

# 53:086 Civil Engineering Materials

Spring 2008

## Student Laboratory Manual



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**53:086 Civil Engineering Materials  
Spring 2008**

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**Lab Schedule:**

<b>Week of:</b>	<b>Lab Activity</b>
1/22-1/25	<b>No Lab</b>
1/28-2/1	Introduction – Set up groups
2/4-2/8	1.1 Tensile Testing of Structural Metals
2/11-2/15	1.2 Torsion Testing of Structural Metals
2/18-2/22	1.3 Charpy Impact Test <sup>1</sup> PCA: PCC Mix Design
2/25-2/29	2.1 Sieve Analysis and Specific Gravity of Aggregates*
3/3-3/7	2.2 Portland Cement Concrete Mixing and Initial Tests*
3/10-3/14	2.3 PCC 7-day Compression Test
3/17-3/21	<b>SPRING BREAK</b>
3/24-3/28	2.4 PCC Tensile Strength (Split-cylinder & 3-point bend)
3/31-4/4	2.5 PCC 28-day Compression Test <sup>2</sup>
4/7-4/11	3.1 Asphalt Binder Test*
4/14-4/18	3.2 Asphalt Mixing; Gyrotory Compaction; Specific Gravity & Strength Tests*
4/21-4/25	<b>No Lab</b>
4/28-5/2	4.1 Tensile Testing of Composite Materials <sup>4</sup>
5/5-5/9	<b>No Lab</b>
5/12-5/16	<b>FINALS WEEK</b>

\* Please wear old clothes that you don't mind getting dirty.

<sup>1</sup> Lab report due by 4:30 Friday February 29, 2007

<sup>2</sup> Lab report due by 4:30 Friday April 11, 2007

<sup>3</sup> Lab report due by 4:30 Friday April 25, 2007

<sup>4</sup> Lab worksheet to be completed in class

**Lab Materials:**

Lab write-ups and other materials will be made available on the following website:  
[www.engineering.uiowa.edu/~rwillia/coursemat.htm](http://www.engineering.uiowa.edu/~rwillia/coursemat.htm). Please printout and read the materials before you come to class. Some labs will require a lot of work in a relatively short amount of time, being prepared before class will help.

**Lab Rules:**

- Safety, Safety, Safety!!!
- Attendance is required for every lab session.
- If you have questions, please be patient – the instructor will be with you as soon as possible.
- If you have problems with any equipment, tell the instructor immediately!

**Lab Reports:**

- Must follow the format outlined in the first class. **Use both SI and US units!**
- One report will be turned in for each group. Every group member is expected to do his/her fair share. Lab reports must be signed by each member on the cover sheet, acknowledging their work.
- Must be turned in by the time and date mentioned above. Late reports will not be accepted – no exceptions.

## A Typical Lab Report Format: *(third person/passive voice)*

- **Title Page**

- **Introduction**

The introduction will state the objective for performing the lab in your own words. Overall, it should let the reader know why you performed this experiment and have an idea of what results are being sought.

- **Background**

This section will focus on the knowledge and comprehension of the relevant materials and tests you have covered. You should describe the context in which the materials will be used and the associated engineering concepts (i.e. stress, strain). Equations and diagrams are useful in this section.

- **Materials and Methods**

In this section, clearly list the materials used and then describe the setup of the equipment. In another paragraph, describe (do not list) exactly what you did during the lab to take data.

- **Data/Data Analysis<sup>†</sup>**

Record all measurements and any other data in a *clear, typed spreadsheet*. Make sure that the data is clearly labeled as to what it is. You will take all relative data and begin to extract your results through the use of formulae. Use the correct number of significant figures and the correct units. When applicable, diagrams and any other physical data, such as photos, should be included. Use short phrases to explain each calculation or graph.

- **Discussion<sup>†</sup>**

From your data analysis, you should have come up results that will hopefully support the whole purpose of the experiment. Start this section with a condensed table of results from the data analysis. Follow this table with a paragraph on how your results are relevant and how it compares with reference data. Finally, write a paragraph about types and sources of error. This means discuss what problems that may have been confronted (both quantity and measurement) in the experiment and whether they were random (human) or intrinsic (non-human).

- **Conclusion**

Summarize the experiment and whether or not you met the objective successfully.

