جامعة الإمام عبدالرحمن بن فيصل
IMAM ABDULRAHMAN BIN FAISAL UNIVERSITY
College of Engineering كلية الهندسة

Department of Civil and Construction Engineering

Engineering Materials

Laboratory Manual

2017 - 2018

Engr. Muhammad Nasir

Preface to First Edition

Engineering materials' laboratory is one of major laboratory tools used to evaluate material performance and establish compliance for the quality of plain concrete and steel rebar.

This Laboratory Manual will be used in the courses in the Bachelor of Engineering program in College of Engineering.

During the last few years, the College of Engineering in the Imam Abdulrahman Bin Faisal University developed a state of art, research and professional laboratories in the area of Environmental Engineering and the main aim of these laboratories is to increase the engineering skills capabilities in the Kingdom of Saudi Arabia towards improving the Engineering Practices in Environmental Engineering industry.

On behalf of College of Engineering, I take this opportunity to thanks Dr. Walid Al-Kutti, Dr. Muhammad Saleem and Engr. Muhammad Nasir who have taken keen interest in preparation and publication of this Manual. Without their help it would not have been possible to take this Manual to the students.

Dr. Othman Subhi Alshamrani
Dean - College of Engineering
Imam Abdulrahman Bin Faisal University

Contents

INTRODUCTION TO THE ENGINEERING MATERIAL LAB

The behaviour and properties of structural materials such as concrete and steel can be better understood by detailed, well-designed, first-hand experience with these materials. The students will become familiar with the nature and properties of these brittle and ductile materials by conducting laboratory tests. These tests have been selected to illustrate the basic properties and methods of testing of concrete and steel. Test procedures, sometimes simplified because of time limitation, are mostly those outlined by the American Society for Testing and Materials (ASTM) standards.

Course Objectives

1. To prepare the students to effectively link theory with practice and application and to demonstrate background of the theoretical aspects.
2. To prepare the students to generate data using experiments and analyse by using computer software.
3. To allow the students to have hands on experiments and to have exposure to equipment and machines.
4. To prepare the students to solve problems related to their course work including design elements and improve their communication skills through report presentation.
5. To emphasize the knowledge and application of safety regulations.

Student Responsibilities

In the very beginning of the laboratory work, the students will be organized into groups. For this reason, regular attendance is strictly required.

Every laboratory session is divided into two parts. In the first part, the instructor will be lecturing on the test objective, procedure and data collection. In the second part, the students, organized in groups required to conduct the experiment. In order to perform the experiment within the assigned period, and to gain the maximum benefit from the experiment, the students must familiarize themselves with the purpose, objective, and procedure of the experiment before coming to the laboratory. Relevant lecture notes and laboratory manual should be studied carefully and thoroughly.

At the end of the test, every group should submit a draft sheet of the data collected for approval by the instructor.

It should be understood that laboratory facilities and equipment are provided to enhance the learning process and to give first-hand experience of structural materials.

The equipment and tools must be properly cared, handled and cleaned during and after every laboratory session. Also, students should always take precautions to avoid any possible hazards. Students must follow laboratory regulations provided at the end of this section.

Report Writing

Every student is required to submit his own separate report for each test conducted. Reports should be written on A4 high-quality paper. The sample of report cover sheet is shown on the following page:

Department Name

Laboratory Report

Experiment # :

Experiment Title :

Student Name :

Student ID :

Student Group :

Date of Experiment :

Date of Submission :

In general, the reports should be arranged in the following order:

1. **Introduction**

   Detail information related to the experiment such as applicable equations theory, application of the experiment in the industry etc.

2. **Objective**

   A brief paragraph of the objective and significance of the experiment along with any applicable equation's theory on the experiment.

3. **Test Procedure**

   Since the assigned experiments are performed in accordance with applicable standard procedures, it is sufficient to cite such standards. When standard is not available or changes in the experimental procedure are suggested, the exact procedure should be carefully studied, followed and written on the report.

4. **Experimental Data and Result**

   These should be presented in the clearest possible form. Tabulations are usually the best way for presenting both the data and results. Graphs can also be used for the same purpose. Portion or complete graph sheet can be used. All graphs must be complete with supplementary information necessary for a complete understanding.

5. **Discussion and Conclusions**

   Analysis of the results and possible sources of errors in experimental work are to be given here. Also, the questions at the end of each test should fully be answered.

Criteria of Grading

1. **Attendance**

   Compulsory and the report marks are based on the attendance.

2. **Laboratory Work**

   Follow the laboratory rules and safety regulations and obey all the instruction given by the instructor or person in charge.

3. **Report Writing**

   Follow the standard report format as given previously accordingly.

Laboratory Regulations

1. Make sure that you know the location of Fire Extinguishers, First Aid Kit and Emergency Exits before you start your experiments.
2. Get First Aid immediately for any injury, no matter how small it is.
3. Do not wear loose dress.
4. Always use safety shoes or boots.
5. Do not play with valves, screws and nuts.
6. Do not try to run and operate any machine without permission and knowledge of the laboratory personnel.
7. In case of any mishap; please do not be panic and report immediately to the laboratory personnel.

ATTENTION!

Please make sure all case hands, hand gloves, equipment or tools should be washed and cleaned in the laboratory sinks as it may lead to chocking of the entire drainage system and make sure all the items used are returned back to its original place and in order.

