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

Department of Civil and Construction Engineering

Concrete Materials

Laboratory Manual

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Preface to Second Edition

Concrete Laboratory is one of major laboratory tools used to evaluate concrete structure performance and establish compliance for the quality of concrete.

This Laboratory Manual of Concrete will be used in the courses in the Bachelor Science program in College of Engineering, and also planned to be used in the Postgraduate Structural Engineering courses.

During the last seven years, the College of Engineering in the Imam Abdulrahman Bin Faisal University has developed a state of art, research and professional laboratories in the area of Construction 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 Construction Engineering industry.

On behalf of College of Engineering, I take this opportunity to thanks Dr. Nabil Al Akhras, Dr. Walid Al Kutti and Engr. Muhammad Hassan Bakri who have taken keen interest in preparation and publication of this Manual. Engr. Muhammad Nasir is also indebted for revising the second edition. Without their help it would not have been possible to take this Manual to the students.

Dr. Othman Subhi Alshamrani
Dean - College of Engineering
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Contents

INTRODUCTION

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 materials by conducting laboratory tests. These tests have been selected to illustrate the basic properties and methods of testing of cement, aggregates, mortar, 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 of Construction Engineering

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 equations 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 outside the Exit door because washing cementitious items in the laboratory sinks may lead to chocking of the entire drainage system. Also make sure all the items used are returned back to its original place and in order.

LABORATORY 1: Normal Consistency and Times of Set of Portland Cement

Introduction

Normal or standard consistency of any given cement sample is that water content which will produce a cement paste of standard consistency. Consistency is determined by the Vicat apparatus, which measures the depth of penetration of a 10 mm diameter plunger under its own weight in the paste. Normal or standard consistency is expressed as that percentage of water, by mass of dry cement, corresponding to which a specified depth of penetration in paste is achieved. For Portland cements, the normal consistency varies from 26 to 33%.

Normal consistency of cement is determined for the purpose of determining the water to cement ratios for preparing the specimens to be used for other quality tests such as: times of set, compressive and tensile strengths, and soundness tests for a particular sample of cement.

Time of set or setting time is a term used to describe the stiffness of the cement paste with passage of time. Setting is mainly caused by a selective hydration of C_3A and C_3S and is accompanied by temperature rise in the cement paste. *Initial time of set* corresponds to a rapid rise and *final time of set* corresponds to the peak temperature. Time of set tests are also conducted using the Vicat apparatus but with the changed needles. Initial time of set is measured from the moment water is added to the cement to the moment when the standard needle having 1 mm diameter penetrates the paste under its weight to a depth of 25 mm in the Vicat mould. Final set is determined by a needle with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm in diameter and set 0.5 mm behind the tip of the needle. Final time of set is measured from the moment water is added to the cement to the moment when the needle makes an impression but the cutting edge fails to do so. For Portland cements, the initial time of set should usually be not less than 45 minutes whereas the final time of set should not be usually more than 10 hours.

Initial time of set is required to be measured to make sure that the concrete will remain in sufficiently plastic state till it is finished after placing and compacting. The final time of set is required to know that how long the concrete would take in attaining a significant stiffness after it is placed and finished.

Objective

The objective of this laboratory is to:

- Determine the normal consistency and times of set of the given sample of Portland cement.

Applicable Standards

- Normal consistency: ASTM C187
- Time of setting: ASTM C191

Apparatus

1. Vicat's apparatus including conical ring and glass plate as shown in **Figure 1.1**
2. Stop watch
3. Mixing Equipment: Balance, Mixing Bowl, 250 ml Graduated Cylinder, Trowel and Scoop
4. Ordinary Portland Cement

Figure 1.1: Vicat's apparatus

Procedure

Normal Consistency

1. Place 650 gm of cement in mixing bowl, form crater in cement and add the required water. Fold in the cement for 30 sec. with trowel, wait for 30 sec. and then knead by hand for one and a half minutes.

2. Form the cement paste into a ball and toss it six times from hand to hand, holding hands six inches apart.

3. Press ball into larger end of Vicat ring, completely filling the ring. Remove the excess from the larger end by hand and place the ring, large end down, on a glass plate and strike off the upper (smaller) end with a single trowel stroke. Carefully make this end smooth with the trowel but do not compress the paste.

4. Place the ring and paste in the Vicat apparatus and bring down the flat end of the plunger (10 mm in diameter) so that it may just touch the paste surface. Take an initial scale reading, then release the plunger and read after 30 secs. Normal consistency is obtained when the plunger settles 10 mm below the surface in 30 secs.

5. The entire operation should be repeated at different water percentages making different samples so as to reach the desired value. A plot of plunger penetrations versus water percentages can then be made to find the water percentage for normal consistency. It is important that temperature and humidity should be uniform during this process. The paste should be handled carefully.

Times of Set

1. Once the normal consistency has been obtained, prepare a new sample of cement paste using that water percentage.

2. Mold the specimens as before and cover with a damp cloth for 30 minutes.

3. Place the ring and paste in the Vicat apparatus and determine the penetration of the 1 mm needle in 30 secs. Repeat every 15 minutes until a reading of less than 25 mm is obtained. Time of set shall be the total period taken between addition of water and the stage when the penetration is 25 mm. Plot the penetration versus time curve to obtain the correct time of set. The Vicat apparatus should be free from vibration and the needle should be cleaned before each reading.

Result

Normal Consistency (10 mm needle)

	Group I	Group II	Group III	Group IV
Water (ml)				
Cement (gm)				
Water / Cement (w/c) Ratio				
Penetration (9 – 11 mm)				

Initial Setting Time (1 mm needle) => Optimum water content for Normal Consistency =

Time (min)	Penetration (mm)	Time (min)	Penetration (mm)
0		105	
15		120	
30		135	
45		150	
60		165	
75		180	
90		195	

Report and Discussion

Using the data pertaining to your group, plot the following graphs:

1. Penetration vs. water content for determination of normal consistency
2. Penetration vs. time for detecting the initial time of set

Answer the following questions related to above experiments:

3. Is the measured normal consistency lies in the range for the Portland cements?
4. Is the time of set of the cement satisfactory?
5. What are the factors affecting time of set?
6. What is meant by unsound Portland cement?
7. What is the difference in meaning of the two words "setting" and "hardening"?
8. What is the significance of time of set?