- **Appendices**

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<sup>†</sup> Be sure to use both SI and US customary units.

# **Structural Metals**

## Tensile Testing of Structural Metals

### Standards

- *ASTM E8: Tension Testing of Metallic Materials*

### Purpose

- To obtain the material's stress-strain relationship.
- To determine the following structural properties: modulus of elasticity, yield strength, ultimate tensile strength, failure strength, and strain to failure.
- To determine the reduction of cross-sectional area.

### Equipment and Materials

- *Tinius-Olsen* load frame (Figure 1.1.1)
- Computer with *LabVIEW*<sup>®</sup>
- Extensometer
- Caliper to measure original dimensions of specimen
- Permanent marker
- Specimens: 1018 steel, annealed 1018 steel and 6061-T6 aluminum
- Safety glasses



Figure 1.1.1. Lab setup

### Experimental Procedure

1. Label each specimen with your group's initials and an identification number (i.e., #1, #2, etc.) on each end.
2. Using the caliper, take approximately five measurements of both the width and the thickness and average each dimension to calculate the cross-sectional area. Measure the length of the test section between fillets. *[See worksheet at the end of this lab.]*
3. With the zero-pin in place, attach the extensometer to the specimen.

- Carefully place the specimen in the grips of the testing machine (figure 1.1.2).



Figure 1.1.2. Specimen inserted into grips.

- Carefully remove the zero-pin by rolling it back and forth.
- Set the crosshead speed of the load frame to 0.500 cm/min
- Type initial data into the tensile test program (figure 1.1.3). Click Run.

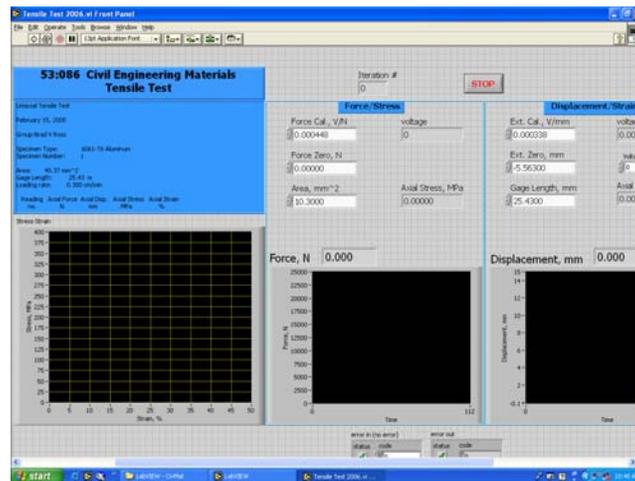


Figure 1.1.3. Screenshot of program.

- After the *LabVIEW*<sup>®</sup> program has started collecting data, start the testing machine. (We will go over this in more detail in class.)

9. Continue applying the load until the specimen fails. At this point, stop *LabVIEW*<sup>®</sup>.
10. Obtain the data/results file from the computer and copy it to your own disk.

### Analysis and Results

- Plot the stress versus strain curve.
- Determine yield strength,  $\sigma_{yd}$ , using the 0.2% offset method.
- Calculate (or use your stress-strain plot) the ultimate tensile strength.

$$\sigma_{t,ult} = \frac{P_{max}}{A_0} \quad (1.1.1)$$

Where:

$\sigma_{t,ult}$   $\equiv$  ultimate tensile strength, MPa (psi)

$P_{max}$   $\equiv$  maximum load carried by the specimen during the test, N (lb)

$A_0$   $\equiv$  original cross-sectional area of specimen, mm<sup>2</sup> (in.<sup>2</sup>)

- Calculate the strain to failure, or elongation.

$$\%Elongation = \frac{(L_f - L_0)}{L_0} \times 100 \quad (1.1.2)$$

Where:

$L_f$   $\equiv$  gauge length after failure, mm (in.)

$L_0$   $\equiv$  original gauge length, mm (in.)

For elongation > 3.0%, fit the ends of the fractured specimen together and measure  $L_f$  as the distance between two gauge marks. For elongation < 3.0%, fit the fractured ends together and apply an end load along the axis of the specimen sufficient to close the fractured ends together, then measure  $L_f$  as the distance between gauge marks.