LABORATORY 1: Casting of Concrete Specimens

Introduction

Casting or Preparation of concrete specimens is required prior to the testing of compressive and flexural strength or any other test on concrete. For both tests, students will be divided into two groups and they will jointly cast the concrete specimens. For compressive strength test, total 4 Cylinders (having 100 mm diameter and 200 mm height) and 4 Cubes (100 mm) will be prepared. Each group will test either 3 Cubes or Cylinders while one specimen will be cast extra. For Flexural strength test, 3 Beams (having size of 100 x 100 x 500 mm) will be prepared. Each group will test 1 Beam specimen while remaining one specimen will be cast extra.

Concrete Casting Procedure:

Following are the steps for casting concrete specimens:

1. Bring all the required moulds to the concreting site and make sure that the moulds are assembled properly.
2. Lubricate all the moulds from inside with the help of oil and brush.
3. Weigh all the ingredients of concrete as per mix design and quantities depending on volume of concrete.
4. Wash concrete mixer or mixing tray, scoop, trowel, graduated cylinder outside the laboratory.
5. Put the dry ingredients into the mixer or tray first and mixing is carried out for one minute.
6. Mix water and superplasticizer together.
7. Add half of the liquid and mix for about 2 – 3 minutes.
8. Add remaining amount of fluid into the mixer or tray and thoroughly remix for another few minutes.
9. If the mixing is carried out in the mixer, put the mould on the vibrating table and fill each mould with concrete in two layers by scoop and vibrate each layer for 10 seconds holding the moulds by hand or clamping.
10. If the mixing is carried out by hand in the tray (usually in case of small mix), fill each mould with concrete in two to three layers by scoop and consolidate each layer 25 times with the help of tamping rod or by vibrating table.

11. Level the surface of the concrete with the help of trowel.
12. Clean all the tools immediately after casting outside the laboratory.
13. Place all the moulds and tools to its own position.
14. After about 24 hours, carefully de-mould all the specimens.
15. Tag the specimen with water-proof marker such as date and group number.
16. Submerge the concrete specimens into the water tank with care.
17. Clean and assemble all the moulds and keep everything at its own position.
18. After 28 days of water curing, take out the specimens from the tank and place on to the table.
19. Specimens are ready to test now.

The quantity required for each ingredient of concrete on the basis of required number and size of specimens (i.e. 4 Cylinders, 4 Cubes and 3 Beams) will be as follows:

Required Mix Design Quantities		
Type I Cement	10.62	kg
Water (0.4 w/c)	5.06	Ltr
19 mm Aggregate	28.34	kg
9.5 mm Aggregate	5	kg
Dune Sand	22.23	kg
Super plasticizer Plasticizer (Sikament NN) (1% by mass of OPC)	118.9	ml

Pictures of ccommonly used Lab Equipment and Tools:

a) Concrete Mixer

b) Vibrating Table

c) Set of Scoop

d) Set of Trowel

e) Water Curing Tank

Fig. 1: Commonly used Lab Equipment and Tools

LABORATORY 2: Compressive Strength of Concrete

Introduction

Compressive strength of hardened concrete is the most important parameter and representative of almost overall quality of concrete. It mainly depends on cement content, water/cement ratio of the mix and curing and age after it is cast. Compressive strength of concrete is determined by testing the cylindrical or cubical specimens of concrete using a compression testing machine, at various ages such as: 3 days, 7 days, 14 days and 28 days. Compressive strength test is conducted during mix proportioning for assessing the quality of concrete cast at site.

Objective

The objective of this laboratory is to:

- Determine compressive strength of concrete.

Applicable Standards

- Compressive strength: ASTM C39

Apparatus

1. Weighing scales sensitive to 1 gram
2. Mixing pan (22" x 22") or mixer
3. Weighing pan
4. Trowel
5. Scoop
6. 1000 ml graduated cylinder
7. Slump cone with 5/8" tamping rod, ruler and base for slump test
8. Vibrating table
9. Calliper, 12-in steel scale
10. Compression testing machine
11. Steel Mould (cylinder 75 x 150 mm or 150 x 300 mm & Cubic 100 x 100 x 100 mm)
12. Cement, graded coarse aggregate, fine aggregate, water and superplasticizer

Fig. 2: Compression and Flexural Testing Machine

Procedure

Samples to be Prepared

For compressive strength of concrete students will be divided into groups. The water-cement ratio of 0.4, curing period of 28 days (water curing), and shapes (cylindrical and cubical) will be considered.

Each group will cast a total number of 3 cylinders or cubes having size 75 mm x 150 mm or 100 mm. After de-moulding at 24 hours, all the cylindrical specimens will be submerged in water tank for the period of 28 days. Thereafter, cylinders will be tested for compressive strength by using Compression Testing Machine (CTM) or Universal Testing Machine (UTM).

Compressive Strength Testing of Cylindrical or Cubical Specimens

Test the cylinders or cubes under compression in the compression testing machine by adopting the following steps:

1. Clean the loading platens of the compression testing machine and place the cylinder or cube on the lower platen in such way that it is in the center of the platen.
2. Carefully align the top platen of the compressive testing machine ensuring that the loading platens are parallel to the specimen surfaces.
3. Load the specimen continuously and without shock at the rate of 3.3 kN/sec. Do not change the rate of loading when the specimen starts to yield.
4. Observe and sketch the fracture shapes of the cylinders or cubes.
5. Record the failure load and determine the compressive strength as:

$$fc' = P / A$$

where, fc' is compressive strength in MPa, P is load in kN and A is area of cylinder or cube in mm^2.

