mohr's strain circle constructed for each test condition. From this circle the strain at any position relative to the principal axes may be determined.

V. Procedure:

1. Connect the thin cylinder to the data logger and to the PC
2. Switch on the power on the thin cylinder. Wait 5 minutes before take readings.
3. Operate the software, select the thin cylinder application and make connection with the apparatus, then select open end conditions and the required parameters.
4. Open the pressure control screw (CCW) and set the cylinder to open end conditions.
5. Shut the pressure control screw, press and hold zero button to zero all strain gauge display readings.
6. Take the first set of readings at zero pressure by pressing the take data icon.
7. Pump the hand pump until pressure reaches 0.5 MN/m2. Wait for few seconds and press the data icon to collect the data.
8. Continue increasing the pressure in 0.5 MN/m2 increments up to 3 MN/m2. At each time take all readings.
9. Open the pressure control screw to reduce the cylinder pressure to zero.

VI. Experimental Work:

Analysis:

Young's Modulus of elasticity

1. Calculate the hoop stresses σ_H
2. Calculate the hoop strain ε_H (The average readings of gauge 1 and 6)
3. Plot hoop stresses σ_H (y-axis) against hoop strain ε_H (x-axis).[Linear relation]
4. Find the slop of your line which represents the modulus of elasticity experimental.
5. Compare with the theoretical value and find % error.

Poisson's Ratio

1. Determine the hoop strain ε_H (The average readings of gauge 1 and 6)
2. Determine the Longitudinal strain ε_L (reading of gauge 2).
3. Calculate the Poisson's Ratio.
4. Calculate the % Error.

Principal strains and Mohr's circle [Optional]

1. Calculate the theoretical strain and compare it with experimental for gauges 3, 4 & 5.

Results:

Cylinder end condition: Open Ends							
Pressure MN/m^2	Hoop Stress MN/m^2	Strain($\mu\varepsilon$)					
		Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Gauge 6

Hardness Test

I. Objective:

1. To understand what hardness is, and the specification of Rockwell, Brinell, and Vickers hardness tests.
2. To conduct typical engineering hardness tests and be able to recognize commonly used hardness scales and numbers.
3. To be able to understand the correlation and conversions between hardness numbers and the properties of materials.
4. To learn the advantages and limitations of the common hardness test methods.

II. Test Standard

ASTM Standard	Description
E10	**Standard Test** Method for Brinell **Hardness** of Metallic Materials
E18	**Standard Test** Methods for Rockwell **Hardness** and Rockwell Superficial **Hardness** of Metallic Materials
E92	**Standard Test** Method for Vickers **Hardness** of Metallic Materials

III. Theory:

What is Hardness?

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting.

Measurement of Hardness:

A hardness property value is the result of a defined measurement procedure. The usual method to achieve a hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry.

Rockwell Hardness Test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F0 (Fig. 1A) usually 10 kgf.

When equilibrium has been reached, while the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Fig. 1B). When equilibrium has again been reached, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Fig. 1C). The permanent depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

