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Strength of Materials Lab.

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Introduction to strength of materials

-INTRODUCTION

Strength of materials, is concerned with methods for finding internal forces, stresses, and deflections/deformations in deformable bodies when subjected to loads.

This branch of science helps to understand the behavior of a material under load, and determines its range of useful applications, Moreover, explains properties of a material by manufacturing processes or the composition of the material itself.

-TYPES OF MATERIALS:

1-Ductile Materials:

Materials that can be plastically twisted with no crack. They have the tendency to hold the deformation that occurs in the plastic region.

Examples: Aluminum, Copper, and Steel.

2-Brittle Materials:

Materials when subjected to stress, it breaks without significant plastic deformation. Brittle materials absorb relatively little energy prior to fracture, even those of high strength.

Examples: Chalk, Concrete, ceramics and glass.

-IMPORTANT DEFINITIONS

1-Strength:

Is the ability of the material to resist the influence of the external forces acting upon.

2-Stress:

When a force is applied to a certain cross-sectional area of an object, stress can be defined as the internal distribution of forces within the object that balance and react to the force applied to it.

3-Strain:

Is defined as the amount of deformation in the direction of the applied force divided by the initial length of the material.

4- Stiffness:

Is the ability of the object to resist the strains caused by the external forces acting upon it

5-Stability:

Is the property of the object to keep its initial position of equilibrium.

6-Durability:

is the property of the object to save its strength, stiffness and stability during its life time.

7- Toughness

is the ability of a material to absorb energy and plastically deform without fracturing.

-Types of loadings

- **Transverse loadings** : Forces applied perpendicular to the longitudinal axis of a member. Transverse loading causes the member to bend and deflect from its original position, with internal tensile and compressive strains accompanying the change in curvature of the member. Transverse loading also induces shear forces that cause shear deformation of the material and increase the transverse deflection of the member.

- **Axial loading** : The applied forces are collinear with the longitudinal axis of the member. The forces cause the member to either stretch or shorten.

- **Torsional loading**: Twisting action caused by a pair of externally applied equal and oppositely directed force couples acting on parallel planes or by a single external couple applied to a member that has one end fixed against rotation.

-TYPES OF BEAMS AND LOADS

I-TYPES OF BEAMS:

Beam can be defined as a structural element that primarily resists loads applied laterally to the beam's axis

1-Cantilever Beam:

Is a beam whose one end is fixed and the other end is free.

Figure 1 Cantilever Beam

2-Simply Supported Beam:

is a beam that has pinned support at one end and roller support at the other end.

Figure 2 Simply Supported Beam

3-Overhanging Beam:

Is a type of Simply Supported Beams, which overhangs from its supports.

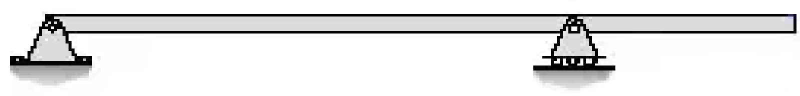


Figure 3 Overhanging Beam

4-Continous Beam:

Is a beam that has more than two supports along its length, commonly used in bridges.

Figure 4 Continous Beam

II-TYPES OF LOADS ON BEAMS

Structural loads are forces applied to a structure or its components. A load is the amount of weight a structure has to carry. Loads cause stresses, deformations, and displacements in structures.

1-Concentrated or Point load:

is a load applied to a single, specific point on a structural member.

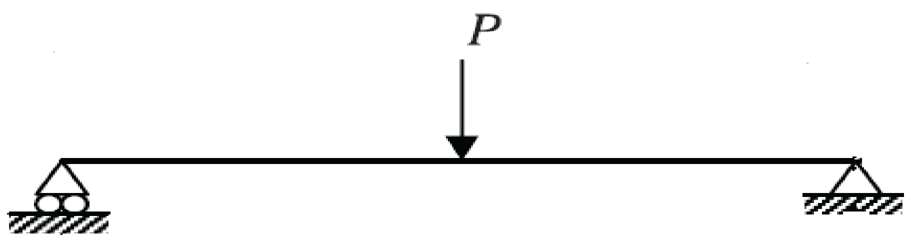


Figure 5 Point Load

2-Uniformly Distributed Load:

A type of load, which is distributed uniformly over certain length of the beam.

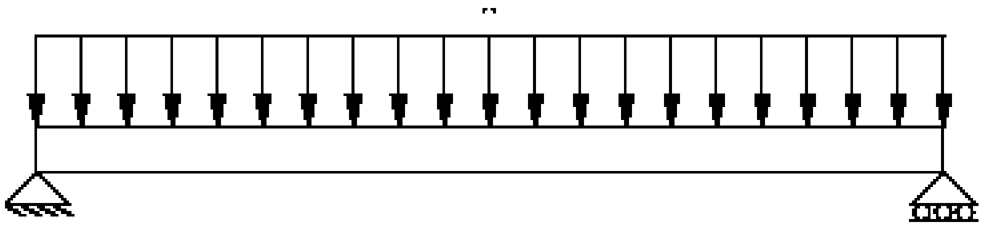


Figure 6 Uniformly Distributed Load

3-Uniformly Varying Load:

Are loads varying uniformly from zero to a particular value and spread over a certain length of the beam.

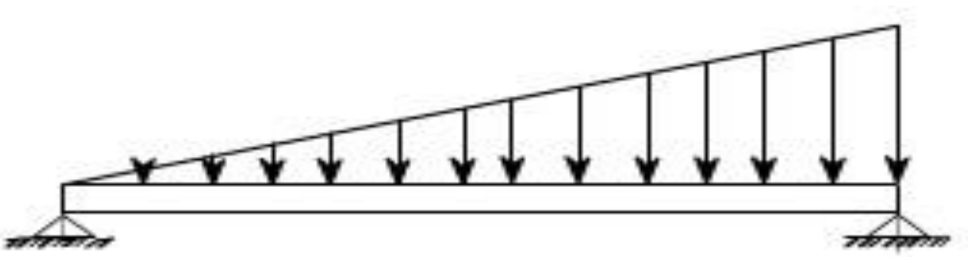


Figure 7 Uniformly Varying Load

-UNITS SYSTEMS

A system of units is a set of related units that are used for calculations. The system includes base units, which represent base dimensions, and derived units, which represent products of powers of base dimensions. Some units exist in more than one system of units.

-International System of Units (**SI)**

Base Units

Dimension Name	Unit Name	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s

Derived Units

Dimension Name	Unit Name	Symbol	
Force	Newton	N	$Kg*m/s^2$
Pressure	Pascal	Pa	N/m^2
Energy , work	Joule	J	N.m

-Report writing

Every student is required to submit his own separate report for each test conducted. Reports should be in hand-writing, on A4 paper. In general, the reports should be arranged in the following order:

1- Abstract

(An abstract is a self-contained, short, and powerful statement that describes a larger work. Components vary according to discipline. An abstract of a social science or scientific work may contain the scope, purpose, results, and contents of the work.)

2- Introduction

(Begin with background knowledge-What was known before the lab? What is the lab about? Include any preliminary/pre-lab questions. Also, include the purpose of the lab at the end of the introduction. Be clear & concise)

3- Materials and Equipment

(Can usually be a simple list, but make sure it is accurate and complete.)

4- Procedure

(Describe what was performed during the lab Using clear paragraph structure, explain all steps in the order they actually happened, If procedure is taken directly from the lab handout, say so! Do NOT rewrite the procedure!)

5- Collected Data

(Label clearly what was measured or observed throughout the lab Include all data tables and/or observation)

6- Calculations

(Show work, include units, and clearly label your results)

7- Results

(Are usually dominated by calculations, tables and figures; however, you still need to state all significant results explicitly in verbal form.)

8- Discussion and Analysis

(Answer any post-lab questions with complete thoughts. Assume the reader does not know anything about this topic.*)*

9- Conclusions

(Refer to the purpose- What was accomplished? Analyze your data, report your findings and include possible sources of error. How does this relate to topics outside of the classroom?)

10- References

Include an alphabetical list of all references used throughout the experiment and/or for writing the lab report. Include your textbook , lab manual, internet, etc.

Experiment 1. Hardness Test

I-Introduction:-

Generally, hardness means the resistance to indentation or scratching. The material is classified according to its hardness to softer or harder material depending on the indenter or the scratcher material. So, hardness is relative measurement depends on both testing and indenting materials. According to the previous definition, if the indenter deform the tested material we can say that the indenter is harder than the tested material and if not, the indenter is softer than the tested material. In nature, diamond is classified as the hardest material.

The measurement of hardness test is classified mainly to three types:-

1. **Scratch hardness:-** this type is roughly used nowadays and it depends on using a diamond. This type is not suitable for metals
2. **Indention hardness:-** this type is suitable for metals and it depends on the indenter material and shapes. In this type, a static load is applied to the specimen for a period of time and the indention shape and dimensions are used to calculate the hardness numbers. Many tests are classified under this type such as: Brinell, Rockwell and Vickers hardness tests. These tests are the core of this experiment.
3. **Rebound or dynamic hardness:-** in this type, an indenter is dropped on the tested material and the hardness is calculated using the impact work results from the impact.

Also There are several hardness classifications they are divided into two main categories: Macro-hardness and Micro-hardness. Macro-hardness refers to testing with applied loads on the indenter of more than 1 kg, in Micro-hardness testing, applied loads are 1 kg and below.

Macro-hardness is used on tools, dies, and sheet material in the heavier gages, while Micro-hardness is used on thin sheets or small test materials that may not respond accurately to Macro-hardness tests.

Macro-hardness is widely used; and has with three methods:

The Rockwell hardness test, Vickers hardness test, and finally the Brinell hardness test. the main differences in these tests are the size, shape and the material used for the indenter in the hardness machine.

Hardness of materials depends on many factors. Generally, we can say that the material is hard if:-

- It has a large value of young's modulus of elasticity
- Its surface is polished well
- The operating condition is at moderated temperature

II-Objective:-

To measure and compare Brinell hardness number for different materials

III- Theoretical Background:-

❖ **Brinell Hardness Number (BHN):-**

In Brinell test, a ball indenter of diameter (D) is pushed inside the tested material as illustrated in Fig.1.1.

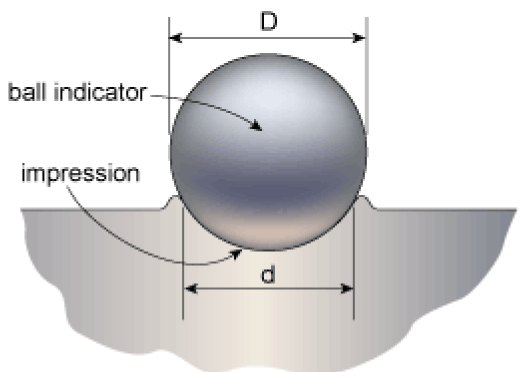


Fig.1.1. Brinell Test

The Brinell Hardness Number (BHN) is calculated by dividing the load over the surface area of the indention:

$$\text{Brinell (HB)} = \frac{Load\ (F)}{Surface\ area\ of\ indentation} = \frac{2F}{\pi D\left[D - \sqrt{(D^2 - d^2)}\right]}$$

$$= \frac{F}{\pi D t}$$

Where:-

F: the applied load (kgf) { 1 kgf = 9.81 N}
D: the indenter diameter (mm)
d: the indention diameter (mm)
t: the depth of the impression (mm)

❖ Rockwell Hardness Number (RHN):-

This type of testing is performed using a direct method to calculate the hardness number. In this test, a ball can be used to indent the specimen as in the Brinell test or a 120^o sphero-conical diamond indenter as illustrated in Fig.1.2.

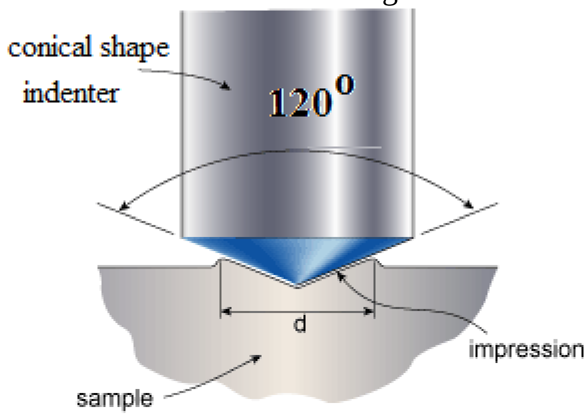


Fig.1.2. Rockwell Test

There are 30 different Rockwell scales, defined by the combination of the indenter and minor and major loads. The majority of applications are covered by the Rockwell C and B scales for testing steel, brass, and other materials. Table 1.1. shows the scale, major load and the type of indenter for the most common Rockwell hardness tests. In this Lab, the value of RHN is taken from the device directly.