Report and Discussion

1. Report the results of Cylindrical specimens as follows:

Specimen No.	Load (kN)	Area (mm^2)	Compressive Strength (MPa)
1			
2			
3			

2. Report the results of Cubical specimens as follows:

Specimen No.	Load (kN)	Area (mm^2)	Compressive Strength (MPa)
1			
2			
3			

3. Also, report the results as follows:
   a) Curing period ______________ days.
   b) Average compressive strength of Cylinders ______________ MPa.
   c) Average compressive strength of Cubes ______________ MPa.
4. Compare the compressive strength of the cylindrical specimens with cubical specimens, cast with same water/cement ratio to see the effect of shape of the specimens on the compressive strength.
5. Answer the following questions:
   a) What considerations beside strength affect the selection of a W/C ratio?
   b) What is the effect of age of the concrete upon the W/C ratio - strength curve?

c) What relative compressive strengths would you have obtained in your tests if 150 x 300 mm cylinders had been used in place of 75 x 150 mm cylinders?

d) What relative compressive strengths would you have obtained in your test if 150 mm cubes had been used in place of 100 mm cubes?

LABORATORY 3: Flexural Strength of Concrete

Introduction, Scope and Significance:

- This test method is used to determine the flexural strength of specimens prepared and cured in accordance with the specifications. Results are calculated and reported as the modulus of rupture.
- The strength determined will vary where there are differences in specimen size, preparation, moisture condition, curing, or where the beam has been molded or swayed to size.
- The results of this test method may be used to determine compliance with specifications or as a basis for proportioning, mixing and placement operations. It is used in testing concrete for the construction of slabs and pavements.
- The modulus of rupture is also used as an indirect measure of the tensile strength of concrete.

Objective

The objective of this laboratory is to:

- Determine flexural strength of concrete using simple beam with third-point loading.

Applicable Standards

- Flexural strength: ASTM C 78

Apparatus

- Flexural testing machine (Figure 2 and 3)
- For preparation of beam specimens all apparatus used in compression test will be required

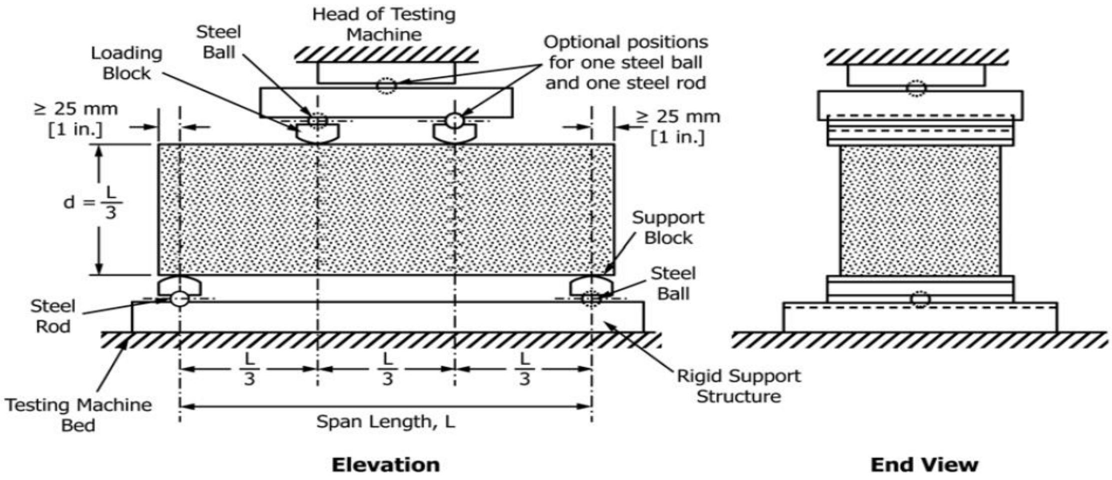


Fig. 3: Schematic diagram of Test setup according to ASTM

Related Theory:

Difficulties in determining Tensile Strength of Concrete:

There are considerable experimental difficulties in determining the true tensile strength of concrete. In direct tension test following are the difficulties:

1. When concrete is gripped by the machine it may be crushed due the large stress concentration at the grip.
2. Concrete samples of different sizes and diameters show large variation in results.
3. If there are some voids in sample the test may show very small strength.
4. If there is some initial misalignment in fixing the sample the results are not accurate.

Tests for Tensile Strength of Concrete:

Following tests are used to determine the tensile strength of concrete.

- Split Cylinder Test
- Double Punch Test
- Modulus of Rupture Test

Modulus of Rupture:

In a flexural test on a plane concrete specimen, the maximum tensile stress reached at the bottom fiber of a standard size prism (beam) under predefined loading type is called modulus of rupture.

Type / Size of the Specimen for the Test:

The specimen used is a prism, square in cross-section and having a certain length. There are two standard sizes of the specimen that can be used for specified aggregate sizes.

1. 150 x 150 x 750 (mm)
2. 100 x 100 x 500 (mm)

The size (150 x 150 x 750 mm) can be used for all sizes of the aggregate particles.

The size (100 x 100 x 500 mm) can only be used for the aggregate sizes less than 25 mm. We are using this size for our test.