- Calculate the modulus of elasticity.

$$E = \frac{\sigma}{\varepsilon} \quad (1.1.3)$$

where:

$E$   $\equiv$  modulus of elasticity, MPa (psi)

$\sigma$   $\equiv$  stress, MPa (psi)

$\varepsilon$   $\equiv$  corresponding strain, mm/mm (in./in.)

- Calculate (or use your stress-strain plot) the failure strength.

$$\sigma_f = \frac{P_f}{A_0} \quad (1.1.4)$$

where:

$\sigma_f$  ≡ failure strength, MPa (psi)

$P_f$  ≡ final load carried by the specimen during the test, N (lb)

$A_0$  ≡ original cross-sectional area of specimen, mm<sup>2</sup> (in.<sup>2</sup>)

- Calculate the reduction of cross-sectional area.

$$\% \text{Reduction} = \frac{(A_0 - A_f)}{A_0} \times 100 \quad (1.1.5)$$

where:

$A_f$  ≡ cross-section after failure, mm<sup>2</sup> (in.<sup>2</sup>)

To calculate the cross-section after failure, fit the ends of the fractured specimen together and measure the mean diameter or width and thickness at the smallest cross-section.

**53:086 Civil Engineering Materials**

**Tension Test Worksheet**

Group: \_\_\_\_\_ Date: \_\_\_\_\_

Spec. #	Material	Before Test		After Test		From Data					
		A <sub>0</sub>	L <sub>0</sub>	A <sub>f</sub>	L <sub>f</sub>	σ <sub>yd</sub>	σ <sub>t, ult</sub>	σ <sub>f</sub>	E	%Elong.	%Red. Area
1											
2											
3											
4											
5											
6											
7											
8											
9											

## Torsion Testing of Structural Metals

### Standards

- *ASTM E143: Shear Modulus at Room Temperature*

### Purpose

- To determine the shear modulus of structural metals

### Equipment

- *Tinius-Olsen Lo-Torq* Torsion Machine (figure 1.2.1)
- Computer with *LabVIEW*<sup>®</sup>
- Twist gauge
- Caliper to measure dimensions of specimen
- Permanent marker
- Specimens: 1018 steel (tube) and 6061-T6 aluminum (rod)
- Safety glasses



Figure 1.2.1. *T-O Lo-Torq* torsion machine

### Experimental Procedure

1. Obtain one steel and one aluminum specimen and label them for your group and draw a straight line along the specimen using the maker.
2. Using the caliper, find the mean diameter using at least five measurements. From the diameter, calculate the mean radius,  $r$ . Calculate the corresponding polar moment of inertia,  $J$ .

$$J_{solid} = \frac{\pi}{2} r^4 \quad (1.2.1)$$

$$J_{tube} = \frac{\pi}{2} (r_o^4 - r_i^4) \quad (1.2.2)$$

3. Ensure that the twist gage is set to 0°.

- Place the specimen in one of the grips so that you can see the line and “lightly” tighten the wedges using the provided hex wrench. Slide the torque meter/grip toward the motor until the free end of the specimen is fully inserted into the other grip and tighten the wedges (figure 1.2.2). Tighten the grip slide mount. Calculate the gage length of the specimen by measuring the distance between the faces of the grips and adding 14 mm.

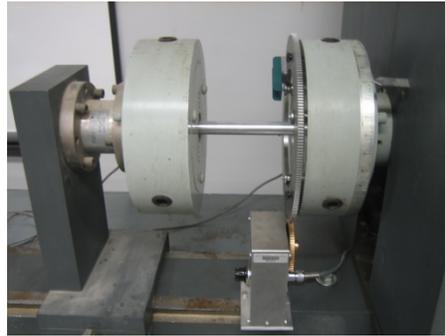


Figure 1.2.2. Specimen mounted in grips.

- Type initial data into the torsion test program (figure 1.2.3). Click Run.

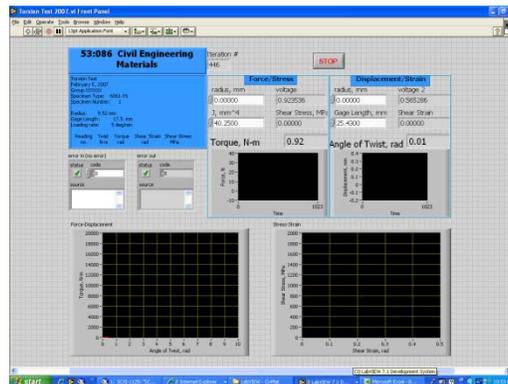


Figure 1.2.3. Screenshot of program.