LABORATORY 2: Mechanical Properties of Portland Cement Mortar

Introduction

Compressive strength of any given cement sample is determined on the cubical specimens of 50 mm size made of mortar prepared by mixing together the water, the cement sample, and the standard sand in a specified proportion. The specimens are cured in a water tank and then taken out for the determination of compressive and flexural strength using a compression testing machine, at various ages such as: 3 days, 7 days, and 28 days. Compressive strength test is one of the important tests on cement and is carried out to make sure that the measured strength of cement is in compliance with the strength requirement at a particular age.

Tensile strength is determined by testing the standard briquettes made of mortar prepared in the same way as for the compressive strength. Tensile strength test on mortar is not practically relevant. However, it is useful for explaining the fact that the brittle materials, like set cement-mortar, have a very less tensile strength as compared to its compressive strength.

Objective

The objective of this laboratory is to:

- Determine compressive, flexural and tensile strengths of a of Portland cement mortar.

Applicable Standards

- Compressive Strength: ASTM C349, ASTM C109
- Flexural Strength: ASTM C348

Apparatus

1. Compression testing machine and briquettes tensile testing machine as shown in **Figure 2.1** and **Figure 2.2**
2. Mixing Equipment: Balance, Mixing Bowl, 250 ml Graduated Cylinder, Trowel and Scoop
3. Cube moulds with base plates and briquettes moulds with base plates
4. Ordinary Portland Cement

Figure 2.1: Mortar Compression and Flexural testing machine

Figure 2.2: Briquettes Tensile testing machine

Procedure

Sample Preparation

Each group will prepare three briquettes, three cubes and three prisms in accordance with the following Table shown below:

Group	Assigned W/C Ratio	Specimen		
		No of briquette	No of cube	No of Prism
I	0.4	3	3	3
II	0.45	3	3	3
III	0.50	3	3	3
IV	0.55	3	3	3

Cement to sand ratio for mortar to be used for preparing briquette: 1: 3.00 (by mass)

Cement to sand ratio for mortar to be used for preparing cubes: 1: 2.75 (by mass)

Preparation of Briquette

1. Weigh the cement and the sand separately so that the total weight of dry material is 600 gm (150 gm cement, 450 gm sand). Use a balance to measure the weight of mixing water so that the water-cement ratio is 0.4, 0.45, 0.5 or 0.55.
2. After that, follow the steps for mixing the ingredients shown below:
   i. Place the water in a dry bowl
   ii. Add cement to the water and mix for 30 sec
   iii. Add approximately one-half of the sand and mix for 30 sec
   iv. Add the remainder of the sand and mix vigorously for 2 min
3. Immediately after mixing, fill the moulds heaping full without compacting while resting on an unoiled metal base plate. Then press the mortar in firmly, using both thumbs simultaneously. Apply this pressure 12 times to each briquette over the entire surface, then heap the mortar above the mould and smooth it off with a trowel. Cover the mould with an oiled base plate, turn the mould upside down and remove the unoiled base plate. Repeat the operation of heaping, thumbing and smoothing off.

Preparation of Cube

1. Weigh the cement and the sand separately so that the total weight is 1125 gm (300 gm cement, 825 gm sand). Use a balance to measure out the mixing water so that the water-cement ratio is 0.4, 0.45, 0.5 or 0.55.

2. Mix the ingredients following the same procedure as for the cubes, described above.

3. The cube and prism moulds cleaned and oiled, should be filled in three layers and vibrated on vibrating machine till the slurry comes over the surface.

Curing the Samples

All specimens will be moist cured for one day and after moist curing the specimens will be water cured for six more days. Testing will be done after seven days.

Testing the Samples

Testing Briquette

1. Remove the briquette specimens from the curing tank and test as soon as possible and keeping all samples covered with a damp cloth until tested.

2. Measure the width and thickness of each specimen before testing.

3. Wipe each briquette to a surface-dry condition and remove loose particles from the surface.

4. Carefully center the briquettes in the test machine clips and apply the load carefully.

   Record the maximum load indicated by the testing machine.

Testing Cube and prism

1. Remove the specimens from the water bath and test as soon as possible, keeping all specimens covered with a damp cloth until tested.

2. Measure the critical cross-sectional dimensions.

3. The cubes should be placed in the testing machine after the removal of loose particles from the surface.

4. Apply the load at a constant rate of 4.5 kN/sec (0.2 MPa/sec BS or 0.15 MPa/sec ASTM standard) so that the maximum load will be read within 20 to 30 seconds. Record the maximum load indicated by the testing machine.

5. Remove the broken cube from the testing machine and observe the apparent angle between the failure surface and the base of the cube.

Report and Discussion

1. Compile the test results of all the groups in the following tabular form:

Compressive Strength, f_c' Test Results obtained through Cubes Testing

Group	W/C	Load, kN				f_c', MPa
		Sample 1	Sample 2	Sample 3	Average Load, kN	
I	0.40					
II	0.45					
III	0.50					
IV	0.55					

Flexural Strength, σ_f Test Results obtained through Prisms Testing

Group	W/C	Load, kN				σ_f, MPa
		Sample 1	Sample 2	Sample 3	Average Load, kN	
I	0.40					
II	0.45					
III	0.50					
IV	0.55					

Tensile Strength, f_t Test Results obtained through Briquettes Testing

Group	W/C	Load, kN				f_t, MPa
		Sample 1	Sample 2	Sample 3	Average Load, kN	
I	0.40					
II	0.45					
III	0.50					
IV	0.55					

2. Using the above data plot the following graphs:
    - f_c' vs W/C Ratio
    - f_t vs W/C Ratio
    - $f_t / \sqrt{f_c'}$ vs W/C Ratio
3. Discuss the effect of W/C ratio on:
    - f_c'
    - f_t
    - $f_t / \sqrt{f_c'}$
4. Discuss the field significance of compressive and tensile strength of cement mortar.

LABORATORY 3: Physical Characteristics of Coarse and Fine Aggregate

Introduction

Particle size distribution (i.e., gradation), specific gravity, absorption capacity, loose and rodded unit weights are among the important characteristics of coarse and fine aggregate used for making concrete.

Grading or particle size distribution is the most important physical characteristics of aggregates. It is determined through sieve analysis, which is a process of dividing a sample of aggregate into fractions of same particle size. Results obtained through the sieve analysis are used to plot the grading curves (i.e., a plot of sieve size vs. percentage passing). Grading of coarse aggregate affects the various important aspects, such as: relative aggregate proportion (i.e. Fine Aggregate/Coarse Aggregate ratio), cement and water ratio, workability of fresh concrete, uniformity of concrete from batch to batch, porosity, shrinkage, and durability of hardened concrete, and economy in concrete production.