Units:

- ASTM follows the Foot Pound System
- BS follows/uses the SI System

Relationships for Calculating the Average value of MOR:

There are some relationships which relate modulus of rupture, fr with compressive strength of concrete, fc’

$$fr = 0.69 \sqrt{fc'}$$

where, fc’ and fr are in MPa

ACI code gives formulae for fr

$fr = 0.5 \sqrt{fc'}$ (ACI code for Strength Calculation)

$fr = 0.625 \sqrt{fc'}$ (ACI code for Deflection Control)

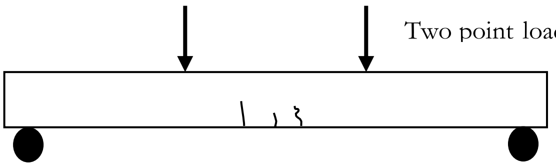
Generally,

$$\text{Tensile Strength} \propto \sqrt{\text{Compressive Strength}}$$

As a rough estimate, we take 8 – 15% of compressive strength as the MOR.

Derivation of Modulus of Rupture of a Prismoidal Beam:

The MOR for the test specimen can be computed by using the relation derived below;



$$Y = d/2$$

$$fr = \frac{My}{I}$$

where,

$$I = \frac{bd^3}{12} \qquad \text{and} \qquad s = \frac{I}{y} = \frac{bd^3/12}{d/2} = \frac{bd^2}{6}$$

$$\therefore \quad fr = \frac{M}{I/y} = \frac{M}{s} = \frac{P}{2} \times a \times \frac{6}{bd^2}$$

$$\Rightarrow \quad fr = \frac{3Pa}{bd^2} \qquad (MPa)$$

Test Specifications:

Rate of Loading:

The rate of loading should be such that we get a stress of 0.02 — 0.10 (MPa/s).

Acceptance Criteria of the Specimen:

If proper compaction is not done, then the specimen may fail outside the central portion i.e. near the ends.

In such a case, if;

1- (a – a') > 0.05 l → Ignore the specimen and discard the results.

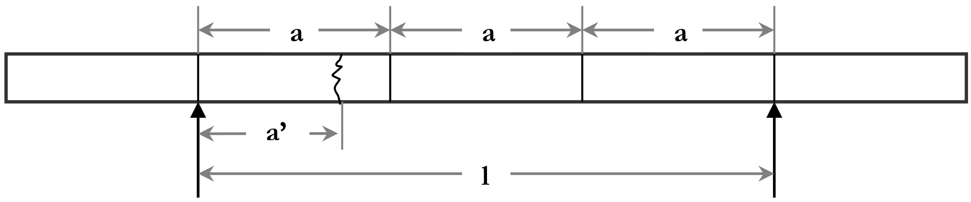
2- (a – a') =< 0.05 l → Use the derived formula but instead of a, use a' for MOR calculation.

where,

a'= distance from the support center to the crack

a = one-third distance between the supports

l = distance between the supports



The final result should be reported in multiples of 0.1 MPa.

Size of the Specimen:

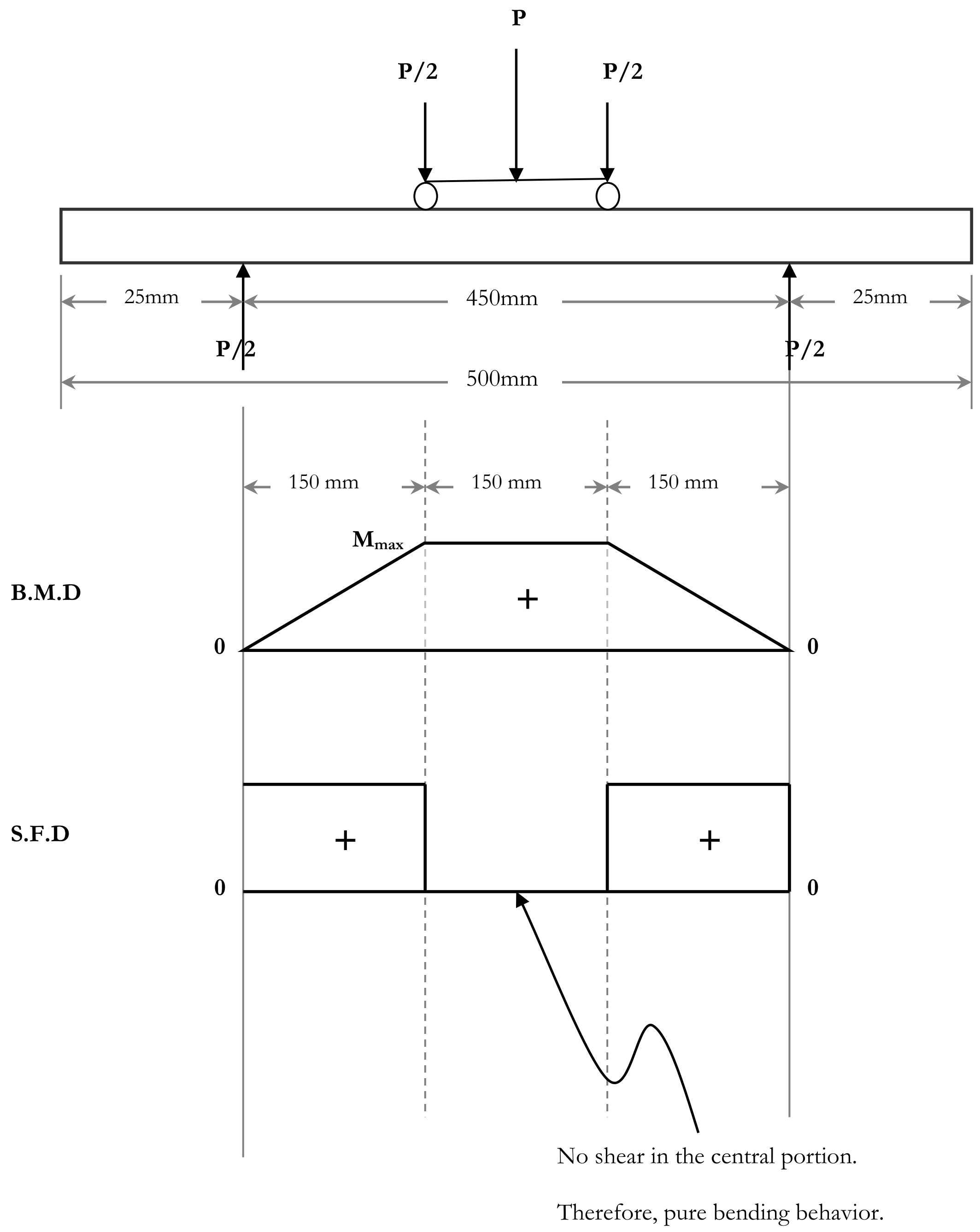
The specimen used is a prism of 100 x 100 (mm) square in cross-section and having a length of 500 mm.