- Set speed to  $\sim 5^\circ/\text{min}$ , zero the torque and start test (figure 1.2.4).



Figure 1.2.4. Torsion controls.

7. When the specimen reaches the plastic range (permanent deformation), stop the machine. Notice the line is now twisted. Remove the specimen.
8. Obtain the data/results file from the computer and copy it to your own disk.

### Analysis and Results

- For each measurement of torque and angle of twist, the shear stress and shear strain are calculated.

$$\tau = \frac{Tr}{J} \quad (1.2.3)$$

$$\gamma = \frac{\theta r}{L_0} \quad (1.2.4)$$

where:

- $\tau$   $\equiv$  shear stress, MPa (psi)
- $\gamma$   $\equiv$  shear strain, radians
- $T$   $\equiv$  applied torque, N·m (in·lb)
- $\theta$   $\equiv$  angle of twist, radians
- $J$   $\equiv$  polar moment of inertia, mm<sup>4</sup> (in<sup>4</sup>)
- $r$   $\equiv$  mean radius, mm (in)
- $L_0$   $\equiv$  gage length, mm (in)

- Plot the shear stress versus shear strain curve.
- If possible, determine yield shear strength,  $\tau_{yd}$ , using the 0.2% offset method.
- Calculate the shear modulus.

$$G = \frac{\tau}{\gamma} \quad (1.2.5)$$

where:

- $G$   $\equiv$  shear modulus, MPa (psi)
- $\tau$   $\equiv$  shear stress, MPa (psi)
- $\gamma$   $\equiv$  corresponding shear strain, radians

- Calculate the Poisson's ratio. Recall:

$$G = \frac{E}{2(1+\nu)} \quad (1.2.6)$$

where:

- $E$   $\equiv$  modulus of elasticity (found in lab 1.1), MPa (psi)

**Theory Discussion**

If you are really observant and compare this experiment to the tensile test, you might question why these specimens appear to yield at a different stress than they did during the tensile test. To understand this, you must understand the failure criteria of materials. There are several failure theories available and they basically boil down to fracture (brittle materials) and yielding (ductile materials). The specimens that we are testing are considered ductile materials; therefore we will use a yield criterion. Common yield criteria are the *Tresca* yield criterion and the *von Mises* yield criterion.

- The *Tresca* criterion states that yielding will occur when the maximum shear stress reaches a critical value, which was found using the simple uniaxial tension test. The Tresca criterion is given as:

$$\max\left(\left|\frac{\sigma_1 - \sigma_2}{2}\right|, \left|\frac{\sigma_2 - \sigma_3}{2}\right|, \left|\frac{\sigma_1 - \sigma_3}{2}\right|\right) = \frac{\sigma_y}{2} \quad (1.2.7)$$

- The *von Mises* criterion states that yielding will occur when the octahedral shear stress reaches a critical value, also found using the uniaxial tension test. The von Mises criterion is given as:

$$\frac{1}{3}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2\right] = \frac{\sqrt{2}}{3}\sigma_y \quad (1.2.8)$$

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**53:086 Civil Engineering Materials****Torsion Worksheet**

Group: \_\_\_\_\_ Date: \_\_\_\_\_

**6061-T6 Aluminum**

Average Diameter: \_\_\_\_\_

Average Radius ( $r$ ): \_\_\_\_\_Polar Moment of Inertia ( $J$ ): \_\_\_\_\_Gage Length ( $L_0$ ): \_\_\_\_\_Yield Shear Stress ( $\tau_{yd}$ ): \_\_\_\_\_Shear Modulus ( $G$ ): \_\_\_\_\_Poisson's Ratio ( $\nu$ ): \_\_\_\_\_**1018 CR Steel**

Average Diameter (out): \_\_\_\_\_

Average Radius ( $r_o$ ): \_\_\_\_\_

Average Diameter (in): \_\_\_\_\_

Average Radius ( $r_i$ ): \_\_\_\_\_Polar Moment of Inertia ( $J$ ): \_\_\_\_\_Gage Length ( $L_0$ ): \_\_\_\_\_Yield Shear Stress ( $\tau_{yd}$ ): \_\_\_\_\_Shear Modulus ( $G$ ): \_\_\_\_\_Poisson's Ratio ( $\nu$ ): \_\_\_\_\_

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## Charpy Impact Test

### Standards

- *ASTM E23: Test Methods for Notched Bar Impact Testing of Metallic Materials*

### Purpose

- To determine the energy required to fracture a v-notched specimen. This energy translates into the toughness of the material.