Grading of a given sample of coarse aggregate is carried out in order to know whether the aggregate under consideration is in compliance with the grading requirements or not.

Absorption capacity of coarse aggregates affects the water/cement ratio. Therefore, this test is important to make sure that effective or actual w/c is maintained according to requirement.

The test results on *specific gravity and unit weight* of aggregates are required during concrete mix proportioning.

Objective

The objective of this laboratory is to:

- Determine the particle size distribution (i.e., grading), loose and rodded unit weights, water absorption, and specific gravity of given samples of coarse and fine aggregate.

Applicable Standards

- Sieve analysis of fine and coarse aggregate: ASTM C136
- Bulk density or unit weight of aggregate: ASTM C128
- Relative density and absorption of coarse aggregate: ASTM C29

Apparatus

1. Set of standard sieves of the following sizes: 3/4", 1/2", 3/8", No. 4 and No. 8 with pan and cover.
2. Mechanical shaker as shown in **Figure 3.1**
3. Weighing scales sensitive to 1 gm.
4. Weighing pan
5. Standard 1/10 cu. ft. measuring bucket
6. 5/8 in. diameter tamping rod
7. Scales sensitive to 1 gm.
8. Air dry coarse aggregate
9. Saturated coarse aggregate

Figure 3.1: Mechanical shaker

Procedure

Particle Size Distribution (Coarse Aggregate)

1. Take 5 kg representative sample of coarse aggregate by the quartering process. (Care must be taken to avoid loss of fine material). Weigh this sample to the nearest 1 gram.
2. Weigh each sieve empty and then put the sieves in order of decreasing size of opening from top to bottom. Now place the weighed sample on the top sieve. Shake the sieves by the mechanical shaker for 5 minutes. Check by shaking each sieve by hand for 15 sec.
3. Assemble sieves in following order:

   Coarse aggregate: 25, 19, 12.5, 9.5, 6.3, 4.75 mm and pan

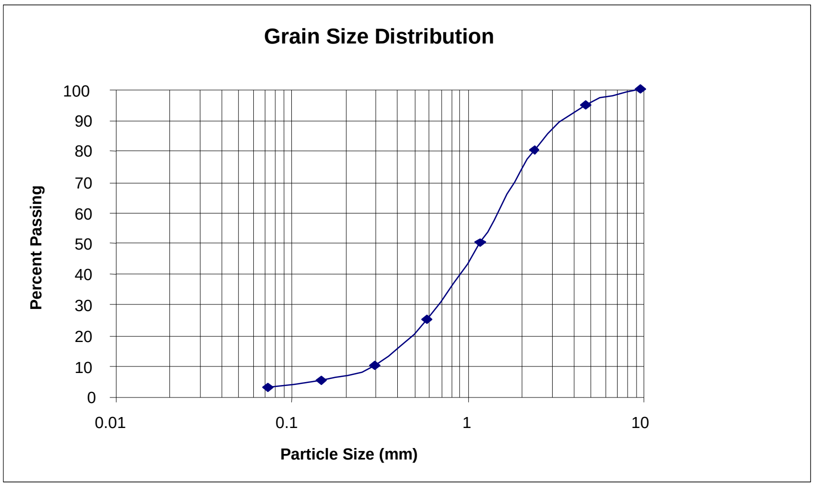
4. Weigh the material retained on each sieve. To do this, weigh the sieve with the retained material. Subtract the empty sieve weight from this total weight to obtain the weight of aggregate retained on a given sieve.

Particle Size Distribution (Fine Aggregate)

5. Obtain proper weight of dry aggregate
   Fine aggregate: 400 grams
6. Assemble sieves in following order:

   Fine aggregate: 8" diameter size sieves, #8, #16, #30, #50, #100, #200 and pan

7. Place the aggregates in the top of the sieve stack and cover with the lid. Properly secure the sieves in the mechanical shaker and turn on the shaker for five minutes.
8. Weigh the materials that are retained on each of the sieves, including the weight retained on the pan, and record on the data sheet. If the sum of these weights is not within 0.1% times the number of sieves used (0.6%) of the original sample weight, the procedure should be repeated. Otherwise, use the sum of the weight retained in the pan to calculate the percentage retained on each sieve.
9. Compute the cumulative percent retained on, and the percent passing each sieve. Plot the gradation curves for the fine aggregates from the experiment on the gradation chart as shown below in the example plot below.
10. Compute the Fineness Modulus for the fine aggregate.



Loose and Compacted Unit Weight of Coarse Aggregate

Loose Unit Weight

1. Find out the volume of the yield bucket (V) by completely filling it with water and then finding out the weight of water, W_w.

$$W_w = \gamma \text{ x } V$$

Where; V = Volume of bucket in cm^3

γ = unit weight of water (1 gram/ cm^3)

W_w = weight of water which fills the bucket completely

V = $W_w/1 = W_w$ (gram)

2. For loose unit weight of aggregate, fill the bucket loosely with the representative sample of Coarse Aggregate and find out the weight, W_L(gram) of loose Coarse Aggregate;

$$W_L = \gamma_L \text{ x } V$$

$$\gamma = \frac{W_L}{V}$$

Where; W_L = weight of Coarse Aggregate which fills the bucket loosely

V = volume of Coarse Aggregate, volume of weighing bucket in cm^3

γ_L = unit weight of loose Coarse Aggregate (1 gram/ cm^3)

Compacted Unit Weight

1. Find out the volume of weighing bucket, V (cm^3)

2. Fill the bucket one-third full, level the surface and tamp it with standard rod using 25 strokes, evenly distributed. The second and third layer should be placed and compacted in the same way taking care not to touch the previously compacted layer. When, placing and compacting is complete the bucket is exactly level full of Coarse Aggregate.

3. Weigh the bucket full of compacted aggregate, W_c(gram)

$$W_c = \gamma_c \text{ x } V$$

Where; V = Volume of compacted Coarse Aggregate bucket in cm^3

γ_c = Compacted unit weight of Coarse Aggregate (1 gram/ cm^3)

W_c = weight of compacted Coarse Aggregate (gram)

γ_c = W_c/V (gram/cm^3)

Absorption Capacity (30 min) and Specific Gravity of Coarse Aggregate

Absorption is related to the increase in the weight of aggregate due to absorption and retention of water in the pores of aggregate but excluding the water adhering to surface of particles and is generally expressed as percentage of dry weight.