Thus the dimensions of the specimen are:

100 x 100 x 500 (mm)

Type of Loading:

The loading pattern on the beam is called the **third-point/two-point loading**. The main advantage of third-point loading is that, the behavior of the beam can be studied under pure bending as there is no shear at the central portion of the beam. The phenomenon is depicted by the figure below.



Procedure:

Flexural tests of moist-cured specimens shall be made as soon as practical after removal from moist storage. Surface drying of the specimen results in a reduction in the measured flexural strength.

When *using molded specimens*, turn the test specimen on its side with respect to its position as molded and center it on the support blocks. When *using sawed specimens*, position the specimen so that the tension face corresponds to the top or bottom of the specimen as cut from the parent material. Center the loading system in relation to the applied force. Bring the load-applying blocks in contact with the surface of the specimen at the third points and apply a load of between 3 and 6 % of the estimated ultimate load or as per ASTM standard.

Grind, cap, or use leather shims on the specimen contact surface to eliminate any gap in excess of 0.004 in. (0.10 mm) in width. Gaps in excess of 0.015 in. (0.38 mm) shall be eliminated only by capping or grinding. Grinding of lateral surfaces should be minimized in as much as grinding may change the physical characteristics of the specimens. Capping shall be in accordance with the applicable sections of Practice C 617.

Load the specimen continuously and without shock. The load shall be applied at a constant rate to the breaking point. Apply the load at a rate that constantly increases the extreme fiber stress between 125 and 175 psi/min (0.86 and 1.21 MPa/min) until rupture occurs. The loading rate is calculated using the following equation:

$$R = Sbd^2 / L$$

where:

r = loading rate, lb/min (N/min)

S = rate of increase in extreme fiber stress, psi/min (MPa/min)

b = average width of the specimen, in. (mm),

d = average depth of the specimen, in. (mm), and

L = span length, in. (mm).

Calculations:

Case — 1:

If the fracture initiates in the tension surface within the middle third of the span length, calculate the modulus of rupture as follows:

$$R = PL / bd^2$$

where:

R = modulus of rupture, psi or MPa,

P = maximum applied load indicated by the testing machine, lbf or N,

L = span length, inch or mm,

b = average width of specimen, inch or mm, at the fracture, and

d = average depth of specimen, inch or mm, at the fracture.

Note: The weight of the beam is not included in the above calculation.

Case — 2:

If the fracture occurs in the tension surface outside of the middle third of the span length by not more than 5 % of the span length, calculate the modulus of rupture as follows:

$$R = 3Pa / bd^2$$

where:

a = average distance between line of fracture and the nearest support measured on the tension surface of the beam, (in or mm).

Note: The weight of the beam is not included in the above calculation.

Case — 3:

If the fracture occurs in the tension surface outside of the middle third of the span length by more than 5 % of the span length, discard the results of the test.

Answer the following questions:

1) Beside modulus of rupture (flexural strength test), which other tests can be used to determine the tensile strength of concrete?
2) What maximum size of aggregate did we use such that our beam specimen was 100 x 100 x 500 mm, not 150 x 150 x 750 mm?
3) Can we use mid-point loading pattern to study the bending phenomenon, instead of third-point loading pattern?
4) Derive the formula for calculating the modulus of rupture (fr) for a beam with two point loading. Consider P is the point load, L is the total length, a is the one-third span length, b is the with and d is depth of beam.
5) Report the curing period of your beam specimen in days.
6) Dram the shear force and bending moment diagram of your beam. Use the same dimension used in the experiment and P obtained from the test result.
7) What was your failure case after the beam failure? why?
8) Show the calculation for determining the modulus of rupture in your case?
9) Calculate the average modulus of rupture from different relationships and thumb-rules. Assume that the compressive strength of 100 mm cubical concrete is 20 MPa.

LABORATORY 3: Tensile Strength of Steel

Introduction

A structural element is a human-made object that serves to transfer load from one place to another. Usually, the stresses and deflection in an element can be determined when the necessary information is given. This information consists of amounts of the applied loads (moments, shear, torque, axial loads, etc.), and the mechanical properties of the material, the support conditions, and the dimensions of the structure.