$$HR = E - e$$

F0 = preliminary minor load in kgf

F1 = additional major load in kgf

F = total load in kgf

e = permanent depth of penetration due to major load F1

E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter

HR = Rockwell hardness number

D = diameter of steel ball

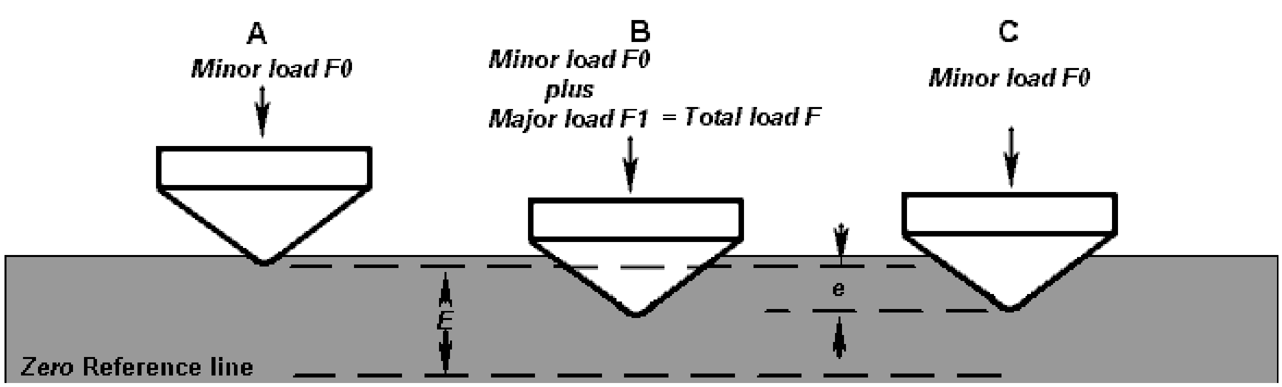


Fig. 1.Rockwell Principle

Table1: Rockwell Hardness Scales

Scale	Indenter	Minor Load *F0* kgf	Major Load *F1* kgf	Total Load *F* kgf	Value of *E*
A	Diamond cone	10	50	60	100
B	1/16" steel ball	10	90	100	130
C	Diamond cone	10	140	150	100
D	Diamond cone	10	90	100	100
E	1/8" steel ball	10	90	100	130
F	1/16" steel ball	10	50	60	130
G	1/16" steel ball	10	140	150	130
H	1/8" steel ball	10	50	60	130
K	1/8" steel ball	10	140	150	130
L	1/4" steel ball	10	50	60	130
M	1/4" steel ball	10	90	100	130
P	1/4" steel ball	10	140	150	130
R	1/2" steel ball	10	50	60	130
S	1/2" steel ball	10	90	100	130
V	1/2" steel ball	10	140	150	130

Table2: Typical Application of Rockwell Hardness Scale

HRA	Cemented carbides, thin steel and shallow case hardened steel
HRB	Copper alloys, soft steels, aluminum alloys, malleable irons, etc.
HRC	Steel, hard cast irons, case hardened steel and other materials harder than 100 HRB
HRD	Thin steel and medium case hardened steel and pearlitic malleable iron
HRE	Cast iron, aluminum and magnesium alloys, bearing metals
HRF	Annealed copper alloys, thin soft sheet metals
HRG	Phosphor bronze, beryllium copper, malleable irons HRH . .. . Aluminum, zinc, lead
HRK	Soft bearing metals, plastics and other very soft materials
HRL	
HRM	
HRP	
HRR	
HRS	
HRV	

Advantages of the Rockwell hardness method include the direct Rockwell hardness number readout and rapid testing time. Disadvantages include many arbitrary non-related scales and possible effects from the specimen support anvil. Vickers and Brinell methods don't suffer from this effect.

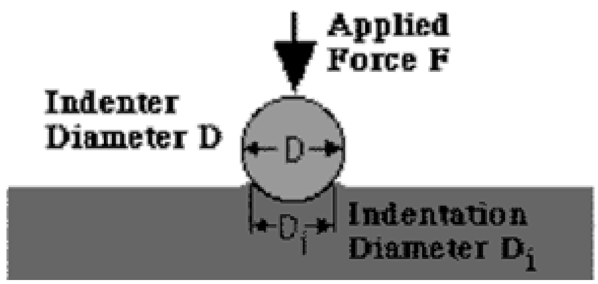
Standards

Rockwell test methods are defined in the following standards:

- ASTM E18 Metals
- ISO 6508 Metals
- ASTM D785 Plastics

The Brinell Hardness Test

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell harness number is calculated by dividing the load applied by the surface area of the indentation.



$$BHN = \frac{2F}{\pi D \times \left(D - \sqrt{D^2 - D_i^2}\right)}$$

On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material.

Standards

Brinell Test methods are defined in the following standards:

- ASTM E10
- ISO 6506

Applications

Because of the wide test force range the Brinell test can be used on almost any metallic material. The part size is only limited by the testing instrument's capacity.

Strengths

- One scale covers the entire hardness range, although comparable results can only be obtained if the ball size and test force relationship is the same.
- A wide range of test forces and ball sizes to suit every application.
- Nondestructive, sample can normally be reused.

Weaknesses

- The main drawback of the Brinell test is the need to optically measure the indent size. This requires that the test point be finished well enough to make an accurate measurement.

- Slow, testing can take 30 seconds not counting the sample preparation time.