30-min. Absorption for Coarse Aggregate

1. Take a completely dry representative sample of Coarse Aggregate and weigh it (W_1).

2. Soak it completely by immersing it in water for 30 minute.

3. Take out the aggregate from the water carefully and make its surface dry by rolling it in a large absorbent cloth or towel so that there are no traces of water on the surface and all visible films of water are removed and it is in saturated surface dry (SSD) condition and then find out its weight W_2.

4. Dry the sample at a temperature of 110 ± 5°C to a constant weight and then weigh it as W_3.

$$\text{30-min. Absorption Capacity} = \frac{W_2 - W_3}{W_3} x100\%$$

Specific Gravity

1. Repeat the steps as in absorption test and obtain W_2.

2. After weighing, immediately place the aggregate (SSD) sample in the special container and determine the weight in water. Consider this weight as W_4.

3. Dry the sample to a constant weight at a temperature of 110 ± 5°C and then weigh it as W_3.

4. Then, determine the apparent specific gravity, bulk specific gravity, bulk specific gravity (SSD).

   Bulk Specific Gravity = $W_3 / (W_2 – W_4)$

   Bulk Specific Gravity (SSD) = $W_2 / (W_2 – W_4)$

   Apparent Specific Gravity = $W_3 / (W_3 – W_4)$

<u>Absorption Capacity and Specific Gravity of Fine Aggregate (sand)</u>

1. Obtain approximately 1 kg air dry fine aggregate and put in a flat metal pan.

2. Bring the aggregate to SSD condition. To speed up the process of obtaining the SSD sand, a procedure slightly different from that used by the ASTM standard test C128 is used. Sprinkle a few drops of water on the air dry sand and thoroughly mix. Hold the conical mold firmly on the flat metal pan with the large diameter down. Place a portion of the sand loosely in the mold by filling it to overflow then heap additional sand above the top of the mold. Lightly tamp the sand into the mold with 25 light drops of the tamping rod. Start each drop about 0.2 in. above the top of the sand. Permit the rod to fall freely on each drop. Adjust the starting height to the new surface elevation after each drop and distribute the drops evenly over the surface. Clean loose sand around from around the base and remove the mold by lifting it vertically. When the sand slumps slightly it indicates that it has reached a surface dry condition. If the sand retains the mold shape, it indicates the sand is in a wet condition.

3. Take approximately 400 g of the SSD aggregate. Record exact weight of SSD sample (D).

4. Fill the flask with water to 500-ml mark and record weight of water and flask in grams (B). The water temperature should be about 73 ± 3oF (23 ± 1.5oC).

5. Empty water in flask and add the entire SSD sand sample to the flask. Fill flask with water to about 1/2 in. above the aggregate. Apply vacuum and rolling action to eliminate the air entrapped in the aggregate. This will take at least 5 minutes.

6. Fill the flask with water up to 500-ml mark. Record total weight (grams) of flask plus water plus aggregate (C).

7. Calculate the Bulk Specific Gravity (SSD) based on the weights B, C, D, and compare the calculated value with the typical value to ensure that the data obtained is accurate.

8. Pour entire contents of flask into a pan and place in oven (party must record the number of their pan). Additional tap water may be used as necessary to wash all aggregate out of the flask. Return next day to measure the weight of the oven-dry aggregate (A).

9. From the above data, calculate specific gravity values and absorption as defined below:

   Apparent Specific Gravity (DRY) = A / (B+A-C)

   Bulk Specific Gravity (DRY) = A / (B+D-C)

   Bulk Specific Gravity (SSD) = D / (B+D-C)

   Absorption = (D-A) / (A) x 100%

Result

Particle Size Distribution (Coarse Aggregate)

Weight of Sample = ______________ g

Sieve size (mm)	Sieve size (inch)	Weight of aggregate retained (g)	Cumulative weight retained (g)	Cumulative percent retained (%)	Cumulative percent passed (%)
25	1	a =	a	(a / W) x 100	100 - (a / W) x 100
19	3/4	b =	a + b	[(a + b) / W] x 100	100 - [(a + b) / W] x 100
12.5	1/2	c =			
9.5	3/8	d =			
6.3	1/4	e =			
4.75		f =	a+b+c+d+e+f	[(a+b+c+d+e+f)/W]x100	100-[(a+b+c+d+e+f)/W]x100
Pan		g =			

Particle Size Distribution (Fine Aggregate)

Weight of Sample = _____________ g

Sieve size (mm or microns)	Sieve size (No.)	Weight of aggregate retained (g)	Cumulative weight retained (g)	Cumulative percent retained (%)	Cumulative percent passed (%)
2.38 mm	8	a =	a	(a / W) x 100	100 - (a / W) x 100
1.19 mm	16	b =	a + b	[(a + b) / W] x 100	100 - [(a + b) / W] x 100
595 µm	30	c =			
297 µm	50	d =			
149 µm	100	e =			
74 µm	200	f =	a+b+c+d+e+f	[(a+b+c+d+e+f)/W]x100	100-[(a+b+c+d+e+f)/W]x100
Pan		g =			

Unit Weight of Loose Coarse Aggregate

Weight of Water, W_w	g
Volume of Bucket, V	cm^3
Weight of Loose CA in Bucket, W_L	g
Volume of Loose CA in Bucket, V	cm^3
Unit Weight of Loose Coarse Aggregate	g/ cm^3

Unit Weight of Loose Coarse Aggregate = ___________________ g/ cm^3

Unit Weight of Compacted Coarse Aggregate

Weight of Compacted CA in Bucket, W_L	g
Volume of Compacted CA in Bucket, V	cm^3

Unit Weight of Compacted Coarse Aggregate = ___________________ g/ cm^3

Absorption Capacity (Coarse Aggregate)

Weight of CA,W_1		g
Weight of SSD CA,W_2		g
Weight of Dry CA,W_3		g

Absorption Capacity of Coarse Aggregate = ____________

Specific Gravity (Coarse Aggregate)

Weight of SSD CA in water,W_4		g

Specific Gravity of Coarse Aggregate = ____________

Absorption Capacity and Specific Gravity of Fine Aggregate (sand)

Weight of SSD sand, D		g
Weight of SSD sand, water & flask, B		g
Weight of SSD sand, added water & flask, C		g
Weight of Dry sand, A		g

Apparent Specific Gravity (dry) of sand =

Bulk Specific Gravity (dry) of sand =

Bulk Specific Gravity (SSD) of sand =

Absorption of sand =

Report and Discussion

1. Tabulate the sieve analysis test results and calculate the percent retained, the cumulative total percent retained and percent passing for each sieve size.
2. Plot the aggregate gradation on a graph paper.
3. Answer the following questions:

   a) What is meant by "good" grading?

   b) In what sizes of particles is coarse aggregate deficient or oversupplied? (Compare with ASTM Limits)

c) What is the difference between bulk and apparent specific gravity?

d) Discuss the significance of the absorption value.

e) What would be the effect upon the unit weight if coarse aggregate is placed in the bucket without rodding or compacting (loose condition)?