Table 1.1. Rockwell tests scaling system

Scale	Major load (kg.f)	Type of indenter
A	60	Brale
B	100	1/16 " Ball
C	150	Brale
D	100	Brale
E	100	1/8 " Ball
F	60	1/16 " Ball
G	150	1/16 " Ball
H	60	1/8 " Ball

❖ Vickers Hardness Number (VHN):-

The Vickers hardness test uses a square base diamond pyramid as the indenter. The included angle between the opposite faces of the pyramid is l36° as illustrated in Fig1.3. The Vickers hardness tester operates on the same basic principle as the Brinell tester, the numbers being expressed in the terms of load and area of the impression. As a result of the indenter’s shape, the impression on the surface of the specimen will be a square. The length of the diagonal of the square is measured through a microscope fitted with an ocular micrometer that contains movable knife-edges. The Vickers hardness values are calculated by the formula:

$$VHN = \frac{2P\sin(\theta/2)}{L^2} = \frac{1.854P}{L^2} \quad (1.2)$$

Where:-
P: the applied load (kg)
*L:*the average length of the diagonals (mm)
θ: the angle between the opposite faces of the diamond = 136°

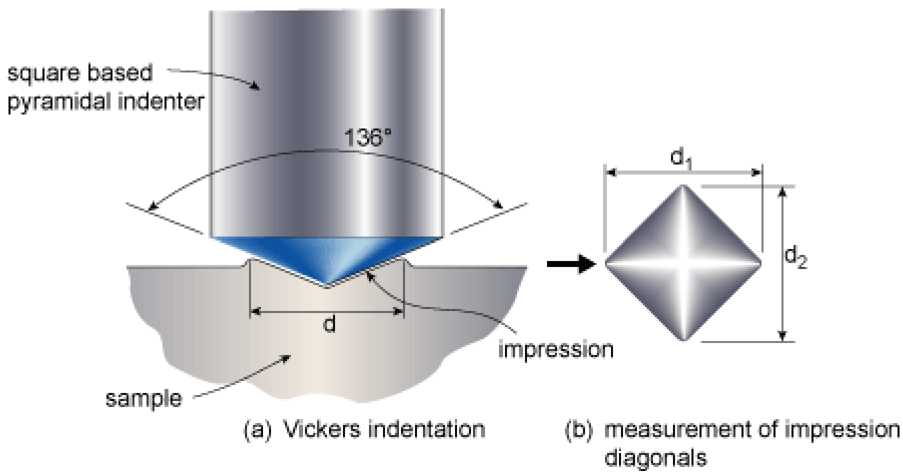


Fig.1.3. Vickers hardness test

<u>IV- System Description:-</u>

In this experiment, the Brinell testing machine as shown in figure below

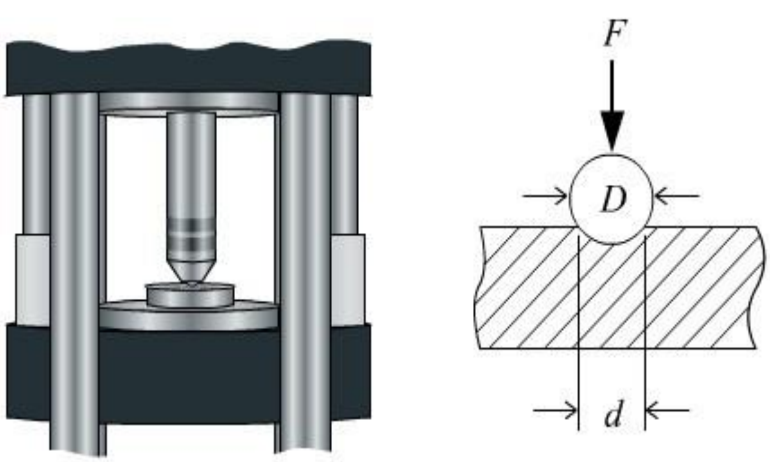


Fig.1.4. Brinell testing machine

V-Experimental Procedures:-

1-Prepare the Universal testing machine for Brinell hardness test, let it warm up for 20 minutes.

2- Create a blank result table, similar to figure 20.

3-Fit the Brinell indenter to the upper part.

4-Carefuly place the specimen to the in bottom part.

5-Set the digital load meter to zero.

6-Use the pump to apply load on the specimen, apply the load for 15 seconds.

7-Measure the diameter of the indentation.

8-Put the specimen back to the machine repeat the experiment twice at least.

**Typical values for Brinell hardness

Materials	Recommended SM1002 Test Load (for 15 seconds)	Nominal Brinell Hardness
Aluminum 6262	14.7 kN	120
Brass CZ121 (CW614N) - Half Hard	14.7 kN	130-170
Mild Steel (Bright Drawn) 220M07 or 230M07	20 kN	>103
Nylon 6	4.9 kN	<60

VI-Collected Data:-

Trial		Force (N)	D(mm)	d(mm)
1	Aluminum			
	Brass			
	Mild Steel			
	Nylon 6			
2	Aluminum			
	Brass			
	Mild Steel			
	Nylon 6			

VII-Discussion and Conclusions:-

1. Compare your results to the typical values, and discuss them.
2. list and discuss conditions that may affect hardness.
3. Discuss the difference between Micro and Macro hardness tests, and when each of them is preferable.

Experiment 2. Tensile Test

I-Theoretical Background:

Tensile test is the most important test can be performed on materials due to the large number of properties can be found from such test. It is known that the materials can be classified into two main categories:

- Ductile materials such as metals, plastic, ..., etc.
- Brittle materials such as glass, concert, ..., etc.

For ductile materials, tensile test is a best choice to find a large number of properties while it is preferred to test the brittle materials using the compression test where the tensile test for such materials finishes fast.

In tensile test, the material is formed in a specimen of specific shape and then a tension force is applied from both sides of the specimen or from one side while the other side is fixed. When the load is applied to the specimen, a *stress* is generated inside the material. You can assume that this stress is the internal resistance of the material to the external effects (*ie.* Load) which try to deform it (*ie.* Change its shape and/or size). In material testing, the deformation is, mainly, called *strain*.

To perform the tensile test, the applied load is increased in separated steps while the elongation is measured at each value of the load. The load is transformed into stress and the elongation (deformation) is transformed into strain. Then, the stress is plotted versus the strain in a diagram which is called the stress strain diagram.

II- Objectives:

- To explore the tensile loading and the tensile test procedures
- Draw both true and engineering stress – strain diagram for three types of metals : steel, copper and aluminium
- Find the mechanical engineering properties for the three chosen metals such as the Young's modulus of elasticity (E), modulus of rigidity (G), the modulus of resiliance (u), poisons ratio (v), bulk modulus (K), yield strength (δ_y), proportional limit (δ_p), ultimate strength (δ_u) and the stress at the fracture point (δ_F)

III- System Description:

In this experiment, TQ unversal tesing machine is used to test three meatls (ductile materials): copper, steel and almiunum. A schmatic diagram for the testing machine and the tensile specimen is shown in Figs.2.1 and 2.2.

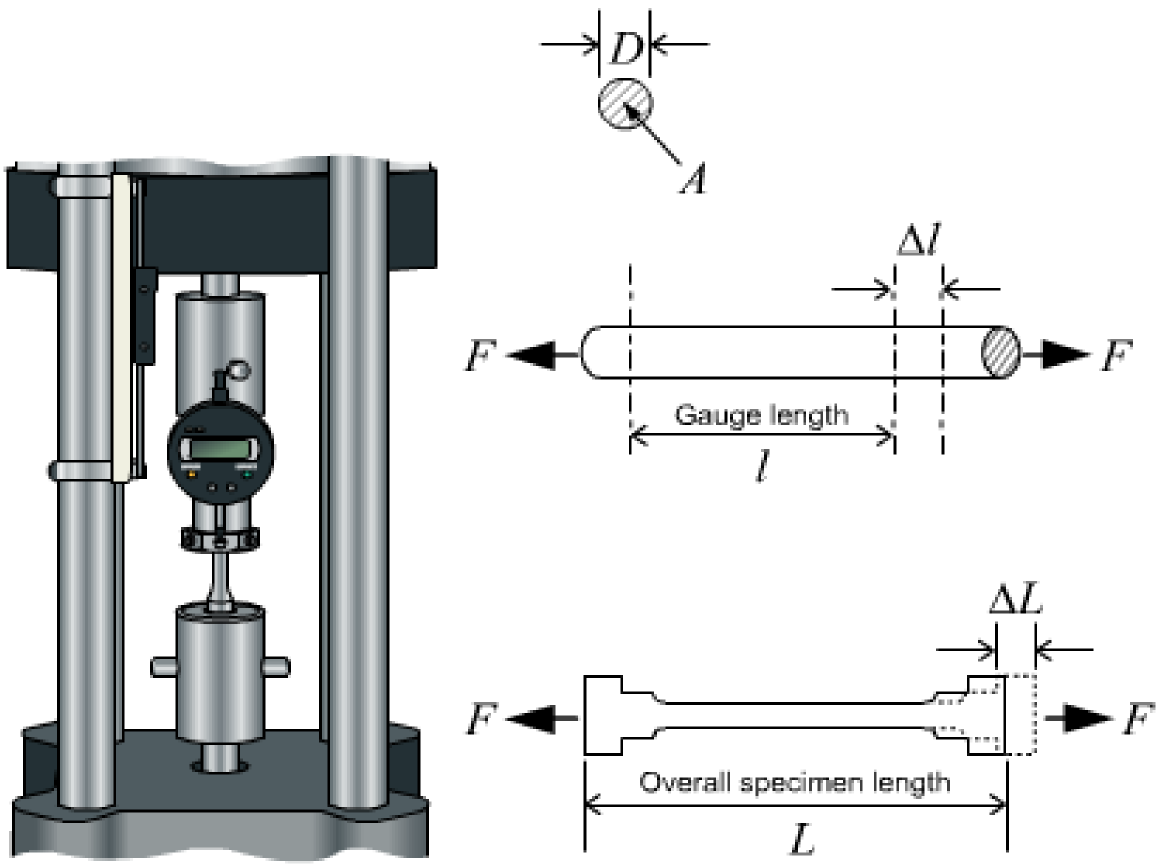


Fig2.1. General Layout of the experiment set-up

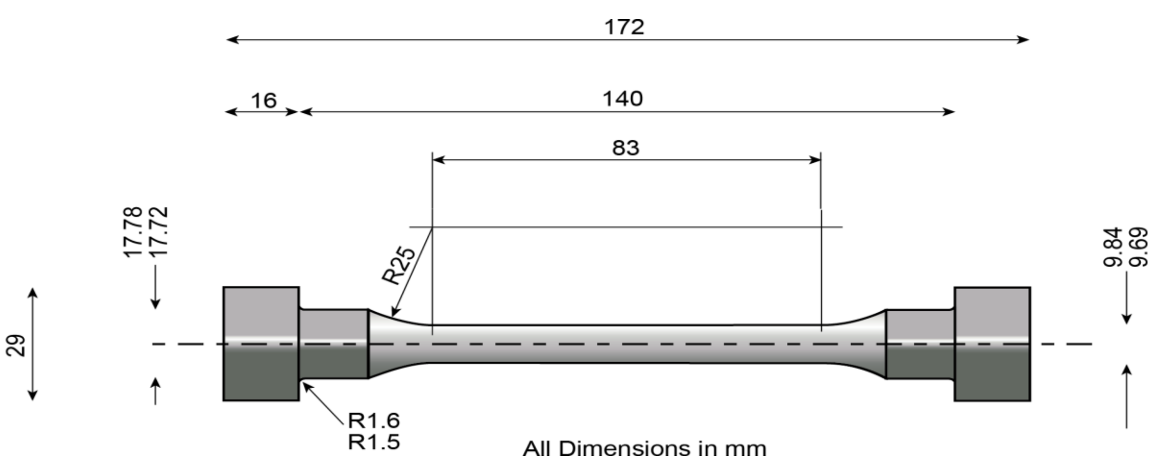


Fig2.2. tensile specimen shape and size

IV- Governing Equations:

The level of stress inside the material depends proportionally on the applied load and inversely on the cross-sectional area of the specimen and so to generalize the properties for materials, the concept of the load is transformed to the stress and the deflection is transformed to the strain by using the following equations:

$$\sigma_e = \frac{F}{A_o} \qquad (2.1)$$

$$\varepsilon_e = \frac{L - L_o}{L_o} \qquad (2.2)$$

Where:-

F: the load (N)
A_o: initial cross-sectional area (m^2)
σ_e: engineering stress (Pa)
L_o: the initial length of the specimen (m)
L: is the measured length of the specimen (m)
ε_e: engineering strain (*dimensionless*)

Note that the stress here depends on the initial cross-sectional area (A_o) while in practical testing, the cross-sectional area (A) well be reduced due to the elongation that the specimen experience or in other word, the mass is constant and so the volume (ie. The density is constant), then the cross- sectional area must decrease to compensate the elongation. Applying the shrinkage in the cross-sectional area in stress definition (Eq.2.1):

$$\sigma_T = \frac{F}{A} \qquad (2.3)$$

Where:-

A: the cross-sectional area of the specimen (m^2).

σ_T: true stress (Pa).

The stress defined in Eq.1.1 is called the engineering stress (σ_e) and the stress defined in Eq.1.3 is called the true stress (σ_T). As in the stress, there are two definitions of the strain (true and engineering). The engineering strain is given in Eq.2.2 while the true strain is given by:

$$\varepsilon_T = ln\left[\frac{L}{L_o}\right] \qquad (2.4)$$

Where:-

ε_T: the true strain.

The concept of the true strain comes from the concept of mass conservation (*ie.* at any point of the test the mass still the same). The density remains constant at the whole experiment and so the volume is also remains constant. To have constant volume, the diameter of the specimen decreases as the length increases. The deformation in the length is called *longitudinal* strain (ε_x) while the deformation in the diameter is called *lateral* strain (ε_y) . Both strains are related to each other by ***poisons ratio* (*v*):**

$$v = -\frac{\varepsilon_y}{\varepsilon_x} = -\frac{\Delta D}{D_o} \Big/ \frac{\Delta L}{L_o} \qquad (2.5)$$

The concepts of the longitudinal and lateral deformation are illustrated in Fig.2.3.

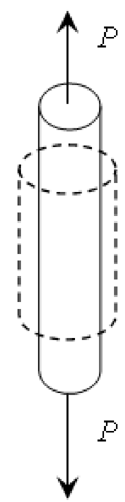


Fig.2.3. longitudinal and lateral strains

The problem now to (ΔD) to be substituted into Eq.2.5. As mentions before, the volume of the specimen is constant during the experiment. Only for the elastic region, the following relation can be used to find (*v*):

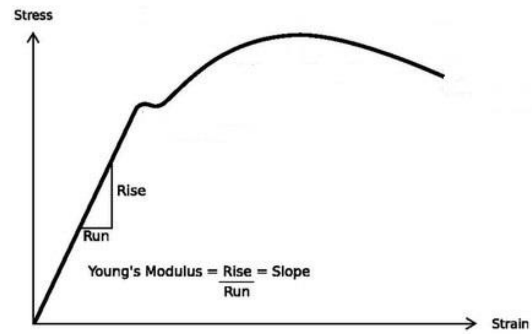
$$A.*L = A_o * L_o \Rightarrow \frac{A}{A_o} = \frac{L_o}{L} \Rightarrow \left(\frac{D}{D_o}\right)^2 = \frac{L_o}{L} \Rightarrow \Delta D = D_o\left(\sqrt{\frac{L_o}{L}} - 1\right) \qquad (2.6)$$

Young's Modulus of Elasticity (E):

Is a material property, that describes its stiffness, "E" can be found using Hock's law:

$$\mathbf{E} = \frac{\boldsymbol{\sigma}}{\varepsilon} \qquad (2.7)$$

Also, Modulus of elasticity can be found graphically as it is the slope of the line in the engineering stress-strain diagram.