### Equipment and Materials

- Charpy V-notch impact testing machine (figure 1.3.1)
- Specimens: 1018 CR steel & 6061-T6 aluminum
- Thermometer
- Water
- Dry ice
- Hot plate
- Oven
- Bowls, tongs
- Heavily insulated gloves,
- Safety glasses

### SAFETY WARNING

- Extreme caution should be used with the Charpy impact machine.
- The pendulum is very heavy and will easily break bones!
- Only one person should be around the machine at a time.
- Use the safety catch until ready to test.
- Make sure the doors are closed before releasing the pendulum.

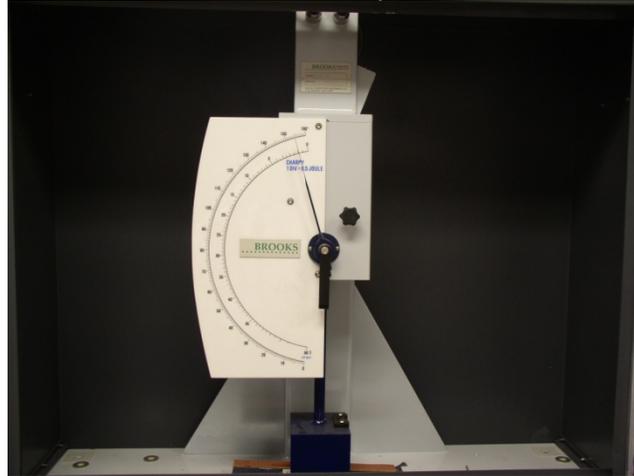


Figure 1.3.1. Charpy impact testing machine.

### Experimental Procedure

1. Place specimens into the available temperature media:
  - Dry ice ( $-78.5^{\circ}\text{C}$ )
  - Ice bath ( $\sim 0^{\circ}\text{C}$ )
  - Ambient room temperature ( $\sim 20^{\circ}\text{C}$ )
  - Boiling water ( $100^{\circ}\text{C}$ )
  - Oven ( $\sim 300^{\circ}\text{C}$ )
2. Setup Charpy machine by lifting the pendulum up to and securing it into the notch. Place the safety catch into the keyhole until ready to test.
3. Remove the desired specimen its temperature medium using the tongs and place it onto the anvil on the Charpy impact machine as quickly as possible.
4. When ready to test, **carefully** remove the safety catch and close the doors. Pull the two levers at the top of the machine apart to release the pendulum. *(The time it takes to remove the specimen from its temperature medium and complete the test should be  $\sim 5$  seconds.)*
5. Record the energy required to fracture the specimen by reading the gauge mark. *[See worksheet at the end of this lab.]*
6. Observe and note the fracture surface appearance. [A digital camera would be a great idea!]
7. Measure the lateral expansion of the specimen using a caliper. *[See worksheet at the end of this lab.]*

**Analysis and Results**

- For each type of material, plot the fracture energy versus the temperature. (All data)
- For each type of material, plot the lateral expansion versus the temperature. (All data)
- If possible, discuss the ductile-to-brittle transition temperature.
- Describe the fracture surface appearance for each type of specimen and for each temperature.
- What is the effect of temperature on the fracture of metal?

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**Charpy Worksheet**

Group: \_\_\_\_\_ Date: \_\_\_\_\_

**1018 CR Steel**

Group <sup>†</sup>	Fracture Energy, J				
	T <sub>1</sub> = -78.5°C	T <sub>2</sub> = 0°C	T <sub>3</sub> = 21.5°C	T <sub>4</sub> = 100°C	T <sub>5</sub> = 300°C

Group <sup>†</sup>	Lateral Expansion, mm				
	T <sub>1</sub> = -78.5°C	T <sub>2</sub> = 0°C	T <sub>3</sub> = 21.5°C	T <sub>4</sub> = 100°C	T <sub>5</sub> = 300°C