LABORATORY 4: Properties of Concrete Paste (Workability)

Introduction

The variation in *fine to coarse aggregate ratio* in preparing a concrete mix, at a fixed water/cement ratio and slump, has significant effect on the required quantities of cement, fine aggregates, and coarse aggregates, and therefore, ultimately affects the cost of concrete.

The fine to coarse aggregates ratio, at a desirable water/cement ratio and slump, may be optimally selected through different trial mixes by varying [me to coarse aggregate ratio while maintaining the desirable water/cement ratio and slump constant. Through this laboratory exercise, a considerable amount of money can be saved without compromising with the required water/cement ratio and slump of the concrete mix.

Objective

The objective of this laboratory is to:

- Select an optimal fine to coarse aggregate ratio at a specified water/cement ratio and slump of the concrete mix.

Apparatus

1. Weighing scales sensitive to 1 gram
2. Mixing pan (22" x 22")
3. Weighing pan
4. Trowel
5. Scoop
6. 1000 ml graduated cylinder
7. Slump cone with 5/8" tamping rod, ruler and base.
8. Yield bucket
9. Cement, coarse aggregate, fine aggregate, water

Procedure

Trial Mix

Four trial mixes having different fine to coarse aggregate ratios (FA/CA) as given in the following table, will be considered. For each mix, following items will be constant:

Total quantity of fine and coarse aggregates (FA + CA) = 14 kg

Slump = 5 to 8 cm (to be maintained by using super plasticizer)

Mix No.	FA/CA ratio (Percent by weight)	Weight of FA (kg)	Weight of CA (kg)
I	40	4.00	10.00
II	50	4.66	9.34
III	60	5.25	8.75
IV	70	5.76	8.24

Preparation of Trial Mixes and determination of their Unit Weights

1. Weigh the fine and coarse aggregates to the nearest gram, using air-dry aggregates from the laboratory bins. Record all weight.
2. Spread the coarse and fine aggregates in even layers in the mixing pan.
3. Weigh out 2.8 kg cement and spread on top of the aggregates in the mix pan. Mix the dry ingredients by hand until a uniformed mixture is obtained.
4. Now add 1.4 kg water (W/C ratio = 0.5) gradually to the dry mixture and mix thoroughly.
5. Make a slump test of this mixture, if the slump is not between 5 to 8 cm add more water and cement but maintain the W/C ratio = 0.5 until the slump reach. For example, if more water and cement needed, return all of the mix to the pan and add one or more increments of 300 gram cement and 150 ml water.
6. Remix and determine the slump again. Repeat this process until the slump reach in between 5 to 8 cm. All data will be taken on this mix.
7. Calibrate the special bucket by finding the weight of water to fill it completely full. Record the weights of the bucket, empty (W_1) and full of water (W_2). The volume is

$$V(cm^3) = W_2 - W_1$$

8. Use a scoop to fill the yield bucket with the final concrete mix in 3 equal layers. Tamp each layer 25 times to remove entrapped air, smooth off the top evenly, clean off the concrete from the sides of the bucket, and weigh it to find out the weight of concrete ($W_{c\text{-}b}$) contained in it by subtracting the empty bucket. The unit weight of the concrete mix is then;

$$\gamma_{conc} = W_{c\text{-}b} / V_b \text{ or } W_{conc} / V_{conc} \ (g/cm^3)$$

or $$\gamma_{conc} = W_{c\text{-}b} / (W_2 - W_1) \ (g/cm^3)$$

where;

$W_{c\text{-}b}$ = weight of the concrete in the bucket

W_{conc} = total weight of the concrete

Calculations

Total Mix Volume, V_{conc} (cm^3)

$$V_{conc} = (W_c + W_a + W_{fa} + W_{ca}) / \gamma_{conc}$$

where;

W_c, W_a, W_{fa} and W_{ca} are total weights of cement, water, fine aggregate and coarse aggregate respectively.

Weight of each ingredient, (g/cm^3)

$$\text{Cement}, C = W_c / V_{conc}$$

$$\text{Water}, W = W_w / V_{conc}$$

$$\text{(Fine Aggregate)}, FA = W_{FA} / V_{conc}$$

$$\text{(Coarse Aggregate)}, CA = W_{CA} / V_{conc}$$

Change all values to kg/m^3 by multiplying with 1000

Report and Discussion

1. Summarize all data from all mix no into the table shown below:

Mix No.	FA/CA ratio (% by weight)	Slump (cm)	γ_{conc}	C (kg/m^3)	W (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)
I							
II							
III							
IV							

2. Plot a graph FA/CA ratio vs. C and obtain the optimum FA/CA ratio, corresponding to the minimum C.

3. Consider the following relevant items:

   a) Draw conclusion from your results regarding optimum FA/CA ratio

   b) Approximately what differences in strength would you expect between the four mixes

   c) Why it is preferable to select the mix giving the greatest yield?

   d) Determine weights of each of the ingredients per cu. m. (cement, water, fine aggregate and coarse aggregate) corresponding to FA/CA ratio.

4. Compute cost of concrete per cubic meter of field mix, assuming following unit prices:

   a) Cement - 12 SR per 50 kg/bag

   b) Fine Aggregate - 10 SR/m^3 (Unit Weight = 1800 kg/m^3)

   c) Coarse Aggregate - 50 SR/m^3 (Unit Weight = 1600 kg/m^3)

LABORATORY 5: Properties of Hardened 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:

Tensile strength of concrete is found to be proportional to its compressive strength. It is determined either using a flexure test on beam specimens or using a split cylinder test on cylindrical specimens. Although the tensile strength of concrete is of no practical relevance, it is determined to show how a brittle material like concrete has very low tensile strength as compared to its very high compressive strength.