Vickers Hardness Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

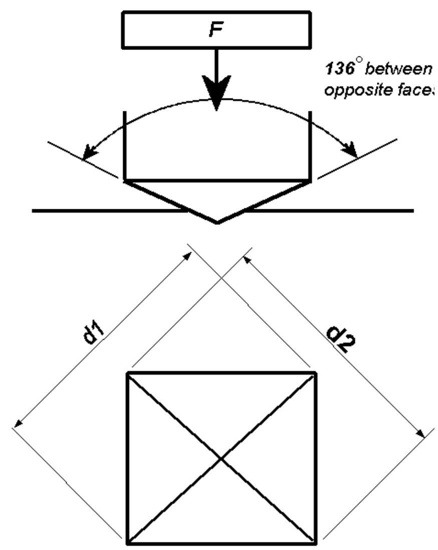
F= Load in kgf

d = Arithmetic mean of the two diagonals, d1 and d2

HV = Vickers hardness in mm

$$HV = \frac{2F\sin\frac{136}{2}}{d^2} \approx 1.854\frac{F}{d^2}$$

When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a



Vickers hardness of 800 was obtained using a 10 kgf force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads.

Standards

Vickers test methods are defined in the following standards:

- ASTM E384 – micro force ranges – 10g to 1kg
- ASTM E92 – macro force ranges - 1kg to 100kg
- ISO 6507-1,2,3 – micro and macro ranges

Applications

Because of the wide test force range, the Vickers test can be used on almost any metallic material. The part size is only limited by the testing instrument's capacity.

Strengths

- One scale covers the entire hardness range.
- A wide range of test forces to suit every application.
- Nondestructive, sample can normally be used.

Weaknesses

- The main drawback of the Vickers test is the need to optically measure the indent size. This requires that the test point be highly finished to be able to see the indent well enough to make an accurate measurement.
- Slow, testing can take 30 seconds not counting the sample preparation time.

<u>Hardness Conversion or Equivalents:</u>

Hardness conversion between different methods and scales cannot be made mathematically exact for a wide range of materials. Different loads, different shape of indenters, homogeneity of specimen, cold working properties and elastic properties all complicate the problem. All tables and charts should be considered as giving approximate equivalents particularly when converting to a method or scale which is not physically possible for the particular test material and thus cannot be verified {See the attached conversion tables}

<u>Hardness and tensile strength</u>

Hardness tests often are used to quantify strength and are considered to be nondestructive in most applications because the indentations are small and do not adversely affects surface quality. In the case of steel, there is a common relationship between the Brinell hardness number (BHN) and the ultimate tensile strength (UTS) given in pounds force per square inch (psi), or MPa:

$$TS(MPa) = \{3.55 \ \times HB(HB \leq 175)\ 3.38 \ \times HB(HB > 175)$$

$$TS(psi) = \{515 \ \times HB(HB \leq 175)\ 490 \times HB(HB > 175)$$

Where HB is the Brinell hardness of the material, as measured with a standard indenter 10mm ball and a 3000 kgf load.

However, similar relationships can be shown for brass, aluminum and cast irons, or you can use the attached conversion tables to find the ultimate tensile strength (UTS) for any material.

<u>Test Precaution</u>

1) Ensure that contact surfaces such as the indenter attachment face, between the specimen and specimen platform, and between the specimen platform and raising/lowering screw are continually maintained in a clean state. Accurate hardness values may not be obtained if foreign matter such as dust, rust, or oil is included on contact surfaces.

2) The specimen measurement location must be spaced at least 4d (where d is the indentation diameter) from the center of indentations already present.

The measurement location must also be separated at least 2.5d from the edge of the specimen.

3) The surface (test face) and reverse face of the specimen must be kept as horizontal as possible. Care is also needed in providing a satisfactory finish to the reverse face of the specimen, and not just the test face. Correct hardness values will not be obtained if the specimen surface is concave, as deformation will occur under the load.

4) The specimen thickness or hardened layer thickness must be at least 10 times the indenter penetration depth.

5) The condition of the indenter greatly affects the hardness value.

IV. Apparatus:

Figure 1 shows the Hardness tester which is a combined machine to measure the hardness of metals, alloys and plastics using Rockwell and Brinell, or Rockwell, Brinell and Vickers methods.