"E" in Stress-strain diagram

Each material (natural or composite) has its own response to the applied load (stress strain diagram). However, all the materials are sharing the same stages of deformation. Fig. 2.4 shows a typical stress strain diagram:

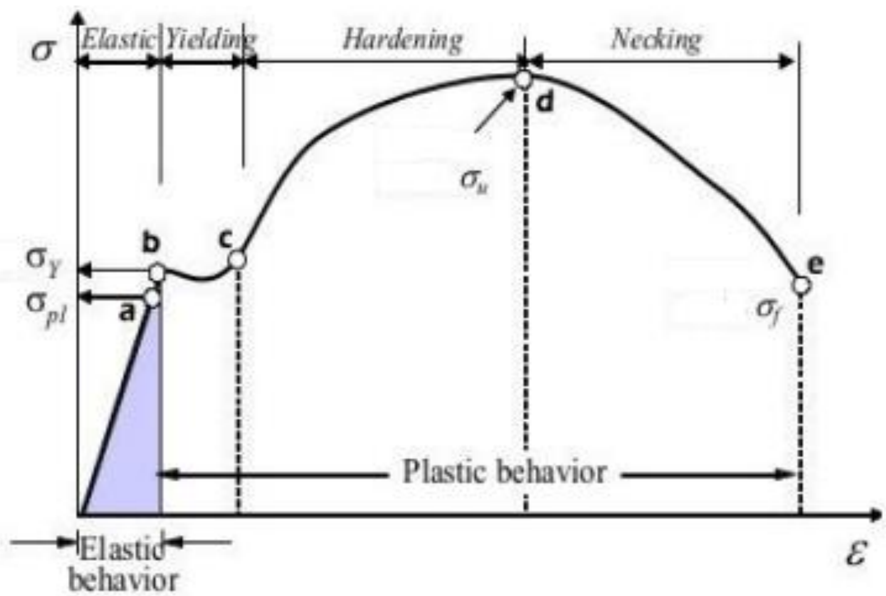


Fig.2.4. typical ductile material engineering stress-strain diagram

From Fig.1.4 you can note that typically there are four stages of deformation:

❖ From (0,0) point to point (a): this stage is called the *elastic deformation* stage. In this stage, the material returns to its original condition when the load is released. Also, this region is considered as linear and the slope ($\Delta\sigma/\Delta\varepsilon$) is called the *Young's modulus of elasticity* (*E*) and its unit is *(Pa)*. This region is governed by *Hock's Law*: $\sigma = E\varepsilon$.

❖ From Point (*a*) to point (*c*): this stage is called the *yielding* stage. In this stage, the material dose not return to its original condition (*i.e.* it has remains with plastic deformation). As seen from the diagram, no need for extra stress to deform the material and this is the reason behind calling it *yielding*.

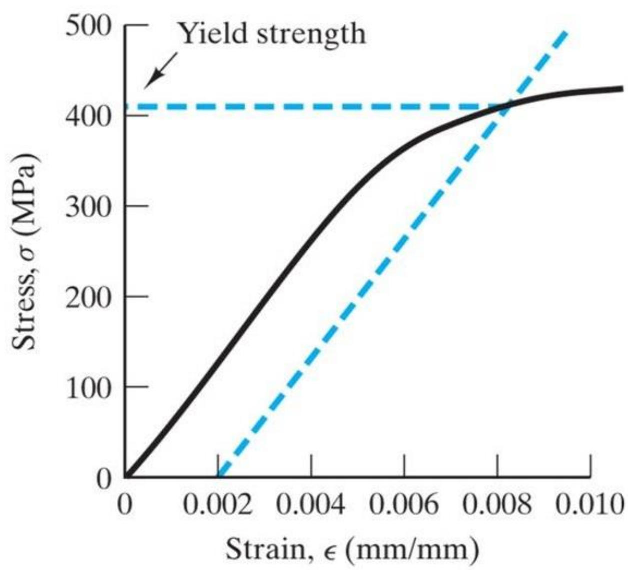
❖ From point (*c*) to point (*d*): this stage is called *strain hardening* stage. In this stage, the material fights the applied load so to have more strain it needs a higher level of applied load. As in the yield stage, strain hardening stage ended with plastic deformation. This plastic deformation is important in hardening the materials in many of manufacturing processes.

❖ From point (*d*) to point (*e*): this stage is called *necking* stage. In this stage, the material in pushed to its maximum limit and the internal forces between its particles start to fail down. The specimen shrinks at a certain position which reduces the area until the fracture (rupture).

Also you can note that there are some significant points in the diagram which are:

❖ Point (*a*): this point is called *the proportional limit.* This limit is the end of the elastic region and so Hock's law is not applicable more longer than this limit.

❖ Point (*b*): the stress at point (*b*) is called *yield strength* (σ_y). In most cases, this value is hard to find so a method called *the offset method* is used. In this method, you take offset value of strain (ε = 0.002) and draw a line parallel to the elastic line and corresponding value of stress to the intersection point with the engineering stress-strain diagram is the yield strength (σ_y) as figure below.



❖ Point (c): lower yield point stress is the minimum stress required to maintain the deformation in the material.

❖ Point (*e*): the stress at this point is called *the ultimate or maximum strength* (σ_u). This stress is taken in most of the application as a design parameter and it is important to indicate the beginning of necking phenomena.

The previous points represent some properties of the material under test. However, other properties can be found indirectly from the stress-strain diagram which are:

❖ The shear modulus (G): shear modulus represents the material ability to handle shear load. This modulus will be introduced properly in shear test. The shear modulus is found from the Young's modulus and the poisons ratio by using the following relation:

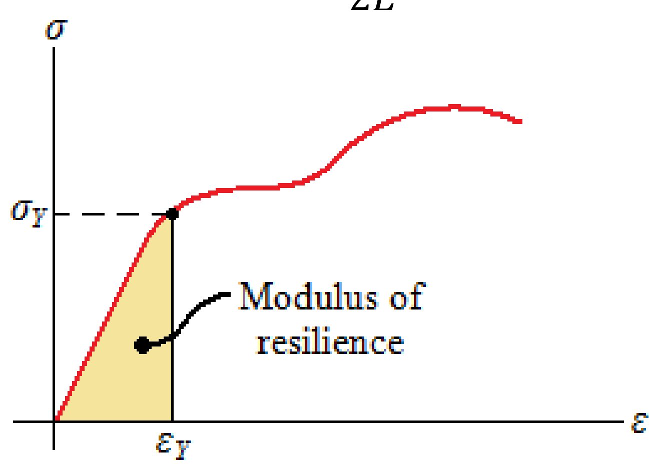
$$G = \frac{E}{2(1+v)} \tag{2.8}$$

❖ The bulk modulus (K): bulk modulus measures the material resistance to uniform compression. The bulk modulus is found by using the following relation:

$$K = \frac{E}{2(1-2v)} \tag{2.9}$$

❖ Modulus of Resilience (u_r):Is defined as the maximum energy that can be absorbed without creating a permanent distortion. It can be calculated by integrating the stress–strain curve from zero to the elastic limit, or by using the following equation:

$$u_r = \frac{\sigma_y^2}{2E} \tag{2.10}$$



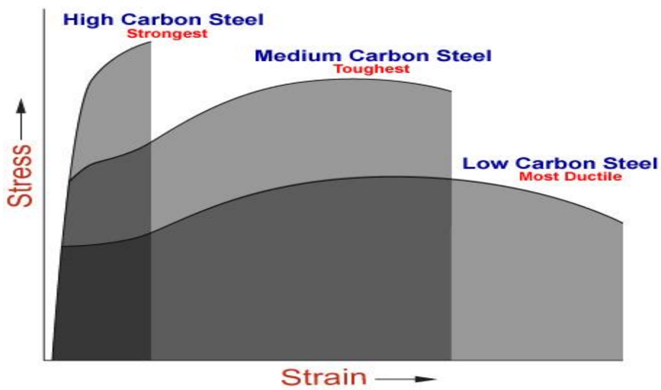
Ductility is an important property that can be found from tensile tests. It is the ability of a material to withstand plastic deformation without fracturing, but just because a material is ductile does not make it tough. Ductility can be described with the percent elongation or percent reduction in area

$$\%\ \text{Elongation} = \frac{Lf - Lo}{Lo}\ 100\% \tag{2.11}$$

$$\%\ \text{Reduction in area} = \frac{A_o - A_f}{A_o} 100\% \tag{2.12}$$

Toughness (u_t): the amount of energy that a material can absorb just before it fractures. The modulus of toughness is calculated as the area under the stress-strain curve up to the fracture point.

$$u_t = \left(\frac{\sigma y+\sigma u}{2}\right)*\varepsilon_u - \left(\frac{\sigma y+\sigma u}{2}\right)*\frac{1}{2E} \qquad (2.13)$$



V- Experimental Procedures:

1- Prepare the Universal testing machine for Tensile test, let it warm up for 20 minutes.

2- Determine the Initial dimensions of the specimen (length, diameter).

3-Carfully place the specimen into the machine.

4-Start the test.

5-Record the time needed for the specimen to break.

6-Take the specimen out of the machine.

7-Measure the final length and diameter.

8-Repeat the same steps for the other specimens.

VI- Collected Data:

Table-2.1 geometrical properties and dimensions

Material	*L_o (m)*	*D_o (m)*	*A_o(m^2)*

Table-2.2 Data collected from the experiment execution

Material			
Trial	***F(kN)***	***L(m)***	***δ(L-L_o)***
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

VIII- results

A-Calculations

Material		
Trial	***stress(F/A_o)***	***strain (δ/L_o)***
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		

B- Draw engineering stress-strain diagram.

C-fill the following table

Parameter	Value	Parameter	Value
Modulus of elasticity		Ductility	
Proportional stress		Toughness	
Yield stress		Modulus of Resilience	
Ultimate stress		Yield force	
Elastic strain		Ultimate force	
Fracture stress			

Discussion :

- Answer the following questions:-

1. At which point dose the necking occurs? Explain why?
2. In Eq.2.5. why there is a minus sign (-ve) in the definition of the poisons ratio?
3. What are the main differences between the true stress-strain and engineering stress-strain diagrams?

- Mention the main sources of errors in this experiment

Experiment 3.Creep Test

I-Introduction:-

Creep: is slow plastic deformation that occurs with prolonged loading usually at elevated temperature so, in studding creep property we must include in our consideration the temperature, stresses and time.

The material, which has a higher milting point, has a good resistance to creep. Usually creep happens at long time with strength less than material strength therefore we must be careful for this point in design (constructions, machines, …………etc), creeping occurs under multiple types of stresses such as: static tension, compression, bending, torsion or shear stress.

The importance of creep:

- Soft metals used at about room temperature
- plant operating at high temperature as furnaces

Factors effect on creep:

- Stress: creep increases when the stress increase
- Temperature: creep increase when temperature increase and decrease when milting point of material increase
- Time: creep increase after a long periods of time

In engineering design we must use a material can handle the stresses applied so, there is a concept called "maximum permissible stress " or "creep strength " which indicates the limits of applying loads and this concept defined as: the highest stress that a material can stand for

<u>Creep in metals:</u>

In metallic material, creep occurs above the crystal recovery temperature in the material under load. Whereas in normal tensile test, the material is strain hardened below the crystal recovery temperature and elongation comes to halt under constant load above crystal recovery temperature, an equilibrium may occurs between recrystallization and strain hardening. The material is continuously elongated with certain strain or creep rate.

Significant creep responses generally occur only at temperature above **0.4 to 0.5 T_S**. Where T_S is the **absolute melting temperature** in **degrees Kelvin** .

In creep test the sample is subjected to constant load at certain constant temperature. The extension of the sample over time period is recorded. By recording elongation over time, the so- called creep curve is obtained. Three sections of the creep curves can be distinguished:

Phase 1 (Primary creep): Reduction in the initially extremely high creep rate. At this point, the influence of material hardening predominates.

Phase 2 (Secondary creep): Virtually constant creep rate. At this point the crystal recovery and material hardening are in equilibrium. This section of the curve need not necessarily occur in all experiments.

Phase 3 (Tertiary creep): As a result of increasing reduction area of the sample after failure and rise in effective stresses, the creep rate increase again, leading to fracture of the material. In the case of low ductility fracture, phase three may very short.

These stages are illustrated in Fig3.1.

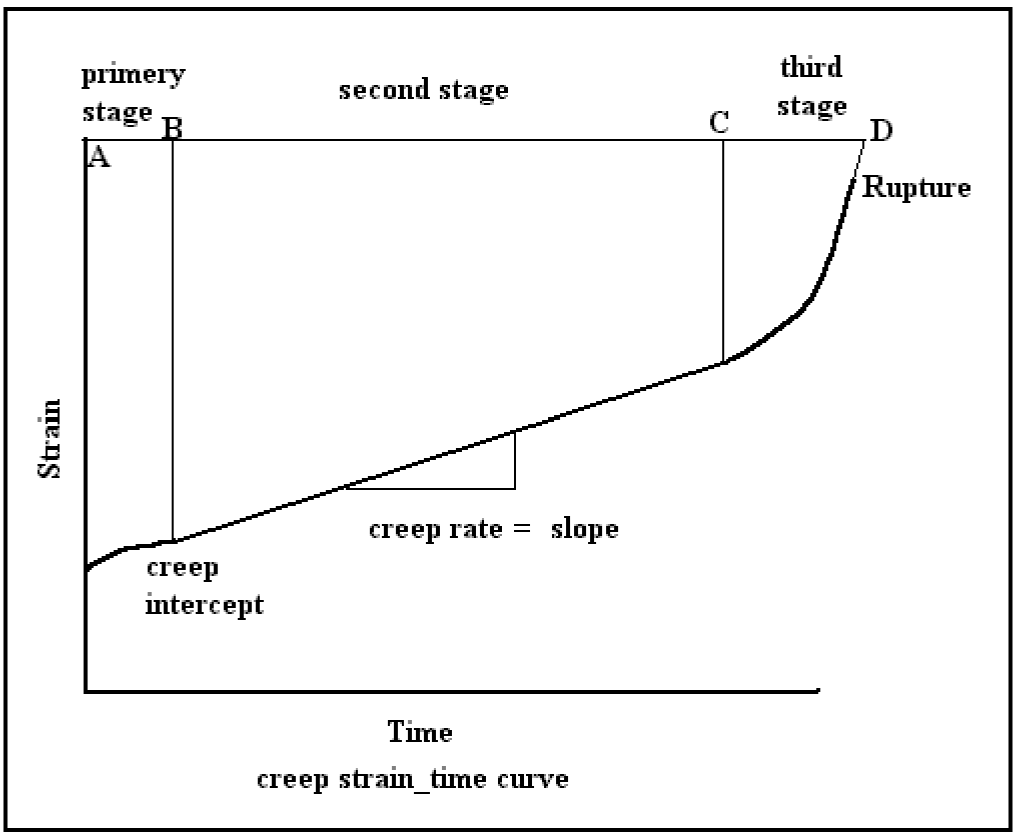


Fig.3.1. creep diagram

Components are generally loaded in such way that they only enter the secondary creep phase. This determines the life of the component. The time until fracture of the sample various loads can be recorded in creep diagram. This produced the creep strength curve.