Modulus of elasticity of concrete is another very important property of hardened concrete. It is obtained through testing cylindrical specimens. The stress applied and resulting deformation in the specimens are plotted and then using the stress-strain curve, the modulus of elasticity is determined. Modulus of elasticity test on concrete is required for calculating deflection and for predicting shrinkage cracking.

Objective

The objective of this laboratory is to:

- Determine compressive strength of concrete and its variation with water/cement ratio, curing, age, and shape of specimens.
- Determine tensile strength and modulus of elasticity of hardened concrete.

Applicable Standards

- Compressive strength: ASTM C39
- Splitting Tensile strength: ASTM C496
- Modulus of elasticity: ASTM C469

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.
8. Vibrating table
9. Calliper, 12-in steel scale
10. Compressometer
11. Compression testing machine
12. Steel Mould (cylinder 75 x 150 mm and 150 x 300 mm, Cubic 100 x 100 x 100 mm)
13. Cement, graded coarse aggregate, fine aggregate, water

Procedure

Samples to be Prepared

For compressive strength of concrete and its variation with water/cement ratio, age, curing, and shape of specimen, students will be divided into four groups. For this purpose, four water/cement ratios which are 0.45, 0.50, 0.55, and 0.60; three curing period which are 3 days, 7 days, and 28 days; two types of curing (air curing and water curing) and two shapes (cylindrical and cubical) will be considered.

Each group will separately consider an assigned water/cement ratio and cast a total number of 15 cylinders of size 75 mm x 150 mm. After de-moulding, all of the 15 cylinders will be submerged in water curing. After 3-day curing, 3 specimens will be tested for compressive strength and a set of three cylinders will be taken out from the curing tank and will be exposed to the normal lab condition and the other set of nine cylinders will remain in tank for further curing. At the age of 7 days, 3 cylinders will be tested for compressive strength and 3 shall be kept in air. The remaining three cured cylinders will be tested for compressive strength at the age of 28 days.

For comparing the 7-day compressive strengths of cubical specimens with the 7-day compressive strengths of cylindrical specimen, 3 cubical specimens of 100 mm x 100 mm will be jointly cast (water/cement ratio = 0.50) and tested for compressive strength at the age of 28 clays.

For tensile strength, three cylinders of 150 mm x 300 mm will be jointly cast (water/cement ratio = 0.50) and tested at the age of 7 days.

For modulus of elasticity, three cylinders of 150 mm x 300 mm will be jointly cast (water/cement ratio = 0.50) and tested at the age of 7 days.

<u>Preparation of Samples</u>

1. Sieve the coarse aggregate to get the following percentages of weights for different sieve sizes.

Sieve Size	Retained Percent	Passing Percent	Quantity (kg)
1”	0.0	100.0	0
3/4”	5.0	95.0	1.00
1/2”	57.5	37.5	11.50
3/8”	30.0	7.5	6.00
3/16”	5.0	2.5	1.00
3/32”	2.5	0.0	0.50
Total =			20.00

2. Use FA/(CA + FA) ratio of 0.35. Hence weight of sand = 10.770 kg.

3. Use 6.155 kg of cement, aggregate/cement ratio = 5.0

4. Use water/cement ratio as given below:

Group	W/C	Water (kg)
I	0.45	2.770
Il	0.50	3.080
III	0.55	3.385
IV	0.60	3.693

5. Each group will prepare a concrete mix with its assigned water/cement ratio and the above mentioned quantities of materials using the mixer. Make a slump test and record the values.

6. Each group will cast fifteen 75x 150mm. dia. cylinders of concrete by compacting on a vibrating table.

7. Jointly prepare three 150 mm cubes, three 100 mm cubes, and six 150 mm x 300 mm cylinders using a mix with water/cement ratio of 0.50.

8. Put the cast specimens in a safe place and de mould them on the next day. Cure the specimens by immersing in water tank until the day of testing or depending upon the age of curing in air.

9. Test the specimens for compressive strength, tensile strength, and modulus of elasticity, according to the program mentioned above.

Compressive Strength Testing of Cylindrical Specimens

Test the cylinder 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 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.

Splitting Tensile Strength Testing of Cylindrical Specimens

Test the three cylindrical specimens for tensile strength by adopting the following steps:

1. Remove the cylinder specimens from the water tank and test in moist condition.

2. For each cylinder measure the length (l) and diameter (d) of the cylinders to the nearest 0.01 inch. Draw diametral lines on each end of the specimen using the callipers and steel rule to ensure that they are on the same axial plane.

3. To position the specimen, align and center the specimen on the two plywood strips so that the lines marked on the ends of the specimen are vertical and centered.

4. Load the specimen continuously and without shock at the rate of 100 to 200 psi/minute (corresponding to about 11,300 to 22,600 lb/minute). Do not increase the rate of loading when the specimen starts to yield.

5. Record the maximum applied load (P) and type of fracture.

6. Calculate the splitting tensile strength $f_t = 2P/\pi ld$

Modulus of Elasticity Testing of Cylindrical Specimens

Test the three cylindrical specimens for modulus of elasticity by adopting the following steps:

1. Study the action of the compressometer, note its gauge length (6") between top and bottom clamping screws, multiplication ratio, and determine the strain corresponding to the least reading of the dial. Attach the compressometer to the central portion of the specimen and then remove the spacer bars.

2. As in previous tests, center the specimen in the testing machine.

3. Adjust the compressometer dial to read zero.

4. Apply a preliminary load up to about 2/5 of the estimated ultimate load for the specimen, at a speed of about 35 psi/sec. and then release the load. This is done primarily to seal the gauge.

5. Reset the compressometer gage and then apply load continuously at a speed of about 10 psi/sec, reading the compressometer after each increment of about 1/12 of the estimated ultimate load. (The f_c' of 3 inch cylinders may be taken as a guide value). Record the loads and corresponding compressometer readings for plotting stress - strain curve.