All solid materials have limits to their strength and deformation. Hence a quantitative and qualitative understanding of the mechanical properties of these materials is essential when designing tools, machines, structures, etc. These properties include among others the following: tensile, shear strength, Poisson's ratio, etc. These properties are usually determined by laboratory testing of a specimen of the material, which is in a specific geometric form. These tests are used widely in engineering to provide basic design information and to determine if the material meets the specifications.

Objective

The objective of this laboratory is to:

- To understand how the tensile test is performed practically and to develop an understanding of basic stress-strain relationships.
- How this relationship is related to the behaviour of the materials under load, including elastic and plastic behaviour.

Background Information

The stress-strain (σ-ε) curve for a material can yield a great deal of valuable properties (mechanical properties) about the material and its suitability for the different applications. From the σ-ε curve (**Figure 4**) we can determine the following properties:

- ***The proportional limit (P.L), σ_p*** : The value of stress beyond which the material is not linearly elastic (i.e. * $E\varepsilon$ stress is not proportional to strain, No P.L for Brittle material)

- ***Elastic Limit (E.L)***: Maximum stress that may be developed during a simple tension test such that there is no permanent or residual deformation. When the load is entirely removed.

- ***Modulus of Elasticity,E*** : It is the constant of proportionality between stress and strain in the linear portion of the σ-ε curve.

  "Ratio of the unit stress to the unit strain"
  E = σ/ε or σ = E ε (Hooke's Law)

  "Slope of straight line from zero to P.L"
  E (steel) = 29 * 10^6 psi
  = 200 * 10^9 N/m^2 = 200 GPa

- ***Yield stress, σ_y***: It is the stress at which there is appreciable increase in the strain with no or little increase in the stress; the stress may even decrease slightly. Materials exhibit different behavior with regard to yielding. For example, low carbon steel exhibits a well-defined yield plateau where one can see increase in strain with no increase in the stress until you reach strain hardening (**Figure 4a**). However, some high carbon steels do not exhibit well defined yielding plateau (**Figure 4b**). For these types of materials, we use the offset method (0.2%) strain offset) to find σ_y in which we draw a line parallel to the classic curve at 0.002 strain and σ_y, is defined where it intersects the σ-ε curve.

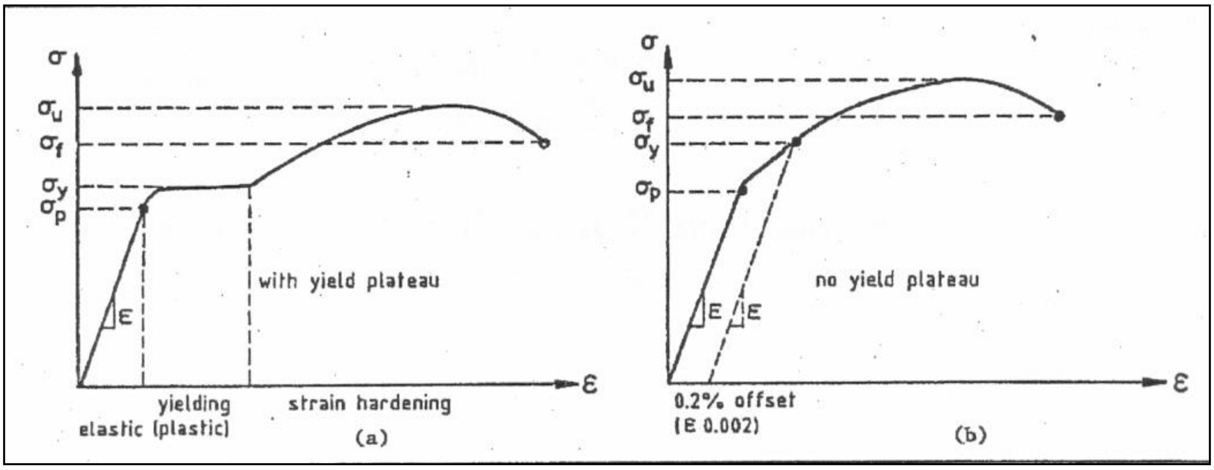


Figure 4: Typical stress-strain curves

- ***Ultimate strength, σ_u***: It is the maximum stress (based on original cross sectional area of the specimen) which can develop in the material before rupture. Hence σ_u can be computed as:

$$\sigma_u = \frac{P_u}{A_o}$$

where;

P_u = the ultimate load

A_o = original cross-sectional area of the bar = $\pi d_o^2/4$

d_o = diameter of bar before loading

As we increase the amount of carbon in steel, strength (σ_u) increases, however ductility is reduced, as shown in **Figure 5.**

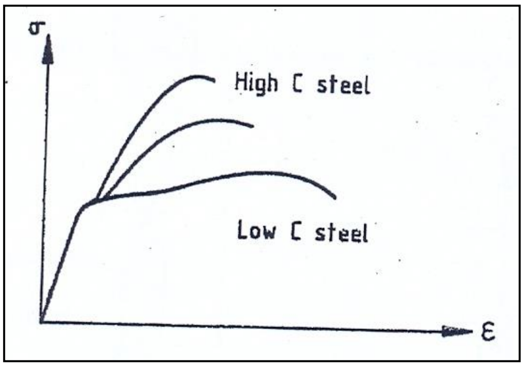


Figure 5: Effect of amount of carbon on ultimate strength

- ***Fracture strength,* σ_f**: It is the rupture or breaking strength; it is the stress at which the specimens fracture and complete separation of the specimen parts occurs. Due to loading, cross-sectional area is reduced & hence actual rupture strength can be obtained by dividing the rupture load with (Rupture area) cross-sectional area at the end of the test.