Part B: Creep in Plastic.

Creep curves in plastic are similar to those of metals. Various plastic such as polypropylene (PP) or polyethylene (PE) also indicates pronounced creep behavior at room temperature. However, the reasons for creep are different from those in metals . in plastic , the macro molecules are straightened and extended. Here, too creep depends on stress and temperature.

In plastic, elongation after fracture is very large, which mean that experiment often do not continue until fracture. When the load is elevated, the creep deformation largely records (relaxation takes place). in this respect , the time response is of the same magnitude as under load

II-Objectives:-

- Inspect the property of creep in metals
- Drawing creep strain Vs time diagram and creep rate curve at constant temperature and use them in analysis
- Find some calculations related to creep phenomena

III- system description

In creep experiment, G.U.N.T WP600 creep machine is used. Two materials are tested: lead and plastic. A schematic diagram of the testing machine and the sample geometry are shown in Fig.3.2.

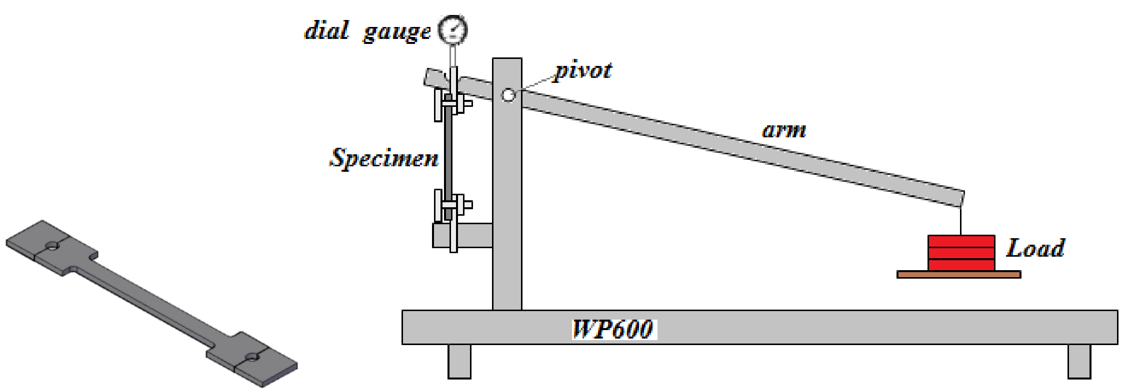


Fig.3.2. system description and sample shape

As seen from Fig.6.1, the sample is gripped by two bolts and the load is applied by using load arm and the deflection is measured using a deal gauge.

IV- Experimental Procedures:-

Before starting the experiment, some precautions must be mentioned:

- ❖ Lead is poisonous and harmful. When handling leads samples, take care to ensure that no lead is absorbed by the body, do not eat , drink or smoke whilst handling lead samples. Do allow the sample to come into contact with food. After handling lead, wash your hands thoroughly
- ❖ The lead sample is very soft. To avoid pending the sample, mount the sample holder on an even table surface.
- ❖ To perform the experiment at law temperature, it is essential that content of the cooler elements are completely frozen. Other wise , the cooling out put will not be content due to the absorption of the heat fusion
- ❖ Insertion of the sample holder and application of the load should be performed gently and without jolting.
- ❖ Immediately prior the experiment, re-adjust the dial gauge.

Experimental proceduers:-

1. Connect a specimen of lead to the grippes
2. Adjust the grippes on the machine
3. Calibrate the dial gauge to zero position
4. Add the load to the arm gently
5. Immediately, start to record the deflection at a certain steps of time. Record your data in the provided tables.
6. Repeat steps 1-5 for two more times for other different loads
7. Repeat steps 1-6 for plastic specimen

V-collected data:-

Table 3.1. Collected data for one specimen

Trial	***Load = __________N***	
	Time(sec)	***δ (mm)***
1		
2		
3		
4		
5		
6		
7		
8		
.		
.		
50		

VI-Data Processing:-

- Draw the strain Vs. the creep time for all the collected data for both lead and plastic.
- Calculate the creep rate from the linear stage
- Compare the effect of load on creep.
- Compare the plastic and lead creep behaviours.

VII- Discussion and Conclusions:-

- ***answer the following questions:-***

    1. What are the main parameters that affect the creep rate in materials
    2. What is the effect of increasing the load on the shape of the creep diagram.
    3. When we add a different load, why we didn't consider about the value of the load on the specimen?
    4. dose the temperature affect the rate of creep? Explain.

- ***Mention the sources of error in this experiment.***
- ***Mention your own observations and your final conclusions***

Experiment 4. Buckling Tests

I- Introduction:

In large members where the length is much larger than the cross-sectional area and with certain, buckling may cause a problem in the structure. In buckling, load type is compressive and the effect vary according to four parameters:

1. slender ratio (λ)
2. The applied load
3. Mounting condition
4. Material properties

Buckling occurs suddenly. As the member starts to buckle, it becomes in a situation where the deformation is totally distortion. For this reason, the buckling deformation is assumed a stability issue.

II- Objectives:

In this experiment, student has to accomplish the following objectives:-

1. Examine the buckling process controlling parameters
2. Be familiar to Euler theory and the mode shapes of buckling

III- theoretical background

Compressive deformation can vary between different cases of members and structure parts depending many parameters. The most important parameter is the ratio between the characteristic length and the characteristic diameter (λ). λ is called *slender ratio*. Fig. 4.1 illustrates two cases of deformation under compressive load.

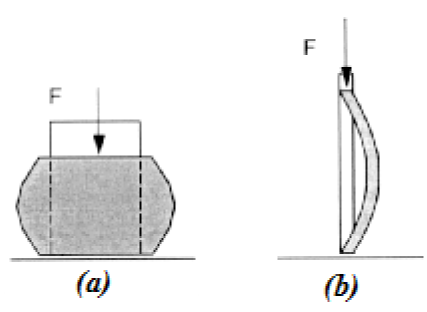


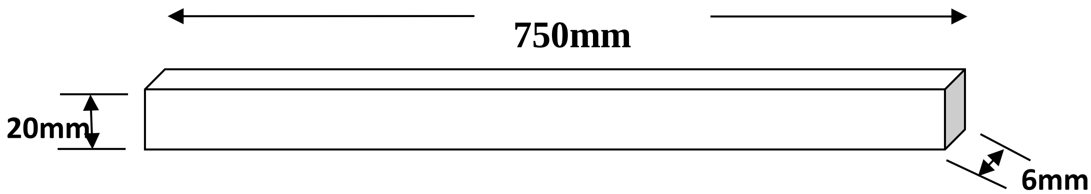
Fig.4.1. effect of compressive load: (a) barrelling phenomena (b) buckling phenomena

As seen from Fig.2.1, λ in member shown in (a) is very small comparing with λ of the member shown in (b). At this moment, you can assume that λ is length / diameter.

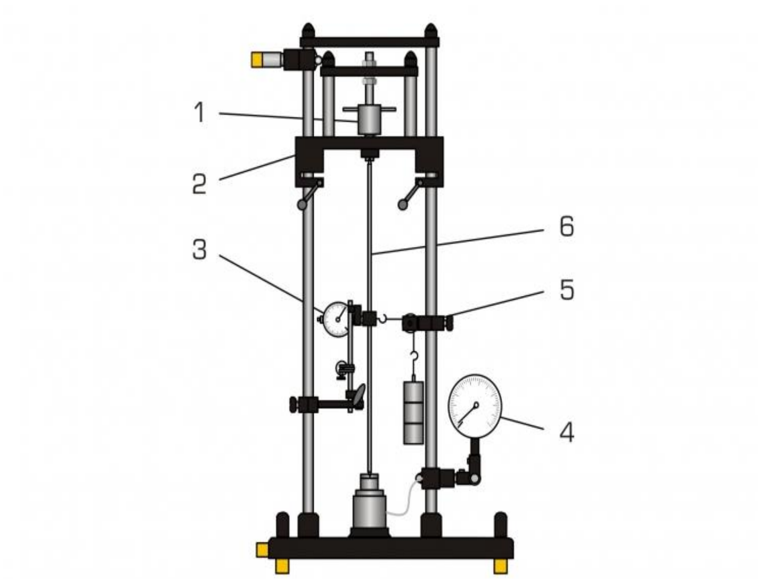
The phenomena shown in (a) is called barrelling while the phenomena in (b) is called buckling. In barrelling shrinkage occurs on the length and the diameter increases at the middle line while in buckling the diameter still the same and the nominal length decreases where the member shape become circular (i.e. the real length still the same)

III- System Description:

To perform the buckling test, the universal test machine WP120 is used. Fig. illustrates the machine & the sample used in the test.



Test bar(sample)



(1) Spindle (2) height-adlustable (3) dial gauge for lateral deflection of test bar (4) force gauge (5) clamping screw (6) test bar

IV- Governing Equations

As said in previous section, bucklind depends on selender ratio (λ). λ is given as:

$$\lambda = \frac{L_C}{i} \qquad (4.1)$$

Where:

L_C: the characteristic length of the buckled member (m)

i : inertia radius (m)

The inertia radius (i) is given as:

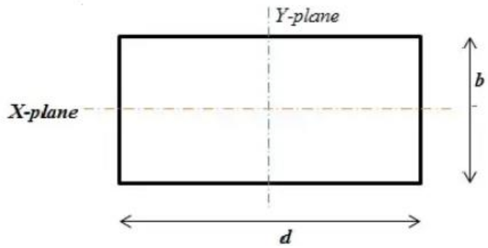
$$i = \sqrt{\frac{I_y}{A}} \tag{4.2}$$

Where:

I_y: the area moment of inertia (m^4).

A: the cross-sectional area of the buckled member (m^2).

If a column has a rectangular cross section, it would fail in certain way.



Rectangular column cross section

Buckling failure occurs at the lowest value of moment of inertia, figure would buckle about the x-plane rather than the y-plane. Achieving a balance that the (I_x approximately equal I_y) would result in better preferred columns. Moment of inertia equations are given:

$$I_x = \frac{db^3}{12}$$

$$I_y = \frac{bd^3}{12}$$

In addition to the slender ratio, the applied load plays a significant rule in buckling phenomena. When the applied load increases, the probability of buckling increases too until a certain value of load where the buckling occurs immediately beneath it. This limit is called *critical force (F_C). F_C* is given as:

$$F_C = \pi^2 \frac{EA}{\lambda^2} \tag{4.3}$$

Where:-

E: the Young's modulus of elasticity (Pa)

Substitute Eqs.2.1 and 2.2 into Eq.2.3:

$$F_C = \pi^2 \frac{EI_y}{L_C^2} \qquad (4.4)$$

The problem now is reduced to define the *characteristic length* (L_C). L_C depends mainly on the end condition of the compression mechanism. Euler defined four cases of buckling which are illustrated in Fig.4.3. The relation between the characteristic length (L_C) and the real length (L) is illustrated in table 4.1.

The area moment of inertia is given as:

$$I_y = \frac{\pi . r^4}{4} \qquad (4.5)$$

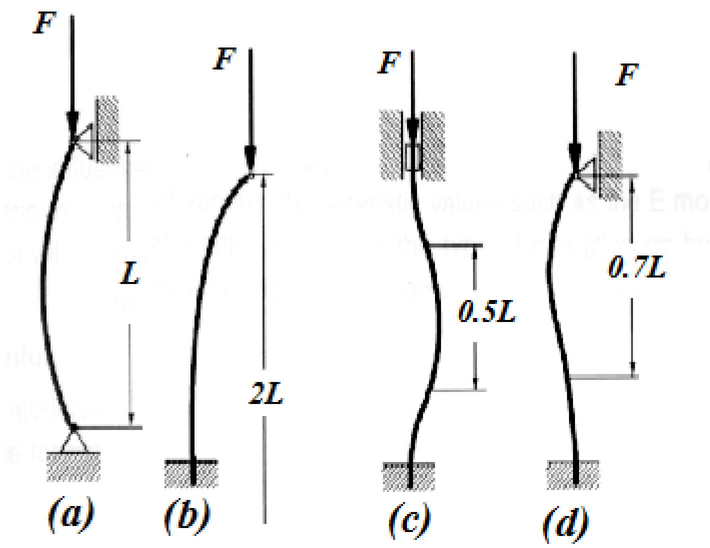


Fig.4.3. Euler cases of buckling

Table 4.1. Euler cases of buckling

Case	End condition	L_C (L)
(a)	Roller – pen	L
(b)	Free - fixed	2L
(c)	Slider – fixed	0.5L
(d)	Roller – fixed	0.7L

V- Experimental Procedures

1. Prepare the testing machine and assembly the compression plates
2. Chose appropriate steel specimens, measure both length and diameter and fill the collected data in table 4.2.
3. Apply a compressive load gradually until the buckling occurs
4. Measure the deflection and fill the collected data tables with the values of the force and deflection
5. Repeat the previous steps for aluminium and copper specimens

VI- Collected Data

Table 4.2. Collected data

	Steel				Aluminium				Copper			
No.	$L(mm)$	$D(mm)$	$F_C(N)$	$L_C(mm)$	$L(mm)$	$D(mm)$	$F_C(N)$	$L_C(mm)$	$L(mm)$	$D(mm)$	$F_C(N)$	$L_C(mm)$
1												
2												
3												
4												
5												
6												

VII- Data Processing

❖ Calculate the slender ratio (λ).
❖ Use Eqs. 4.4 and 4.5 to calculate the values of (F_C) for all the specimens and fill the results tables
❖ Compare the calculated results with the experimental ones.
❖ Draw $F_{C,th}$ and $F_{C,exp}$ versus λ.