6. Remove the compressometer at about 3/4 the estimated ultimate load.

7. Strain = Deformation/gauge length = $\frac{ObservedValue \times MultiplicationRatio}{GaugeLength}$

   Stress = load in kN x 1000/3.14 x 75^2

Report and Discussion

Compressive Strength

1. For each test, report the results as follows:

Specimen No.	Age (Days)	Load (kN)	Compressive Strength (MPa)
1 2 3			

2. Also report the results as follows:

W/C Ratio	Curing Period (Days)		Average f_c' (MPa)
	Moist	Dry	

3. Plot the following results:

   a) Compressive strength vs. W/C ratio - three curves on same graph paper (1 for 7-day moist curing, 1 for 14-day moist curing, and 1 for 21-day moist curing). This plot will show the variation of compressive strength with water/cement ratio and the age.

   b) For any water/cement ratio plot the compressive strength vs. type of curing - two curves on same graph paper (1 for moist curing and 1 for dry curing). This plot will show the variation of compressive strength with the type of curing.

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 is the effect of moist curing on the strength of concrete?

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

e) What relative compressive strengths would you have obtained in your test if 150mm cubes had been used in place of 150 x 300mm cylinders?

f) Discuss the fracture shape of your test cylinders for compressive strength.

Splitting Tensile Strength

Compare the tensile strength with compressive strength of concrete, cast with same water/cement ratio to see how smaller is the tensile strength as compared to the compressive strength of the same concrete.

Modulus of Elasticity

1. Plot the stress versus strain to obtain stress-strain curve for each of the three cylinders.
2. Determine the corresponding modulus of elasticity E_c, as Secant Modulus at 0.5 f_c' in psi. Average the three values to get an averaged E_c.
3. Compare your average E, with that obtained from

   $E_c = 57000\sqrt{f_c'}$ (lb/inch^2)

   $E_c = 5000\sqrt{f_c'}$ (MPa)

   f_c' = average compressive strength of the three cylinders after 28 days in lb/inch^2 or MPa.
4. Discuss the difference, if any, between the two values.
5. How is the modulus of elasticity affected by age?
6. What are the limitations of the size (minimum dimensions) of the specimen with respect to the maximum size of aggregate?

LABORATORY 6: Tension Test on Metal

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:

- make the student understand how the tensile test is performed practically and to develop an understanding of basic stress-strain relationships.
- how these are related to the behavior 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 6.1**) we can determine the following properties:

- ***The proportional limit (P.L),*** $\boldsymbol{\sigma_p}$: The value of stress beyond which the material is not linearly elastic (i.e. * Eε 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 6.1 a**). However, some high carbon steels do not exhibit well defined yielding plateau (**Figure 6.1b**). 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.

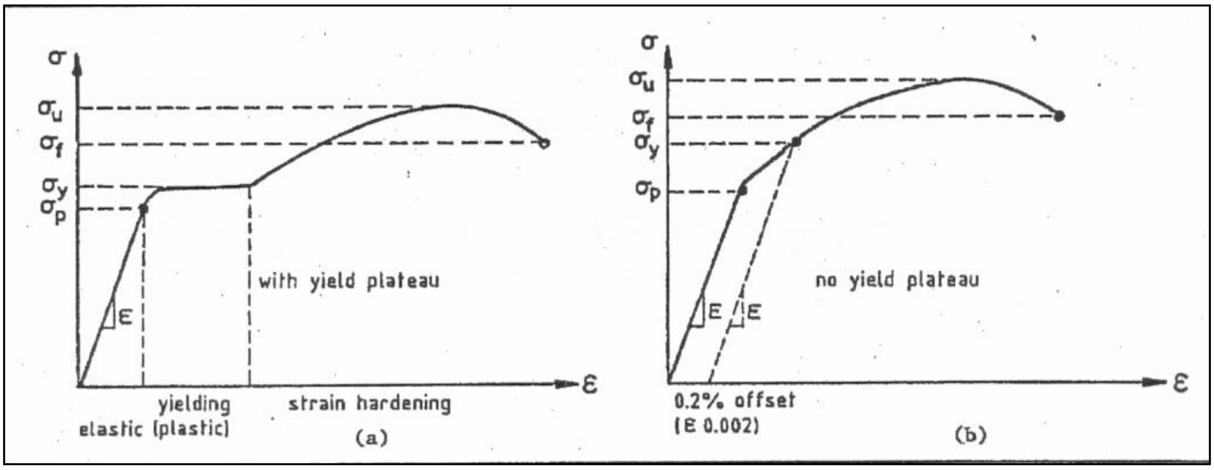


Figure 6.1: Typical stress-strain curves

- ***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 6.2.**

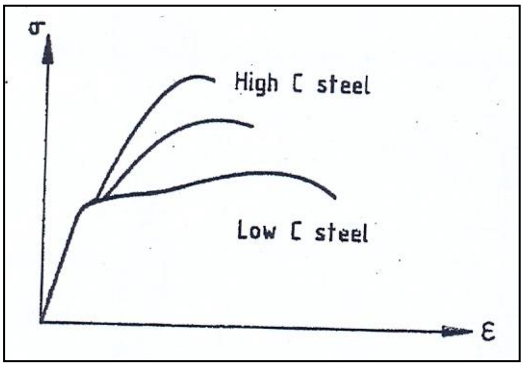


Figure 6.2: Effect of amount of carbon on ultimate strength

- ***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) (**Figure 6.3**)

= $\pi d_f^2/4$

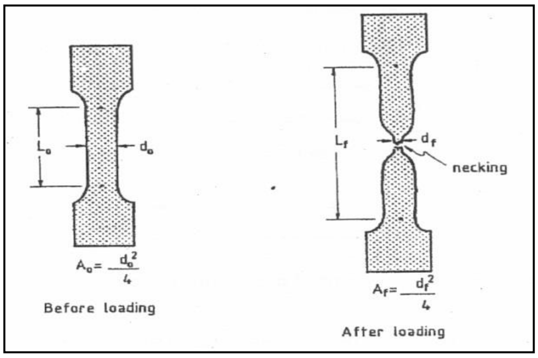


Figure 6.3: Initial and final cross-sectional areas

- ***Poisson's Ratio.v*** : It is the ratio of the lateral (transverse) strain to the longitudinal strain for uniaxial loading (**Figure 6.4**)

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

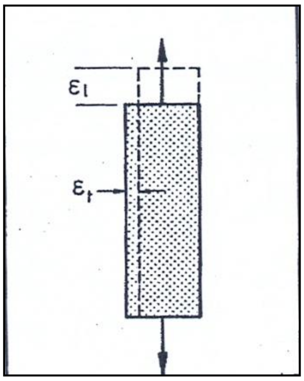


Figure 6.4: Lateral and longitudinal strain in a uniaxially loaded specimen

- ***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 6.5**). Materials which exhibit little or no plastic deformation are ***brittle materials*** such as concrete under tension (**Figure 6.5**).