The microprocessor control provides reliable and accurate results, while being easy to use. It supplies direct digital readout of results and statistical data, using battery backed RAM for computing values and saving constants. The machines can be interfaced to a PC. The “statistics” function includes the number of tests, the maximum, minimum and mean values, the standard deviation and the number of tests that are outside the upper and lower limit values. Unloading the machine after a test automatically resets it for the start of the next test. The machines also include a preload control.

Figure 1: Hardness Tester

V. Procedure:

1. With no load on, turn on the Display by the main switch at the back. Set the range to be tested and upper-and Lower Limits if required.

2. Select indenter required, the indenter is fitted into the Holder and secured.

3. Select the pre-load by setting the Minor Load Selection Lever to either 3kg (Vickers) or 10kg (Rockwell or Brinell).

4. Select the Main Load and place the appropriate set of weights on the dashpot plunger for the scale required with the load hanger disc suspended freely within the claw of the weight stem.

Note: for items 2, 3, and 4 see table 3

Table: Hardness test setup

	Rockwell B	Rockwell C	Vickers 30	Brinell

	HRB	HRC	HV30	HB 2.5/187.5
Preload (Kgf)	10	10	3	10
Main load (Kgf)	100	150	30	187.5
Indenter	Steel ball $\frac{1}{16}\ in\ dia$	120º diamond cone	136º diamond pyramid	Steel ball **2.5 mm dia**

5. Check that when the pre-load is applied the load hanger inside the machine does not foul the weight stem. There should be a clearance of approximately3mm between the weight hanger and the claw of the weight stem.

6. Ensure that the Main load is disengaged with the lever at position 'A'(Forward).

7. Fit a suitable anvil for the test piece to be tested. Place the work piece to be tested on the anvil ensuring that there is no interference on the bearing surfaces.

8. To carry out the test, follow the instructions on the keyboard display and raise the test piece against the indenter by means of the hand wheel to apply the Minor Load. Once the Load is within the indicated limits, stop winding and the machine will set itself to 10.0 or 3.0 kgf.

9. Apply the main load by moving the operating handle to the rear of the machine from A to B towards the rear of the machine. The display will then commence to count the dwell time and give an audible signal to indicate when to remove the main load, by returning the operating handle to its original position.

10. At this point the test will be displayed on the keypad display and the upper LCD screen. This figure is the hardness value of the test piece.

11. Lower the test piece from indenter by means of the hand wheel. This removes the preload and the test piece may now removed and the machine is automatically ready for the next test.

Hardness table

VPN	ROCKWELL SCALES									BRINELL SCALE BHN	U.T.S.	
DPH HV/10	A	B	C	D	E	F	G	H	K	187.5 kg / 2.5 mm ball 3000kg / 10mm ball	Kpsi	Mpa
1865	92		*80*	87								
1787	92		*79*	86								
1710	91		*78*	85								
1633	91		*77*	84								
1556	90		*76*	83								
1478	90		*75*	83								
1400	89		*74*	82								
1323	89		*73*	81								
1245	88		*72*	80								
1160	87		*71*	80								
1076	87		*70*	79								
1004	86		*69*	78								
940	86		68	77								
900	85		67	76								
865	85		66	75								
832	84		65	75						*739*		
800	84		64	74						*722*		
772	83		63	73						*705*		
746	83		62	72						*688*		

720	82		61	72						*670*		
697	81		60	71						*654*	320	2206
674	81		59	70						*634*	310	2137
653	80		58	69						*615*	300	2069
633	80		57	69						*595*	290	2000
613	79		56	68						*577*	282	1944
595	79	*120*	55	67						*560*	274	1889
577	78	*120*	54	66						*543*	266	1834
560	78	*119*	53	65						*523*	257	1772
544	77	*119*	52	65						*512*	245	1689
528	77	*118*	51	64						496	239	1648
513	76	*117*	50	63						481	233	1607
498	75	*117*	49	62						469	227	1565
484	75	*116*	48	61						455	221	1524
471	74	*116*	47	61						443	217	1496
458	74	*115*	46	60						432	212	1462
446	73	*115*	45	59						421	206	1420
434	73	*114*	44	59						409	200	1379
423	72	*113*	43	58						400	196	1351
412	72	*113*	42	57						390	191	1317
402	71	*112*	41	56						381	187	1289
392	71	*112*	40	55						371	182	1255

382	7 0	*111*	3 9	5 5						362	177	122 0
372	7 0	*11* *0*	3 8	5 4						353	173	119 3

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