VIII- Results

Table 4.3. the calculated results

	Steel			Aluminium			Copper		
No.	$F_C,exp(N)$	$F_C,th(N)$	% error	$F_C,exp(N)$	$F_C,th(N)$	% error	$F_C,exp(N)$	$F_C,th(N)$	% error
1									
2									
3									
4									
5									
6									

IX- Discussion and Conclusions

- Answer the follwing quesions:
  1. What are the barling phenomena?
  2. What are the main difrencess between the barling and the buckling?
  3. What is the effect of selender ratio on buckling phenomena?
- Mention some of the applications where the study of buckling is important?
- Mention the sources of errors in this experiment.
- Mention your own observations and your final conclusions

Experiment 5. Fatigue Test

I-Introduction:-

Fatigue in materials represents the material tiring from a large number of variations in stress at a point even if the maximum value of the variation stress in lower than the save value of stress (i.e. yield or the ultimate stresses). The variation in stress does not mean change in its value but it means changes its type (i.e. tensile ↔ compression) at the external surfaces of the material. To explain the fatigue phenomena, let us start with the element shown in Fig.5.1:-

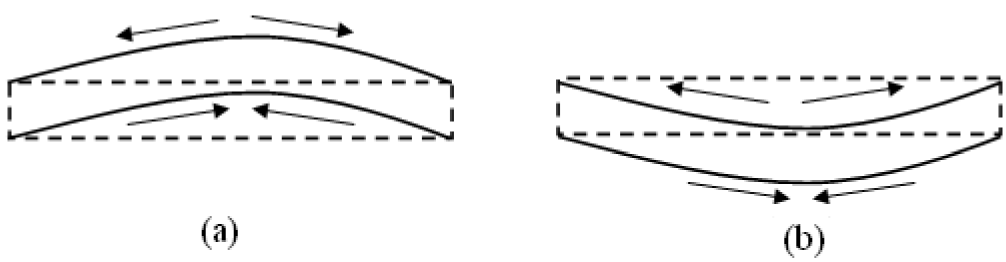


Fig5.1. fatigue stress variation

Look at Fig5.1 branch (a), the upper surface suffers from a tensile load and the lower surface suffers from a compression load and this situation is reversed in branch (b). This continues fluctuating in the stresses types makes both surfaces in disturbing condition where the particles move at one time towards each other and the next time apart of each other. This motion disturbs the bounding forces between the adjacent particles. The influence of this action reflects in increasing the material temperature at the fluctuating point due to the looseness in the bounding between the material particles specially, the particles at the outer surfaces. Finally, the particles at the outer surfaces start to disconnect from each other producing cracks. These cracks propagate from the outer surfaces towards the center. Progressing of cracks propagation reduces the cross-sectional area. Decreasing the cross-sectional area increase the applied stress although the load is constant until the fracture happens. The phenomena of cracks propagation due to the variation of load (i.e. cyclic load) is called ***fatigue.***

Factors affect the fatigue phenomena:-

1. ***Surface condition:-*** as the surface finish is highly polished, the fatigue failure probability decreases.
2. ***Applied load:-*** as the applied load increases, the fatigue failure probability increases.

3. ***Types of applied load:-*** there are two mainly types may be found in fatigue study: the complete cyclic stress and the fluctuating stress. Both of these types are illustrated in Fig.5.2. The complete cyclic stress equals twice of the fluctuating stress type.

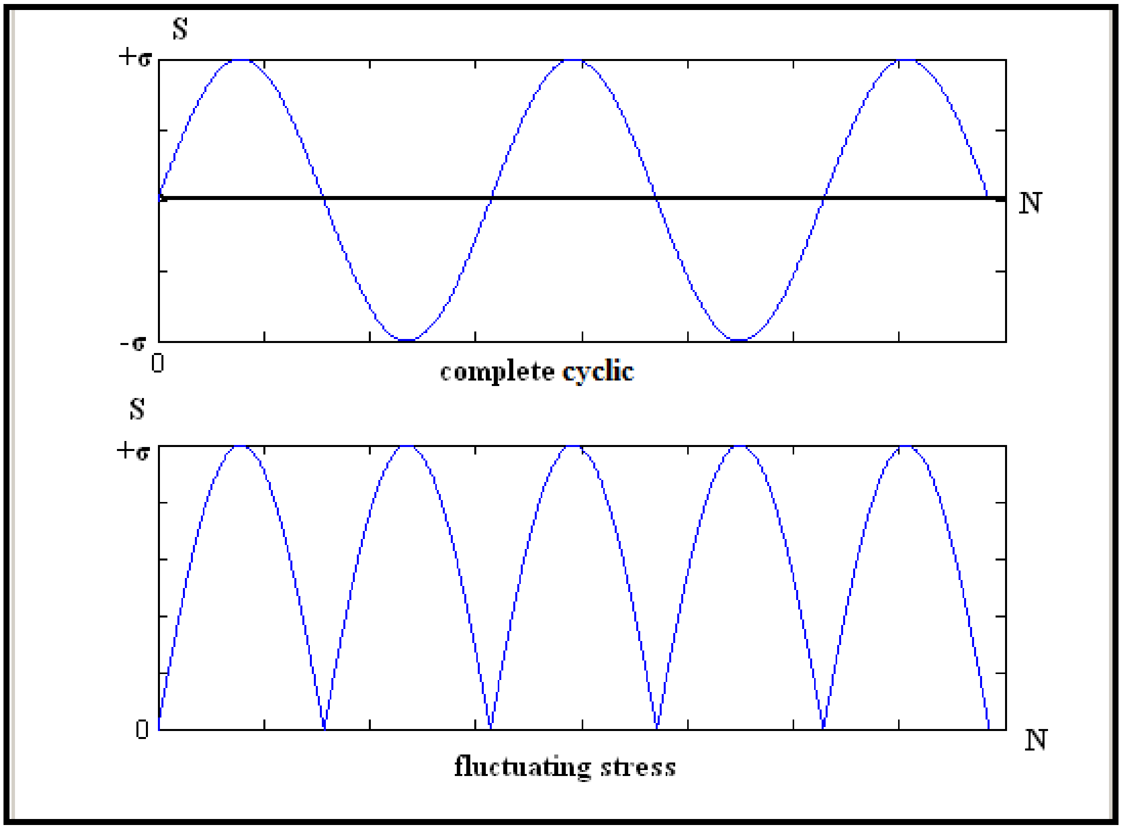


Fig.5.2. complete and fluctuating fatigue loads

4. ***Material shape:-*** when the material has a stress concentration points such as corners or edges. At these points, the surfaces are under excessive stress and so a high fatigue failure probability.
5. ***Material properties:-*** the most important property is the bending stiffness where the flexible material can handle more of fatigue loads than the stiff material.
6. ***Environmental and material conditions:-*** such as the heat, rust, ..,etc.

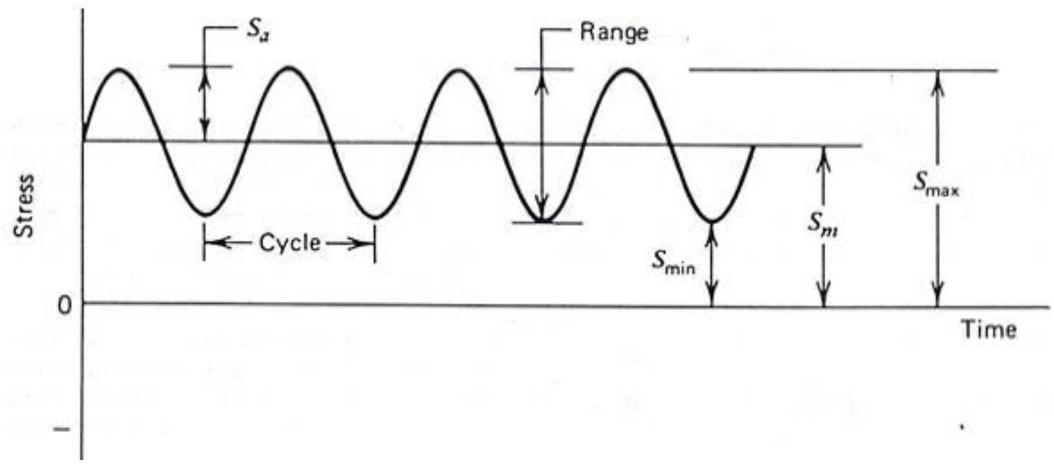
II-Objectives:-

In this experiment, student is expected to:-

1. Perform the fatigue test and be familiar to the experimental procedures
2. Observe the phenomena of cracks propagation after the failure.
3. Draw the fatigue life diagram of steel
4. Evaluate the endurance limit (σ_e)
5. Examine the effect of load variation on fatigue life

III-Theoretical background:-

The following figure shows Stress-time curve, important parameters can be found or calculated using this curve.



Stress-Time curve

-Mean stress:

$$\sigma_m = \frac{S_{max}+S_{min}}{2}$$

-Stress range:

$$\sigma_{r=} S_{max} - S_{min}$$

-Stress amplitude:

$$\sigma_a = \frac{S_{max}-S_{min}}{2}$$

-Stress ratio:

$$R = \frac{S_{min}}{S_{max}}$$

Note that Tensile stresses are normally considered positive and compressive stresses are considered negative.

The Fatigue Life (N_f) is defined by the total number of stress cycles required to cause failure. Fatigue Life can be separated into three stages:

1.) Crack Initiation (N_i)
 Cycles required to initiate a crack. Generally results from dislocation pile-ups and/or imperfections such as surface scratches, voids, etc.
2.) Crack Growth (N_p) –

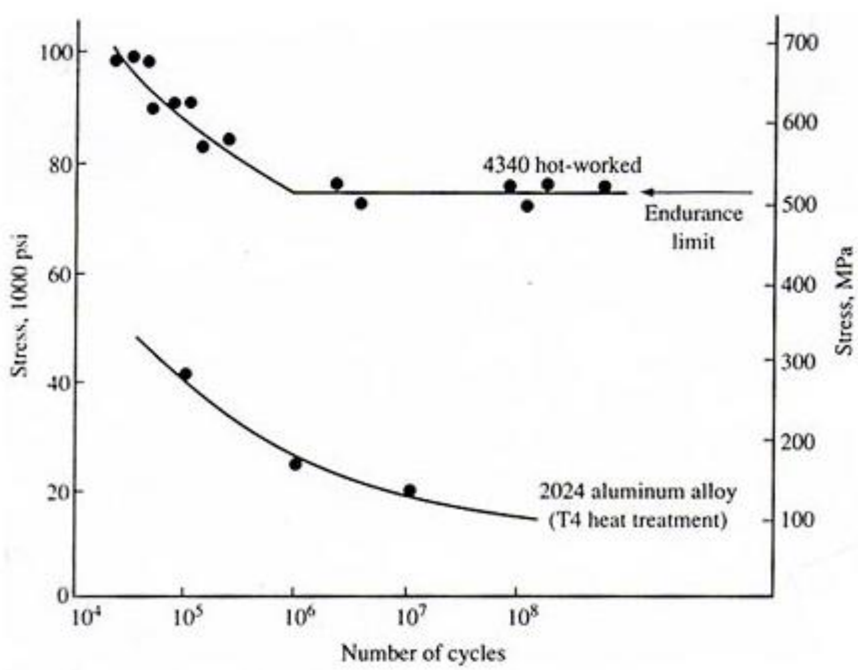
Cycles required to grow the crack in a stable manner to a critical size. Generally controlled by stress level. Since most common materials contain flaws, the prediction of crack growth is the most studied aspect of fatigue.

3.) Rapid Fracture

Very rapid critical crack growth occurs when the crack length reaches a critical value, ac. Since Rapid Fracture occurs quickly, there is no Rapid Fracture term in the Fatigue Life expression.

$$N_f = N_i + N_p$$

Most Fatigue Tests are conducted at what is referred to as "Constant Amplitude" which merely refers to the fact that the maximum and minimum stresses are constant for each cycle of a test. S-N_f refers to a plot of Constant Amplitude Stress Level (S) verses Number of Cycles to Failure (N_f) . S-N_f Curves are generally plotted on semi-log or log-log paper where each dot represents the results of a single test specimen. Fatigue tests tend to be time consuming and expensive; each data point represents many hours of testing. A prediction of failure for various stress levels can be made by studying a material's S-N_f curve. The most important part of the curve is often the portion to the right of the bend (or "knee") in the curve that identifies what is termed the Endurance Limit or the Fatigue Limit. The Endurance Limit defines the stress level below which the material will theoretically withstand an infinite number (~10^8) of stress cycles without fracture.



S-N_f curve

Most fatigue is NOT actually constant amplitude, but methods have been developed for utilizing constant amplitude S-N_f results to predict failure under varying load. This area of fatigue is referred to as "Cumulative Damage".

The most basic cumulative damage approach, and the most often utilized, is referred to as Miner's Law,. Under this approach, the damage caused by one cycle is merely defined as:

$$D = \frac{1}{N_f}$$

Where:

D: Damage.

The damage produced by "n" cycles at a given stress level is given by:

$$D = \frac{n}{N_f}$$

In order to estimate the fatigue life time, sets of specimens is tested under a different values of the variation load until the failure the number of cycles is recorded. The load is transformed later to bending stress. The value of fatigue stress at the failure is drawn with the number of cycle for each reliable specimen in graph called *fatigue life diagram*. A typical diagram for low carbon steel is shown in Fig5.3.