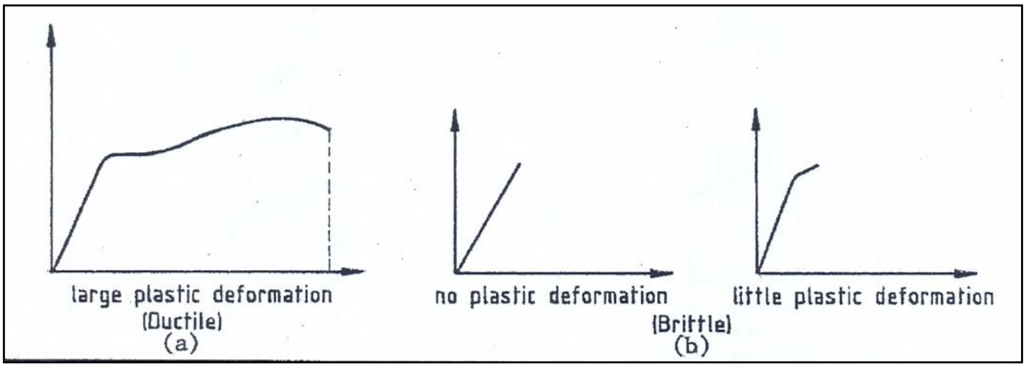


Figure 6.5: Ductile versus brittle materials

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 6.6**)

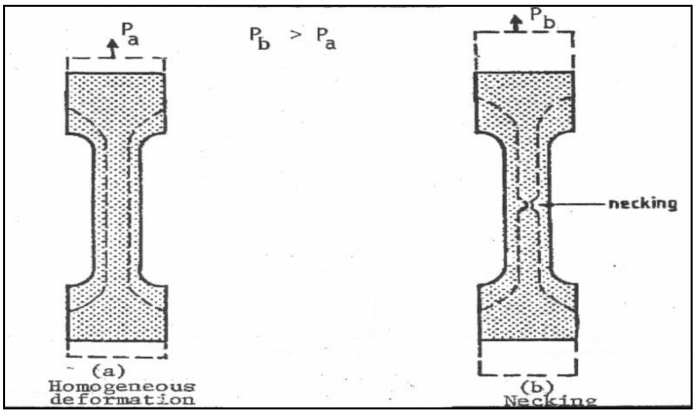


Figure 6.6: Necking phenomena in tensile specimens

- ***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 6.7**.

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

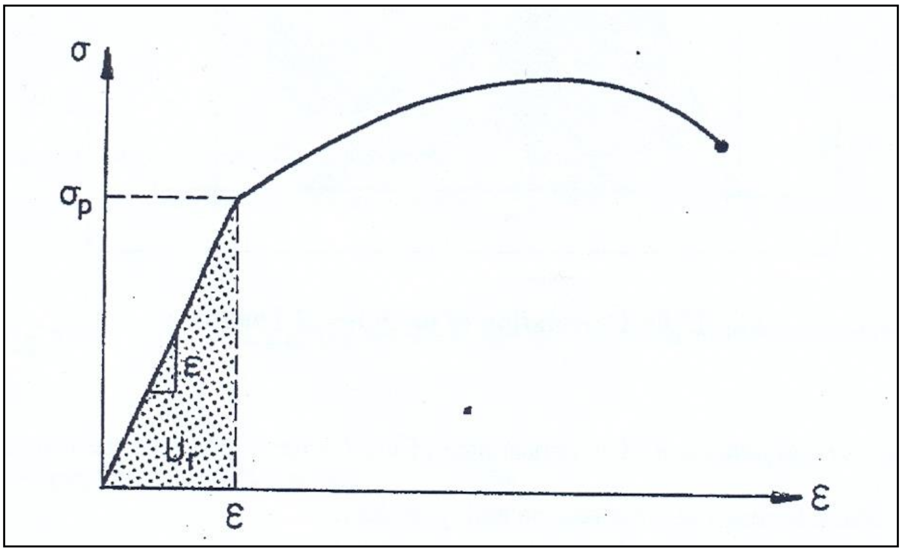


Figure 6.7: Calculation of modulus of Resilience

- ***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 6.8.** 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.

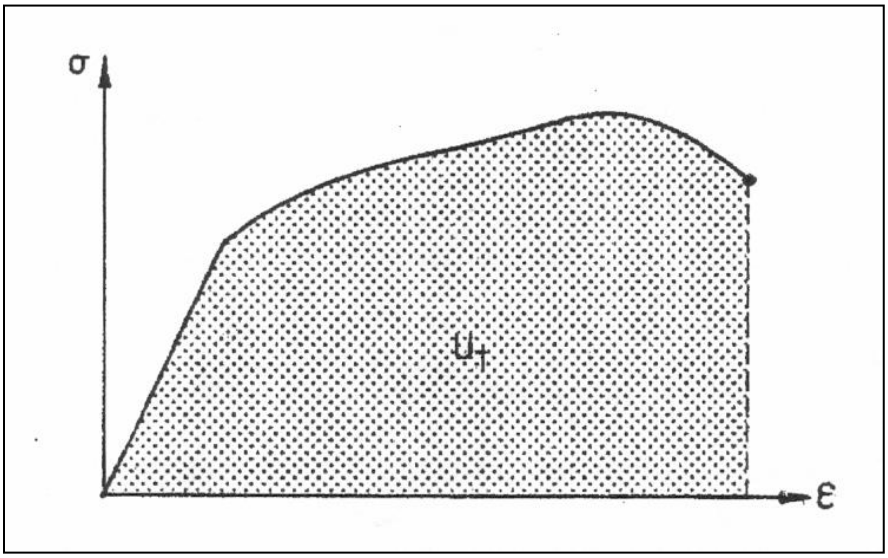


Figure 6.8: Calculation of modulus of Toughness

- ***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 which is 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 6.9**
2. Gauge length marker
3. Micrometer / venire caliper
4. High Tensile steel / Mild steel

Figure 6.9: 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 micrometer.
3. Fix the specimen in the testing machine (use 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.

8. How do the values of 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?