**6061-T6 Aluminum**

Group <sup>†</sup>	Fracture Energy, J				
	T <sub>1</sub> = -78.5°C	T <sub>2</sub> = 0°C	T <sub>3</sub> = 21.5°C	T <sub>4</sub> = 100°C	T <sub>5</sub> = 300°C

Group <sup>†</sup>	Lateral Expansion, mm				
	T <sub>1</sub> = -78.5°C	T <sub>2</sub> = 0°C	T <sub>3</sub> = 21.5°C	T <sub>4</sub> = 100°C	T <sub>5</sub> = 300°C

## Lab Report 1 Guidelines

### Overview:

In this set of labs, we dealt with two to three different types of metal. All of the properties that you have investigated tie into the design codes used in construction. It should be evident that each type of metal available in industry has certain strengths and weaknesses to every possible construction scenario. The purpose of the preceding labs was to give you, the engineer, some insight to how each type of metal differs.

### Data/ Data Analysis:

All relevant data can be obtained from the following location:  
[www.engineering.uiowa.edu/~rwillia](http://www.engineering.uiowa.edu/~rwillia) (go to course materials)

- Tension Test
  - All of your groups data (*tension test worksheet*)
  - One stress-strain graph
    - The graph will have the plots for all relevant specimens
  - Three elastic moduli graphs (one for each material)
    - Each graph will have the plots for all relevant specimens
  - All relevant data from all groups (*from website*)
  - Theoretical (or published) values (try [www.matweb.com](http://www.matweb.com) or other)
  - Quantitatively compare material property differences between specimens of the same material (hint: your stress-strain graphs) and to the class averages.
  - Quantitatively compare the class average material properties of the materials tested to the published values.
  -
- Torsion Test
  - **IF YOU PERFORMED THE LAB, PLEASE INCLUDE THE GRAPHS. IF YOU DID NOT, YOU STILL NEED TO COMPARE THE AVERAGE VALUES TO REFERENCE VALUES.**
  - All of your groups data (*torsion worksheet*)
  - One shear stress-shear strain graph (both specimens)
  - Two shear moduli graphs (one for each material)
  - Shear Modulus (G or  $\mu$ ) for your specimens
  - All shear moduli from all groups (*from website*)
  - Using the class average data, calculate Poisson's ratio.
  - Theoretical (or published) values (try [www.matweb.com](http://www.matweb.com) or other)
  - Quantitatively compare your modulus for each material to the class average.
  - Quantitatively compare the class average moduli and Poisson's ratios to the published values
  -
- Charpy Test
  - All data (every group – *from website*)

- Two plots (one for each material) of fracture energy versus temperature (including all groups data)
- Two plots (one for each material) of lateral expansion versus temperature (including all groups data)

Don't forget to include any relevant photos that you took!

**Discussion:**

- Tension Test
    - Compare the material properties of one material to the others.
    - Discuss general shape of stress-strain curve. Did all materials yield? What effect does the treatment of the steel specimens have on the properties?
    - Discuss the fracture surfaces, percent elongation, and percent reduction of cross-sectional area for each material. How does this relate to ductility?
  - Torsion Test
    - Compare and discuss the class average moduli between both materials
  - Charpy Impact Test
    - Compare fracture energy/toughness, lateral expansion, and fracture surfaces between materials/temperatures.
    - Compare and discuss transition zones between materials.
  - Overall
    - Discuss the suitability of materials to different design and construction scenarios.
-

# **Portland Cement Concrete**

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## Sieve Analysis and Specific Gravity of Aggregates

### Standards

- *ASTM C33: Standard Specification for Concrete Aggregates*
- *ASTM C136: Sieve Analysis of Fine and Coarse Aggregates*
- *ASTM C127: Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregates*
- *ASTM C128: Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregates*

### Purpose

- Determine the grain size distribution, fineness modulus, specific gravity, absorption, and water content of fine and coarse aggregates.
- Use information to design a mix for an assigned scenario according to the *PCA* manual.

### Sieve Analysis

---

#### Equipment and Materials

- Aggregates: coarse and fine
- Balance
- Sieves (figure 2.1.1)
- Mechanical sieve shaker (figure 2.1.2)
- Oven
- Safety glasses



**Figure 2.1.1. Array of sieves.**



Figure 2.1.2. Small sieve shaker.