$$\text{Fracture strength, } \sigma_{f_f}^{T} = \frac{\text{Load at Fracture}}{A_f}$$

where;

A_f = the final cross-sectional area after loading (breaking) = $\pi d_f^2/4$ (**Figure 6**)

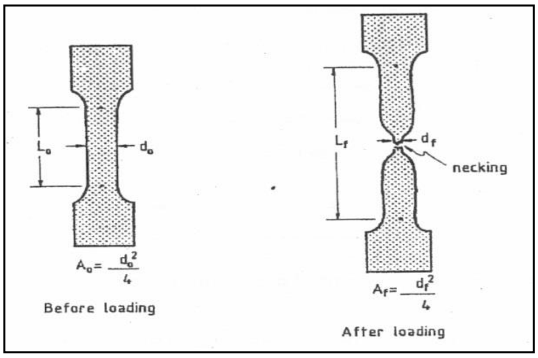


Figure 6: Initial and final cross-sectional areas

- ***Poisson's Ratio, v***: It is the ratio of the lateral (transverse) strain to the longitudinal strain for uniaxial loading (**Figure 7**)

$$v = \frac{-\varepsilon_t}{\varepsilon_l}$$

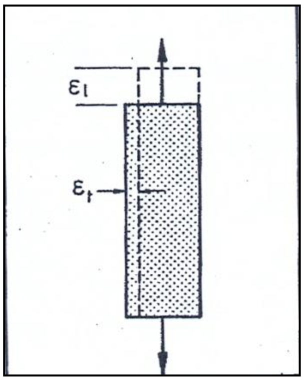


Figure 7: Lateral and longitudinal strain in a uniaxially loaded specimen

- ***Ductility:*** It is a measure of the material's ability to deform plastically. Materials which exhibit large plastic deformations are ***ductile materials*** such as low carbon steel (**Figure 8**). Materials which exhibit little or no plastic deformation are ***brittle materials*** such as concrete under tension (**Figure 8**).

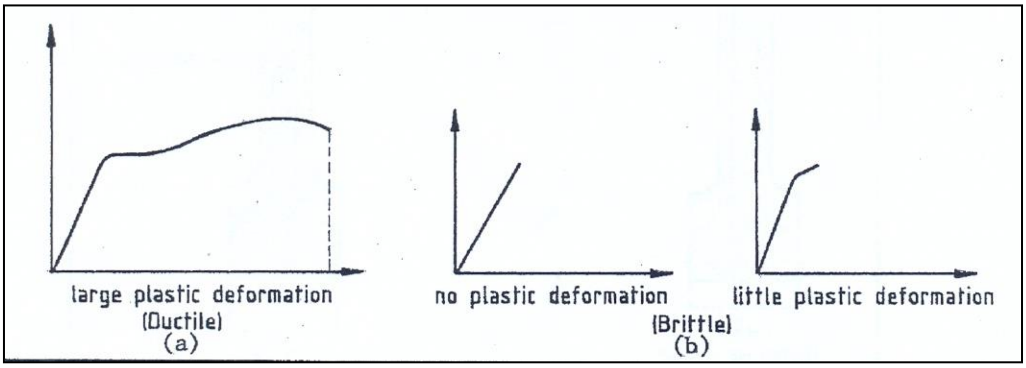


Figure 8: Ductile versus brittle materials

Ductility can be measured by one or two of the following indices:

i. ***Percent Elongation***:

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

ii.***Percent Reduction in Area***:

$$\%\text{Reduction of Area} = \frac{A_f - A_o}{A_o} \times 100$$

Note: During the first portion of the plastic deformation, the specimen deforms homogeneously, but as the test progresses, one region of the specimen begins to deform much quicker than the rest. This localized strain will result in the formation of the "necked" region (**Figure 9**)

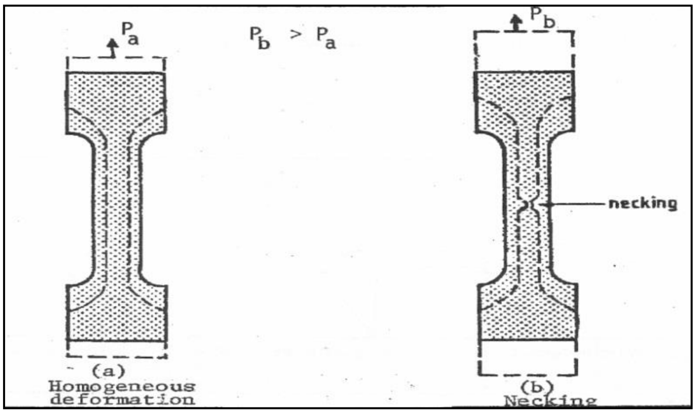


Figure 9: Necking phenomena in tensile specimens

- ***Resilience:*** It is the ability of a material to absorb energy when elastically deformed and return it when unloaded. Resilience is measured by Modulus of Resilience**,** **U**$_r$ which is equal to the area under the elastic portion of the σ-ε curve as shown in **Figure 10**.

$$U_r = \frac{1}{2}\sigma_p\,\varepsilon_p \text{ but } \varepsilon_p = \frac{\sigma_p}{E} \qquad U_r = \frac{1}{2}\sigma_p\,\frac{\sigma_p}{E} = \frac{\sigma_p^2}{2E}$$