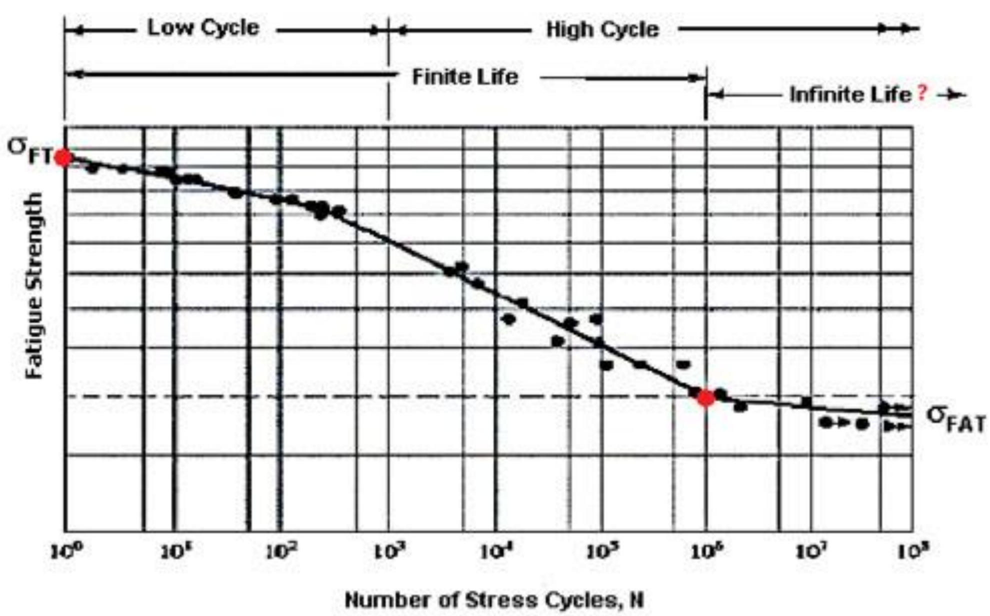


Fig.5.3. typical fatigue life diagram for low carbon steel

A certain point is interesting for us which is σ_{FAT}. σ_{FAT} is called *the endurance limit.* At this limit, the value of stress in lower than the failure stress value for infinite life time. So, in mechanical design, we must insure that the fatigue load is below the endurance limit. The endurance limit depends on the expected life time of the application where there is no thing is called infinite life time.

The value of the bending stress (σ_F) is given as:

$$\sigma_F = \frac{M}{W} = \frac{FL}{\pi d^3 / 32}$$

Where:-

M: produced moment by the applied force (N.m)

W: first polar moment of area (mm^3)

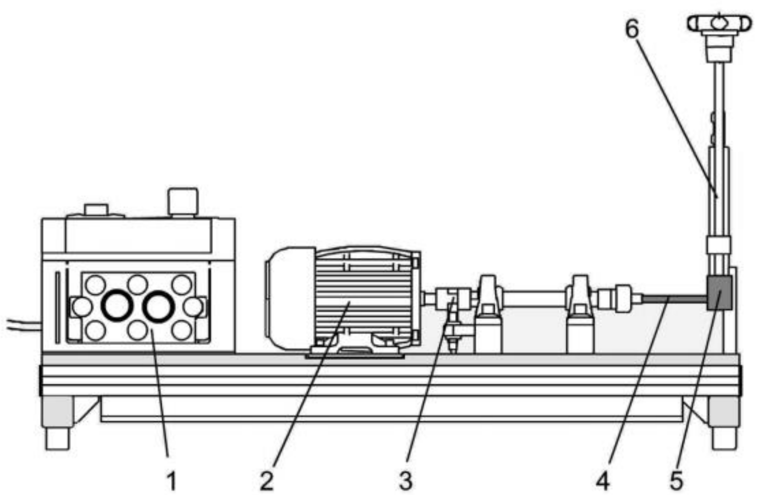
F: the applied load (N)

L: the length of the specimen (m)

d: specimen diameter (m)

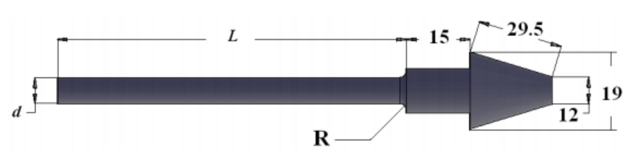
IV-System Description:-

To perform the fatigue test, G.U.N.T fatigue machine WP140 is used. A schematic diagram for the testing machine is illustrated in Fig.5.4:



1 switch box, 2 drive motor, 3 inductive speed sensor, 4 specimen, 5 moveable roller bearing with machine shut down switch built in, 6 loading device with spring gauge and hand wheel for adjustment.

Fatigue machine WP140



Fatigue Specimen

V- Experimental procedures:-

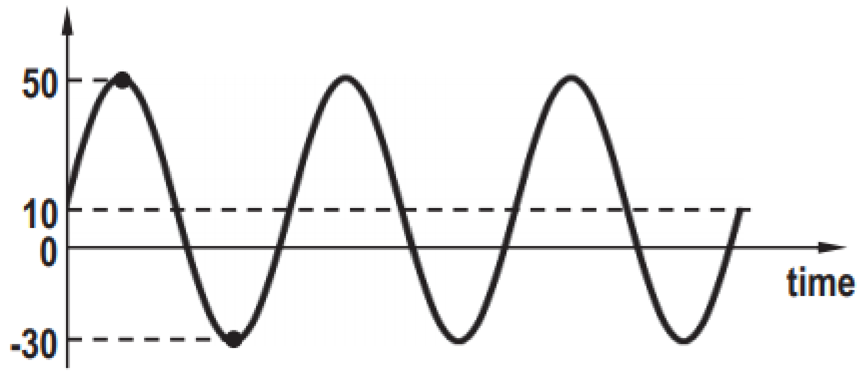
1. Select an appropriate set of specimens and measure the length and the diameter of each specimen and record the data in the collected data tables.
2. Connect the a specimen to the machine
3. Apply a static load using the spring gauge (6)
4. Start the motor
5. Wait until the fracture occur and record the number of cycles (N_{RPM})
6. Repeat steps (2) – (5)
7. Observe the cracks propagation in each sample

VI-collected data:-

Table 5.1: collected data

Trial	*Length (m)*	*Diameter (mm)*	*Force (N)*	N_{RPM}
1				
2				
3				
4				
5				
6				
7				
8				

VII-Results



1-Based on the S-Time graph above fill the table. SHOW ALL OF YOUR CALCULATIONS.

σ_{max}	σ_{min}	σ_m	σ_r	σ_a	R

2-The fatigue data for a brass alloy are given bellow:

Stress MPa	170	148	130	114	92	80	74
Cycles to fail	$3.7*10^4$	$1*10^5$	$3*10^5$	$1*10^6$	$1*10^7$	$1*10^8$	$1*10^9$

-Make a S-N_f curve for this data.

-Determine the endurance limit or fatigue strength which id applicable for this material.

-Determine the fatigue life for 120 MPa.

-Determine the fatigue stress for $2*10^4$ and $6*10^5$ cycles.

-Discussion and Conclusion:

-In your own words discuss the importance of this experiment.

-If there is a flat line in S-N_f curve, what does it mean?

-Explain the endurance limit.

Experiment 6:- Impact Test

I-Introduction:-

Impact test gives the behavior of the material when subjected at a sudden single application of load resulting in multi axils stress associated with notch , it also a good mean to study the behavior of material under suddenly change in cross section . This response of the material is called notched bar sensitivity.

The basic objective of impact test id evaluate the impact work which is defined as the amount of energy released when the material is subjected to a sudden force and it is given a unit (N.m)

The behavior of the ferric steel (low carbon, 0.001% carbons) under notched condition can predicted from their properties as revealed by tensile test, whereas, the behavior of the large group of non-ferrous metals and alloys and the austenitic (high carbon 2%) carbon .

Mainly, the types of impact test are usually performed are *:*

1) ***Izod test***: the impact load is applied to cantilever with a notch at it base.
2) ***Charpy test:*** the impact load strikes the center of simply supported sample; the sample is notched along of center of tension free.

Fig.6.1. illustrates the two common impact tests.

	Izod Impact Test	Charpy Impact Test
Position of Specimen	Vertical	Horizontal
Direction of Notch-Face	In front of striker	Away from striker
Type of Notch	V-Notch	V-Notch & U-Notch
Size of Specimen	75mm x 10mm x 10mm	55mm x 10mm x 10mm
Type of Hammer	Farming Hammer	Ball Pin Hammer
Striking Point	Upper Tip of specimen	Centre of specimen
Material Tested	Metals and Plastics	Metals

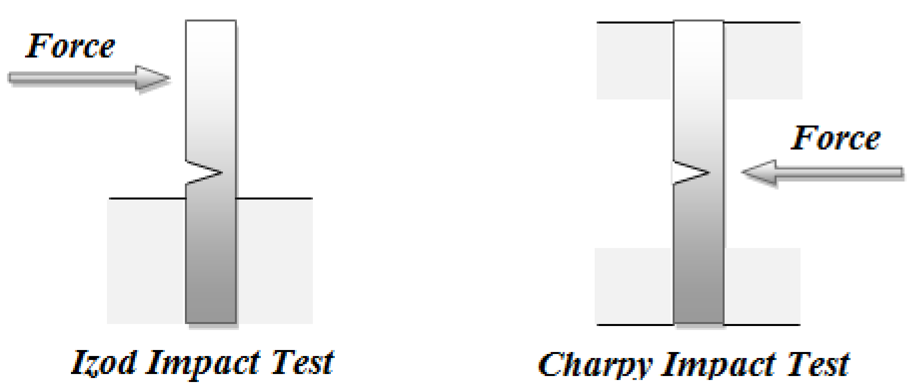


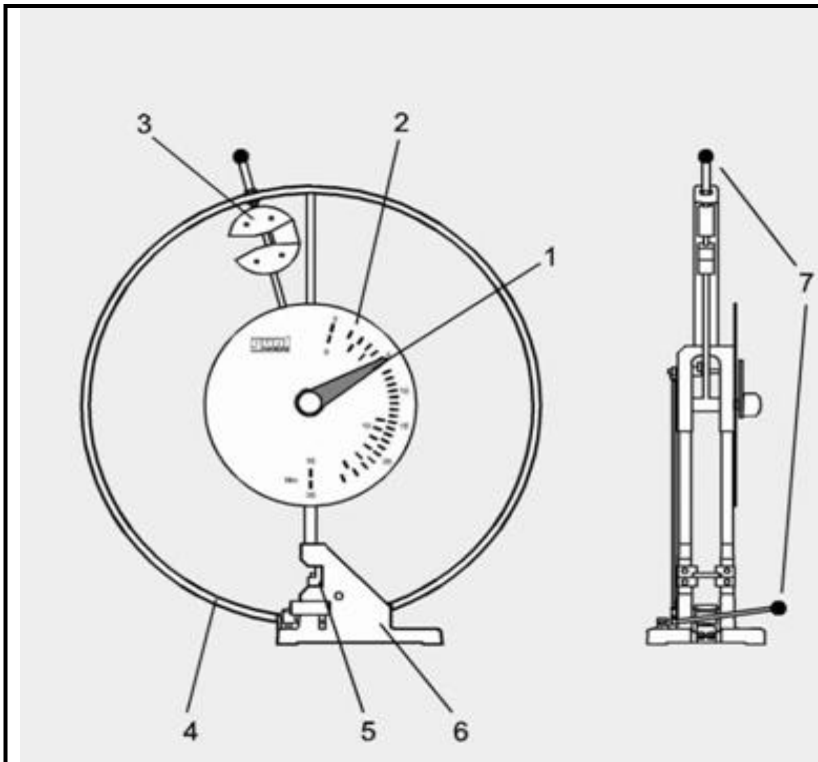
Fig.6.1. Izod vs. Charpy Impact tests

II-Objectives:-

1. Determination of notched bar impact work
2. Evaluation of fracture surface characteristics
3. Influence of notch shape on the notched bar impact work
4. Influence of materials (steel, copper and aluminum) on the notched bar impact work

III-System Description:-

In this Lab, the G.U.N.T WP400 impact pendulum is used. Fig.6.2 illustrates the testing machine:-



1 trailing pointer, 2 measuring scale, 3 hammer, 4 guard ring, 5 specimen holder with specimen, 6 unit base, 7 two hand trigger and brake

Fig.6.2. impact testing machine

As seen from the figure, a hammer(3) is elevated at a certain position and been holed by a hand trigger(7). The specimen(5) is putted in its holder(5) and the test is performed when the hand trigger(3) is pulled up and the reading of the impact work is taken by trailing pointer (1) and measuring scale(2) .

IV-Theoretical Background:-

The *WP400* impact pendulum was designed to calculate the impact work. However, some calculations must be done due to the friction loss from the machine:-

$$A_I = A_p - A_F \tag{6.1}$$

Where:-

A_I: the effective impact work ($N.m$)
A_p: measuring scale(2) reading ($N.m$)
A_F: the friction loss ($N.m$)
The friction losses is given as:

$$A_F = 2.3\left[1 - \frac{25 - A_P}{12.75}\right] \tag{6.2}$$

Finally, the effective impact work (A_I) is transformed to specific impact work by:

$$a_I = \frac{A_I}{A_o} \tag{6.3}$$

Where:-

a_I: is the specific effective impact work (J/mm^2)
A_o: is the stress sectional area (mm^2)

V-Experimental procedures:-

1. Chose a set of specimens that contains a V-notch (90^o and 45^o) and U-notch for steel, copper and aluminum materials
2. Measure the stress sectional are and record the value in the collected data table
3. Adjust the first specimen in the specimen holder(5).
4. Elevate the hammer(3) to the hand trigger(5) until its locked by the trigger.
5. Be insure that there is nothing in the path of the pendulum, step on the brake(7) by your foot and release the trigger.
6. Record your measurements in the collected data tables
7. Repeat steps (1-6) for the rest of the specimens.

Precaution:- in this experiment, be careful when derailing with the hammer(3) to prevent any injuries.