### Experimental Procedure

1. Dry a sizable amount of each aggregate to a constant mass at a temperature of  $110 \pm 5^\circ\text{C}$  and allow to cool to room temperature (*Instructor*)
2. Using the scale, find and record the mass of each sieve then nest the sieves in order.
  - Fine: Nos. 100, 50, 30, 16, 8, 4,  $3/8''$ , and pan
  - Coarse: Nos. 16, 8, 4,  $3/8''$ ,  $1/2''$ ,  $3/4''$ , and pan
3. Place each nested sieve stack in the appropriate sieve shaker and run the shaker for at least ten minutes.
4. Carefully pull apart each sieve. Find and record the mass of each sieve + aggregate.

### Analysis and Results

- Calculate the percent passing, the percent retained, and the cumulative percent retained to the nearest 0.1% in table form for each aggregate. [*See file from website*]

Sieve Size	% Pass	% Retain	% Cumul
...	...	...	...
	Total 1		Total 2

- Plot the grain size distribution of each aggregate. [*See file*]
- Calculate the fineness modulus to the nearest 0.01. [*See file*]

$$FM = \frac{\text{Total 2}}{\text{Total 1}} \quad (2.1.1)$$

### Specific Gravity and Absorption of Coarse Aggregates

**Equipment and Materials**

- Balance
- Wire basket
- Bucket full of water
- No. 4 sieve

**Experimental Procedure**

1. Thoroughly mix a sample of coarse aggregate and pour through a No. 4 sieve. Discard any material passing the sieve and wash the remaining sample to rid of dust.
2. Immerse the aggregate in water at room temperature for 24 hours. (*Instructor*)
3. Remove all aggregate from water and towel dry so that no water is visible (figure 2.1.3).



Figure 2.1.3. Towel dry aggregate.

4. Find and record the mass of this sample in the saturated-surface dry (SSD) condition and record it as *B*.
5. Place all aggregate in the wire basket (figure 2.1.4) and submerge in water bucket. Find and record the mass as *C*.



Figure 2.1.4. Aggregate in wire basket.

6. Dry the aggregate to a constant weight at a temperature of  $110 \pm 5^\circ\text{C}$  and allow it to cool to room temperature and record its mass as *A*.

**Analysis and Results**

- Bulk specific gravity:

$$G_s = \frac{A}{(B-C)} \quad (2.1.2)$$

- Bulk specific gravity (SSD):

$$G_{SSD} = \frac{B}{(B-C)} \quad (2.1.3)$$

- Apparent specific gravity:

$$G_{AS} = \frac{A}{(A-C)} \quad (2.1.4)$$

- Absorption:

$$Absorption, \% = \frac{(B-A)}{A} \times 100 \quad (2.1.5)$$

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## Specific Gravity and Absorption of Fine Aggregates

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### Equipment and Materials

- Balance
- Pycnometer
- Mold in the form of a frustum of a cone
- Tamper having a mass of  $340 \pm 15$  g

### Experimental Procedure

1. Measure the mass of the pycnometer filled with water to the calibration mark. Record the mass as  $B$ .
2. Obtain approximately 1 kg of the fine aggregate sample.
3. Oven dry the aggregate sample in a suitable pan to a constant mass, allow to cool, and then immerse sample in water for 24 hours. (*Instructor*)
4. Decant excess water with care to avoid loss of fine particles. Spread sample onto the bench top and turn on fan to move a current of air over it, stirring frequently to ensure homogeneous drying (figure 2.1.5). Continue to stir the sample until it approaches a free-flowing condition.



Figure 2.1.5. Drying fine aggregate to SSD.

5. Holding the mold firmly on the bench top, fill it to overflowing with a portion of your sample and heap additional material above the top of the mold cupping your fingers around the opening (figure 2.1.6).



**Figure 2.1.6. Filling mold.**

6. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Each drop should start about 5 mm above the top surface of the aggregate. Permit the tamper to fall freely with gravity on each drop.
7. Remove loose sand from the base and lift the mold vertically. If surface moisture is still present, the fine aggregate will retain the shape of the mold (figure 2.1.7a). If this is the case, repeat steps 4-7 until the fine aggregate slumps slightly indicating that it has reached a surface-saturated dry (SSD) condition (figure 2.1.7b).