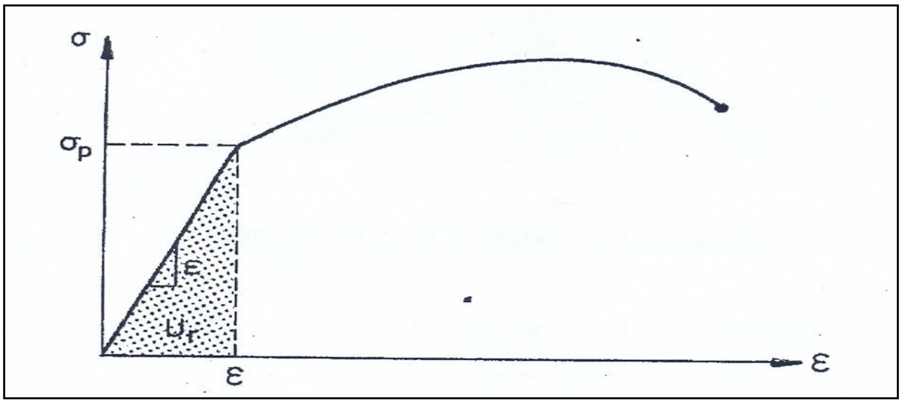


Figure 10: Calculation of modulus of Resilience

- ***Toughness:*** It is the ability of material to absorb energy in the plastic range of the material. Toughness is measured by Modulus of Toughness, $\mathbf{U_t}$ which is equal to the area under the whole σ-ε curve as shown in **Figure 11.** In other words, work done on a unit volume of material as a single tensile force is gradually increased from zero to the value causing rupture.

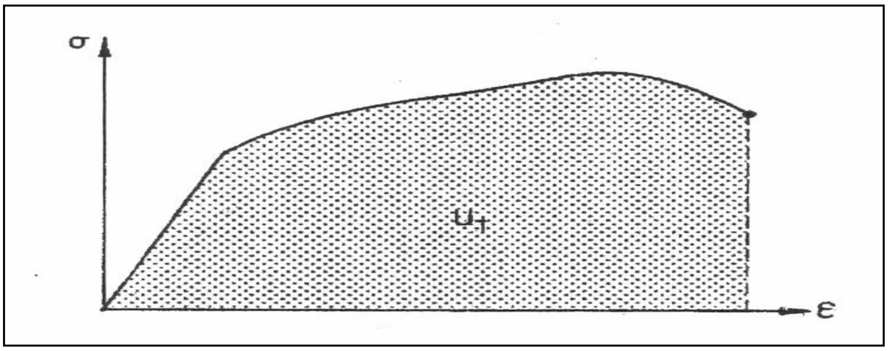


Figure 11: Calculation of modulus of Toughness

- ***Strain Hardening***: Of a ductile material can be stressed considerably beyond the yield point without failure. This is true for many structural metals.

- ***Working Stress (Allowable stress)***: The maximum safe stress a material can carried before failure.

- ***Tangent modulus***: In instantaneous modulus for brittle martial the rate of change of stress with respect to strain at any point.

Experimental Program

In the tension test, two standard, test specimens of a circular cross-section with diameter = 0.55 in. (13.8 mm) and gage length of 2 in. (50.8 mm) will be loaded gradually until rupture (complete failure). An extensometer will be attached to the specimen to measure the longitudinal deformation. Both the load (**P**) and deformation (ΔL) will be recorded to generate the stress-strain diagrams from which some of the important mechanical properties for the tested material will be obtained.

Applicable Standards

- Tension Test: ASTM E8, ASTM A370

Apparatus

1. Universal Testing Machine (UTM) shown in **Figure 12**
2. Gauge length marker
3. Vernier calliper
4. High Tensile steel / Mild steel

Figure 12: Universal Testing Machine (UTM)

Procedure

1. On the specimen using the gage length marker mark the 2 inches marks.
2. Measure and record the dimensions of the cross-section of the specimen at the centre of the gage length to the nearest 0.01 inches (0.25 mm) using vernier calliper.
3. Fix the specimen in the testing machine (take care to ensure axial alignment of the specimen).
4. Load the specimen gradually and take simultaneous readings of the load (P) and the change in length (deformation ΔL) and record the data. The speed of the test shall he determined by the instructor.

5. Continue applying the load until the specimen fails.
6. Record the load at failure.
7. Remove the pieces and fit them back together to measure the final length and diameter.
8. Record and sketch the shape of the failure surface.

Report and Discussion

For each material, the following are required:

1) Plot the stress-strain diagram
2) Calculate percentage elongation and percentage reduction in cross-sectional area.

From the stress-strain diagram, determine:

3) The yield point, σ_y (for materials showing a clear yielding plateau) or the yield strength by the 0.2% offset method (for materials not having distinct yield point)
4) The proportional limit, σ_p
5) Modulus of elasticity, E
6) Modulus of resilience, $U_r = \frac{\sigma_p^2}{2E}$

Answer the Following Questions:

7) Discuss the differences in the shapes of the stress-strain curves for the different types of materials tested (Not required).
8) Define the four fundamental mechanical properties:
    a) Yield strength
    b) Young's Modulus
    c) Ultimate strength
    d) Ductility
9) Discuss the importance to ensure axial alignment of the test specimen.
10) Why stress and strain are more significant than force and elongation?
11) What is the difference between resilience and toughness of a material?