VI- collected data:-

Table 6.1:- stress sectional area

Material	*V-notch (90°)*	*V-notch (45°)*	*U- notch*
Steel	A_o= mm^2	A_o= mm^2	A_o= mm^2
Copper	A_o= mm^2	A_o= mm^2	A_o= mm^2
Aluminum	A_o= mm^2	A_o= mm^2	A_o= mm^2

Table 6.2:- measuring scale reading

Material	*V-notch (90°)*	*V-notch (45°)*	*U- notch*
Steel	A_P= *N.m*	A_P= *N.m*	A_P= *N.m*
Copper	A_P= *N.m*	A_P= *N.m*	A_P= *N.m*
Aluminum	A_P= *N.m*	A_P= *N.m*	A_P= *N.m*

VII- Data processing:-

- Calculate the friction loss (A_F) using Eq.7.2. for each case
- Calculate the effective impact work (A_I) by using Eq.7.1 for each case
- Calculate the specific effective impact work (a_I) by using Eq.7.3 for each case
- Record your calculations in the results tables

VIII- Results:-

Table 6.3:- Friction losses calculations

Material	*V-notch (90°)*	*V-notch (45°)*	*U- notch*
Steel	A_F= *N.m*	A_F= *N.m*	A_F= *N.m*
Copper	A_F= *N.m*	A_F= *N.m*	A_F= *N.m*
Aluminum	A_F= *N.m*	A_F= *N.m*	A_F= *N.m*

Table 6.4:- effective impact work calculations

Material	*V-notch (90°)*	*V-notch (45°)*	*U- notch*
Steel	A_I= *N.m*	A_I= *N.m*	A_I= *N.m*
Copper	A_I= *N.m*	A_I= *N.m*	A_I= *N.m*
Aluminum	A_I= *N.m*	A_I= *N.m*	A_I= *N.m*

Table 6.5:- specific effective impact work calculations

Material	*V-notch (90°)*	*V-notch (45°)*	*U- notch*
Steel	a_I= J/ mm^2	a_I= J/ mm^2	a_I= J/ mm^2
Copper	a_I= J/ mm^2	a_I= J/ mm^2	a_I= J/ mm^2
Aluminum	a_I= J/ mm^2	a_I= J/ mm^2	a_I= J/ mm^2

XI- Discussion and Conclusions:-

- ***In Impact, what types of stress are involved?***
- ***Derive a governing equation for the energy transfer in the pendulum and the specimen. Hint:- energy is transferred between kinetic and potential.***
- ***If it is need energy to break the specimen, where dose this energy go? Explain.***
- ***Give practical examples on impact failure.***
- ***Mention the sources of error in this experiment.***

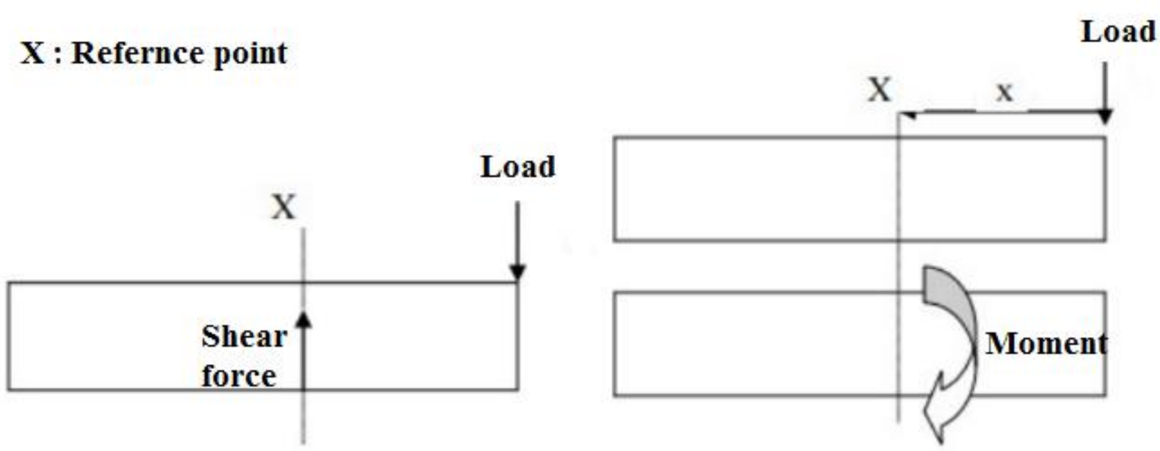
Experiment 7. Shear force and Bending moment

I-Introduction:

Shear force is the internal resistance created in beam's cross section, in order to balance transverse external load acting on it, while bending moment is bending effect due to an applied load at a given distance away from the reference point.

There are several types of beams, such as: cantilever beam, simply supported beam, overhanging beam, and continuous beam, the difference between them is explained in the overview section. In this experiment, simply supported beam will be examined.

Having a good understanding of shear force and bending moment, is very important in the engineering field, in civil engineering a good understanding of these two concepts are the key to design structural element.



Shear force and Moment at point X due to a load

II-Objectives:

1- To calculate theoretical values for shear force and bending moment, resulting from a load acting on simply supported beam.

2- Draw shear force diagram (SFD) and bending moment diagram (BMD).

3- Compare theoretical values to true values.

III-System Description

Shear force and bending moment test stand WP 960 G.U.N.T

Simply supported beam length 80 cm.

Shear force and Bending moment test stand

IV -Procedure:

1- Level the beam by using water level ruler.

2- Set the shear and moment gages to zero.

3- Add a load to hanger A.

4- Record the shear and moment reading from the gages.

5- Repeat steps 1-4 using 2 loads at both A and C.

6- Add uniform load to the beam (by distributing equal loads over the beam length).

7- Record the shear and moment reading from the gages.

V-Theory and Calculations:

The shear and bending moment throughout a beam are commonly expressed with diagrams. A shear diagram shows the shear along the length of the beam, and a moment diagram shows the bending moment along the length of the beam. These diagrams are typically shown stacked on top of one another, and the combination of these two diagrams is a shear-moment diagram. In order to draw a shear force and bending moment diagrams, first the value of shear force and bending moment must be calculated at supports (reactions) and at points where load varies.

It is important to note that The SFD and BMD curves shape depends on the load type (i.e. point load, Uniformly distributed load..etc.).The following table shows the different curve shapes for SFD and BMD, SF and BM equations, depending on load type and location.

After calculating SF, BM, and drawing SFD and BMD, error percentage between true values and theoretical values must be calculated using the following equation:

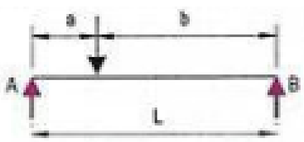
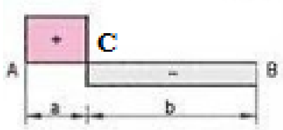
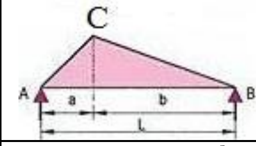
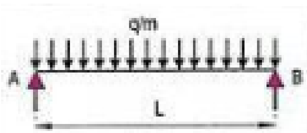
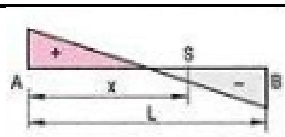
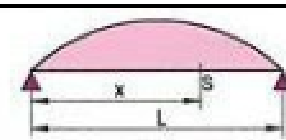
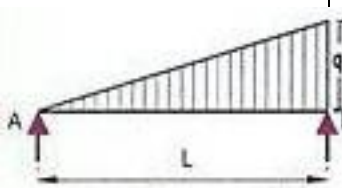
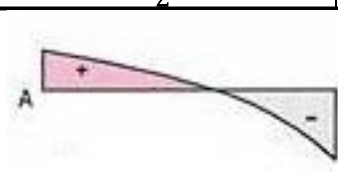
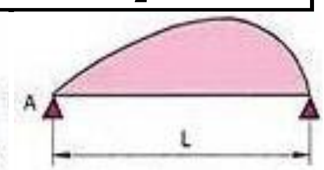
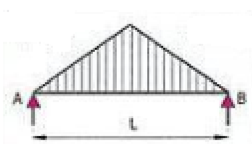
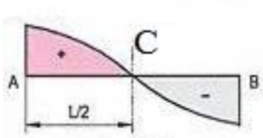
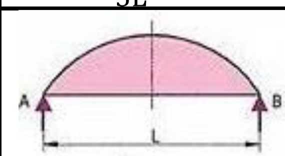
$$E\% = \left|\frac{V_E - V_T}{V_E}\right| * 100\% \qquad (4.1)$$

Where:

E% : Error percentage.

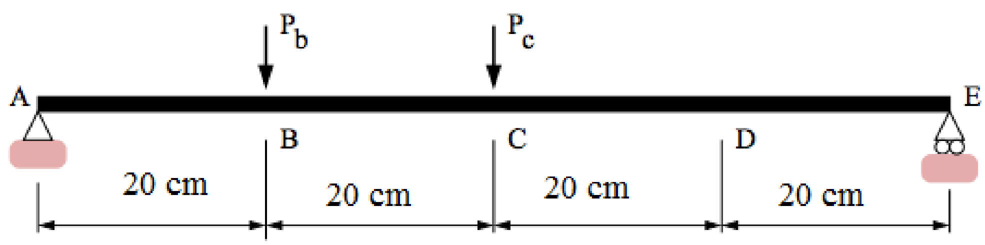
V_E: Experimental value (from gage).

V_T : Theoretical value (calculated).

Load type	Reactions	Shear equation	Moment equation
	$R_A = \frac{Pb}{L}$		
	$R_B = \frac{Pa}{L}$	$V_{A-C} = R_A$	$M_{max} = \frac{Pab}{L}$
		$V_{C-B} = R_B$	$M_{A-C} = \frac{Pbx}{L}$
			$M_{C-b} = \frac{Pax}{L}$
	$R_B = R_A$	$V_{A-P} = P$ $V_{p-p} = 0$	$M_{max} = Pa$
		$V_{p-B} = -P$	$M_x = Px$
	$R_A = \frac{q\,L}{2}$		
	$R_B = R_A$	$V_A = V_B = \frac{qL}{2}$	$M_{max} = \frac{qL^2}{8}$
		$V_x = \frac{qL}{2} - qx$	$M_x = \frac{qx}{2}\,(L - x)$
	$R_A = \frac{qL}{6}$		
	$R_B = \frac{qL}{3}$	$V_x = \frac{q}{3} - \frac{qx^2}{L^2}$	$M_{max} = \frac{qL^2}{9\sqrt{3}}$ $M_{max} @ \frac{L}{\sqrt{3}}$
			$M_x = \frac{qx}{3L^2}(L^2 - x^2)$
	$R_A = \frac{qL}{4}$		
	$R_B = R_A$	V_{max} at the left support	$M_{max} = \frac{L^2 q}{12}$
		$V_{A-C} = \frac{Lq}{4} - \frac{x^2 q}{L}$	$M_{A-C} = \frac{Lqx}{4} - \frac{x^3 q}{3L}$
		$V_{C-B} = -\left[\frac{Lq}{4} - \left(\frac{(L-x)^2 q}{L}\right)\right]$	$M_{C-B} = \left[\frac{Lqx}{4} - \left(\frac{(L-x)^3 q}{3L}\right)\right]$

VI-Collected Data:

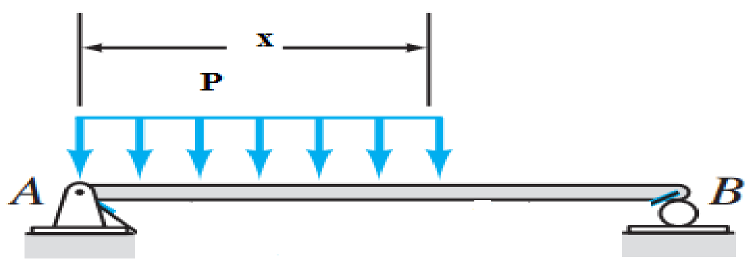
Case 1:



Load P_b = ……… N. Gage reading for shear force= ………N

Load P_c = ………..N. Gage reading for moment= ………… N.m

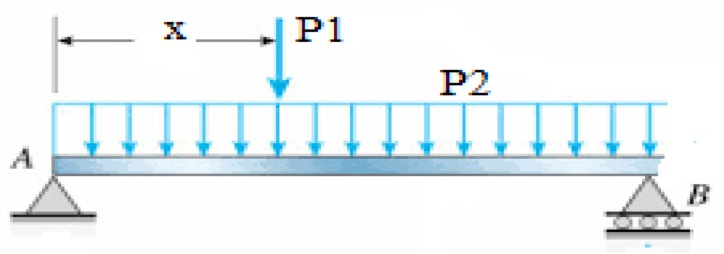
Case 2:



Distance = ……… m. Gage reading for shear force= ………N

Load P= ……….. N/m. Gage reading for moment= ………… N.m

Case 3:



Distance x = ………. m. Gage reading for shear force= ………N

Load P_1= ………. N. Gage reading for moment= ………… N.m

Load P_2=………N.

***VII-Results*:**

1. -Draw SFD and BMD for each Case.
2. -Find equations for SF and BM at distance x for each case.
3. -Calculate the errors in each case.

VIII-Discussion and Conclusion:

1. -Discuss the importance of this experiment.
2. -Discuss the error percentage values; do you think it is accepted? Mention the reasons caused the error.
3. -Discuss how the type load and location affect the SFD and BMD.

Experiment 8. Load of Mechanical Cell (bending)

I-Introduction :-

Bending is the main effect of moment on objects. Bending is measured as the transverse deflection from the original position. The new shape of bent object is called *the elastic line*. The shape of the elastic line depends on the loading and supporting conditions as illustrated in Fig.8.1:

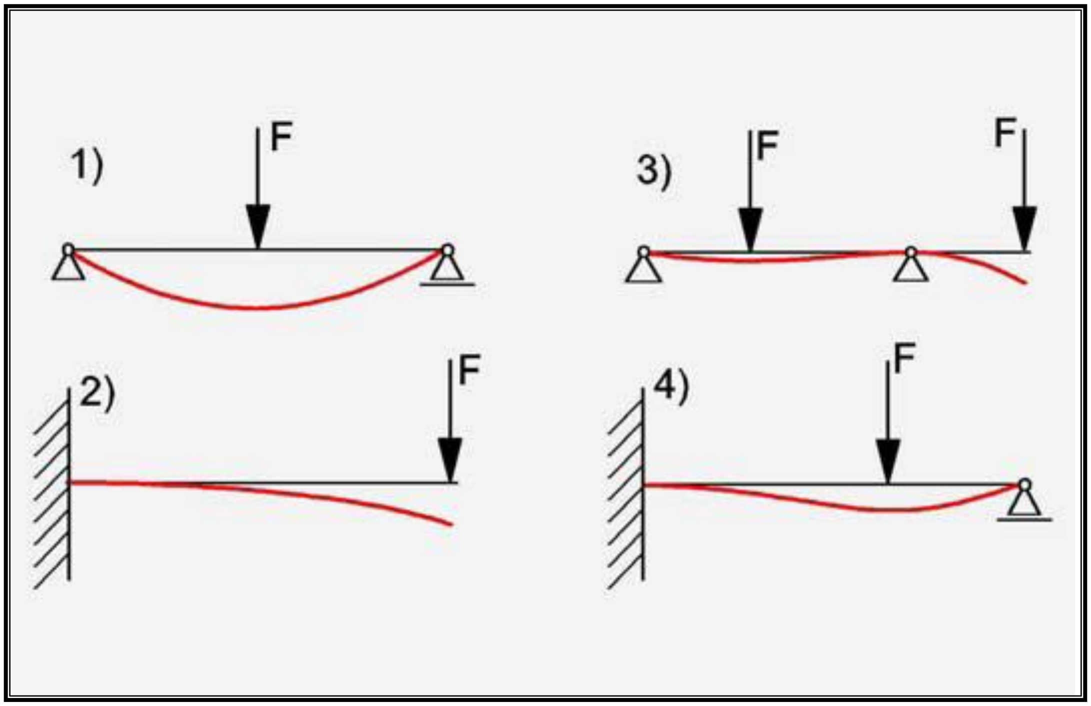


Fig.8.1. Elastic lines for statically determinate (left) and indeterminate (right) cases: 1 single-span beam with fixed and movable support, 2 cantilever, 3 beam with 2 fixed supports, 4 propped cantilever

The maximum deflection depends on the load value and the relation between the maximum deflection (δ_{max}) and the applied load (F) is *proportional*.

Deflection values depends on the type of beam support, type of material, Beam cross-section and length, and finally type of loading, in this experiment two types of beams are investigated simply supported beam and cantilever beam.

Applying moment on members generates bending stresses (σ_b; Pa) which is proportional to the moment ($M; N.m$) and the distance from the symmetrical axis (Z; m) and inversely with the polar moment of area (J; m^4):

$$\sigma_b = \frac{MZ}{J} \qquad (8.1)$$

If the member has a rectangular cross-section , J is given as:

$$J = \frac{wt^3}{12} \qquad (8.2)$$

Where:-

w: the width of the beam (m)
t: is the thickness of the beam (m)

II- objectives:-

1- Calculate theoretical values for deflection using double integration method.

2- Compare theoretical values to the true values of deflection.

3- Calculate bending stress

III-system description:-

To demonstrate the objectives of this experiment, WP 950 G.U.N.T machine is used. Fig.8.2. illustrates this machine and its main components

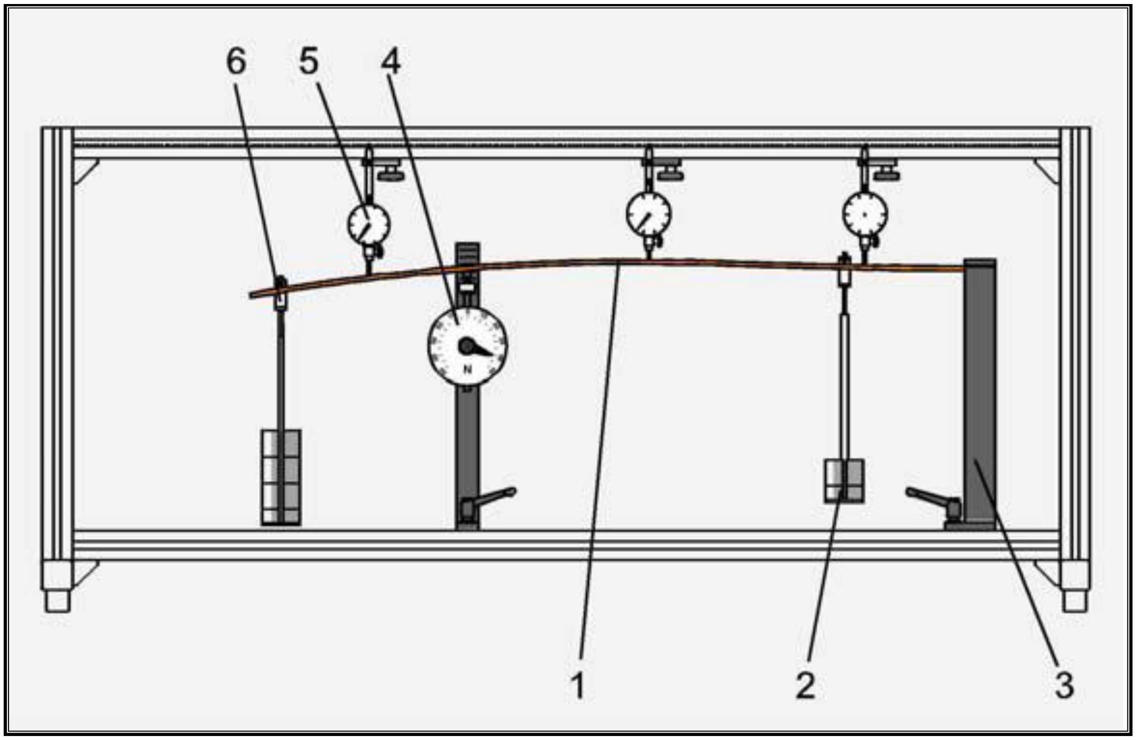


Fig.8.2. apparatus of the experiment: (1) beam, (2) weight, (3) bearing with clamp fixing, (4) bearing with force gauge, (5) dial gauge, (6) adjustable hook

It is obvious from Fig.8.2, WP 950 G.U.N.T machine gives many configurations for bending test however, we will operate this machine on the first and second configurations shown in Fig.8.1. (i.e. two supported and cantilever configurations).

Three metals will be tested in this experiment: steel, copper and aluminium. The configurations of cantilever and two supported beam is insured using parts (4) and (5). The load is applied using weights (2) and the adjustable hook (6). The deflection is measured using the dial gauge (5).

IV-governing equations:-

❖ ***Part one:- cantilever beam***

The used cantilever beam and the coordinate system are illustrated in Fig8.3.

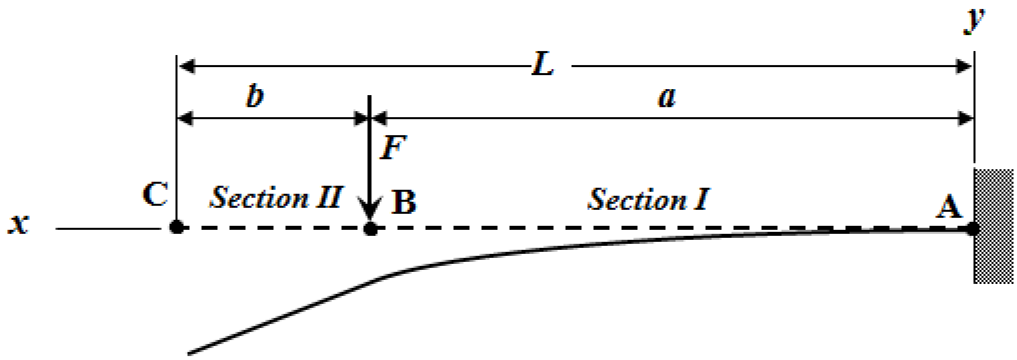


Fig.8.3. cantilever beam configuration

Note:- the axial direction (x) starts from point (A) and finish at point (C)

As you can see from Fig4.3, there are two significant sections:-

➢ ***Section I:-***

Section I is called *lorded section* where the applied load effect is observed. This section starts from the fixing point (A) and ended at the load appliance point (B). The deflection (y_{AB}) is given as :-

$$y_{AB} = \frac{Fx^2}{6EJ}(x-3a) \qquad (8.3)$$

Where:-

y_{AB}: the deflection of the loaded section (m)
J: the polar moment of area which given in Eq.2
E: the modulus of elasticity (Pa)

➢ ***Section II:-***

This section is *unloaded* and the shape of the beam remain linear. This section starts from point (B) and finishes at point (C). The deflection (y_{BC}) is given as :-

$$y_{BC} = \frac{Fa^2}{6EJ}(a - 3x) \quad (8.4)$$

Where:-

y_{CB}: the deflection of the unloaded section (m)

the maximum deflection is found at point (C) and it is given as:

$$y_{max} = y_C = \frac{Fa^2}{6EJ}(a - 3L) \quad (8.5)$$

Note that at point (B) where the load is applied, both Eqs 3 and 4 can give the deflection as:

$$y_B = -\frac{Fa^3}{3EJ} \quad (6)$$

Also note that the deflection is allows in the negative y-direction.

❖ ***Part two:- two supported beam***

The used beam and the coordinate system are illustrated in Fig8.4.

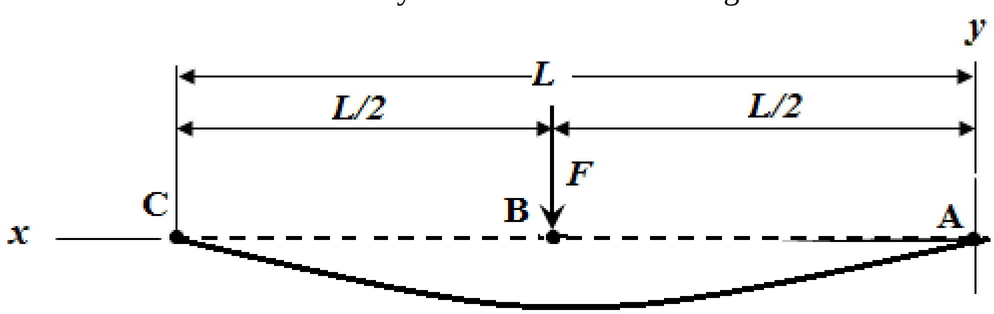


Fig.8.4. two supported beam configuration

At this part, a beam is supported by it ends and the load is applied at its centre.

The deflection is given as:

$$y_{AB} = \frac{Fx}{48EJ}\left(4x^2 - 3L^2\right) \tag{8.7}$$

$$y_{BC} = \frac{F(L-x)}{48EJ}\left(4(L-x)^2 - 3L^2\right) \tag{8.8}$$

Note that y_{AB} is symmetrical with y_{BC} at the centre point. The maximum deflection is found at the centre point and it is given as:

$$y_{max} = -\frac{FL^3}{48EJ} \tag{8.9}$$

V- Experimental Procedures:-

❖ ***Part one:- cantilever beam***

1. Select an appropriate steel beam for the test, measure its length (L), width (w) and thickness (t) and record the data in collected data tables.
2. Divide the beam to 20 equal segments by a marker pen.
3. Connect one end of the selected beam to the fixing clamp (3).
4. Connect an adjustable hock (6) at a certain distance (a) from the fixing clamp (3) and record it in the provided tables.
5. Before adding the load, take a measurement of the residual deflection in the beam and record the values in the provided tables.
6. Add a certain load using the weights (2) and record this value in the provided tables.
7. Start taking the measure of the deflection from the fixing point until the end of the beam and notice the deflection at the load. Record the data in the provided tables.
8. Repeat step (1) - (7) for a copper and aluminium beams

❖ ***Part two:- two supported beam***

1. Select an appropriate steel beam for the test, measure its length (L), width (w) and thickness (t) and record the data in collected data tables.
2. Divide the beam to 20 equal segments by a marker pen.
3. Connect hang the ends of the selected beam on force gauges (4).
4. Connect an adjustable hock (6) at the centre of the selected beam.
5. Before adding the load, take a measurement of the residual deflection in the beam and record the values in the provided tables.
6. Add a certain load using the weights (2) and record this value in the provided tables.
7. Start taking the measure of the deflection from one end until the next end of the beam and notice the deflection at the load. Record the data in the provided tables.
8. Repeat step (1) - (7) for a copper and aluminium beams

VI-Collected Data:-

Table 8.1. Basic geometry and dimensions

Parameter	*Steel*	*Aluminium*	*Copper*
Length (L; m)			
Width (w; mm)			
Thickness (t; mm)			

- ***Part one:- cantilever beam***

Table 8.2. Basic geometry and dimensions for cantilever beam part

Parameter	*Steel*	*Aluminium*	*Copper*
a(mm)			
b(mm)			
F(N)			

Table 8.3. collected data for the cantilever beam part

Trial	*x(mm)*	*Steel*		*Aluminium*		*Copper*	
		y_r	y	y_r	y	y_r	y
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

❖ ***Part two:- two supported beam***

Table 8.4. Basic geometry and dimensions for two supported beam part

Parameter	***Steel***	***Aluminium***	***Copper***
F(N)			

Table 8.5. collected data for the two supported beam part

Trial	***x(mm)***	***Steel***		***Aluminium***		***Copper***	
		y_r	y	y_r	y	y_r	y
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

VII- Data Processing:-

❖ ***Part one:- cantilever beam part***

- Calculate the actual deflection (y_a) by subtracting the residual deflection (y_r) from recorded deflection (y): - $y_a = y - y_r$. Record the results in the provided tables.
- Calculate the theoretical deflection (y_{th}) using Eqs. (8.3) and (8.4) and record the results in the provided tables.
- Draw both theoretical and experimental values of deflection verses axial position (x) on the same chart.
- Find the value of the maximum deflection using Eq.8.5 and compare it with the experimental obtained value
- Find the value of the deflection at the point of appliance the force using Eq8.6 and compare it with the experimental obtained value.

❖ ***Part two:- two supported beam part***

- Calculate the actual deflection (y_a) by subtracting the residual deflection (y_r) from recorded deflection (y): - $y_a = y - y_r$. Record the results in the provided tables.
- Calculate the theoretical deflection (y_{th}) using Eqs. (8.7) and (8.8) and record the results in the provided tables.
- Draw both theoretical and experimental values of deflection verses axial position (x) on the same chart.
- Find the value of the maximum deflection using Eq8.9 and compare it with the experimental obtained value.

VIII-Results :-

❖ ***Part one:- cantilever beam part***

Table 8.6. results for the cantilever beam part

Trial	x(mm)	Steel		Aluminium		Copper	
		y_a	y_{the}	y_a	y_{the}	y_a	y_{the}
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

❖ ***Part two:- two supported beam***

Table 8.7. collected data for the two supported beam part

Trial	*x(mm)*	*Steel*		*Aluminium*		*Copper*	
		y_a	y_{the}	y_a	y_{the}	y_a	y_{the}
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Table 4.8. Maximum deflection for two cases

Cantilever Beam			
Parameter	**Theoretical value**	**Experimental value**	**Percent of error**
y_{max}			
y_B			

Two supported Beam			
Parameter	**Theoretical value**	**Experimental value**	**Percent of error**
y_{max}			

IX- Discussion and Conclusions:-

- ***Answer the following questions:-***

  1. What are the main differences between the two examined cases in this experiment?
  2. The term (*EJ*) has its own importance in the mechanical applications. What does it mean?

- ***Mention the sources of error in this experiment.***
- ***Mention your own observations and your final conclusions***
- ***In the cantilever beam part, if the load is subjected at the free end. Derive the deflection equation.***
- ***In the part of two supported beam, if the load is shifted from the centre. Drive the deflection equation***
- ***Calculate the bending stress using Eq.1 for both cases.***