(a)



(b)

**Figure 2.1.7. Lifting mold and looking for slump.**

8. Weigh  $500 \pm 10$  g of SSD aggregate and record the mass as  $S$ .
9. Partially fill the pycnometer with water and immediately introduce into the pycnometer the SSD aggregate from step 8. Slowly and gently roll the pycnometer on its bottom rim to rid of any trapped air. Fill the pycnometer with water to the calibration mark.
10. Determine the mass of the pycnometer, specimen, and water, and record it as  $C$ .
11. Carefully work the entire sample into a drying bowl. Place in an oven to dry to a constant mass (about 24 hours). Record this weight as  $A$ .

## Analysis and Results

- Bulk specific gravity:

$$G_s = \frac{A}{(B + S - C)} \quad (2.1.6)$$

- Bulk specific gravity (SSD):

$$G_{SSD} = \frac{S}{(B + S - C)} \quad (2.1.7)$$

- Apparent specific gravity:

$$G_{AS} = \frac{A}{(B + A - C)} \quad (2.1.8)$$

- Absorption:

$$\text{Absorption, \%} = \frac{(S - A)}{A} \times 100 \quad (2.1.9)$$

**53:086 Civil Engineering Materials**

Group: \_\_\_\_\_ Date: \_\_\_\_\_

**Coarse Aggregate**

<i>B, g</i>	
<i>C, g</i>	
<i>A, g</i>	
<i>G<sub>S</sub></i>	
<i>G<sub>SSD</sub></i>	
<i>G<sub>AS</sub></i>	
<i>Absorption, %</i>	
<i>Moisture Content, % (Instructor)</i>	

**Fine Aggregate**

<i>B, g</i>	
<i>S, g</i>	
<i>C, g</i>	
<i>A, g</i>	
<i>G<sub>S</sub></i>	
<i>G<sub>SSD</sub></i>	
<i>G<sub>AS</sub></i>	
<i>Absorption, %</i>	
<i>Moisture Content, % (Instructor)</i>	

## Mixing of Portland Cement Concrete

### Standards

- *ASTM C143: Slump of Hydraulic Cement Concrete*
- *ASTM C231: Air Content of Freshly Mixed Concrete by the Pressure Method*
- *ASTM C192: Making and Curing Concrete Test Specimens in the Laboratory*

### Purpose

- Design appropriate PCC mix according to assigned scenario
- Observe the proportioning of concrete mixes.
- Mix Portland Cement Concrete
- Determine: slump, air content, and unit weight
- Examine the effect of different water/cement ratios, water-reducing agents, and air-entraining admixtures.

### Equipment and Materials

- Crushed coarse aggregate
- Fine aggregate – natural sand
- Type I Portland cement
- Admixtures (Air-entrainment & pulverized fly ash)
- Concrete mixer (figure 2.2.1)
- Slump test apparatus
- Air content meter
- Safety glasses



Figure 2.2.1. PCC mixing lab setup.

## Overview

Concrete is a porous material, in which the porosity reduces the overall strength. The pores in concrete range from the size of large air bubbles to the diameter of a water molecule. The cement hydration products are inherently porous and account for the millions of tiny pores ( $< 10$  nm) in cement paste. The larger pores (capillary pores 10 nm to 10  $\mu$ m) result from the spaces occupied by the water introduced during mixing and, in the case of air entrained concrete, from air bubbles (10 to 100  $\mu$ m), which are intentionally created during mixing to impart resistance to freeze-thaw-cycle degradation. For normal concrete mixes, the larger pores are introduced by the water added for hydration. Mixes using lots of water, that is having a high water/cement (w/c) ratio, are fluid and thus easy to place but have low strengths due to their high porosity. Mixes using minimal amounts of water (low w/c ratio) are difficult to place but can achieve much higher strengths because of their lower porosity. The conflict between workability and strength—the competing benefits of high and low porosity—leads to the frequent use of admixtures which increase the workability of dry mixes.

Because of the importance of workability and the ultimate strength of concrete, the properties of a concrete mix are frequently measured at the construction site prior to placement using several common tests described in the Appendix: these tests determine the slump, the unit weight and the air content of the freshly mixed concrete. The results of these tests allow one to monitor the workability and water content of the concrete, and its resistance to freeze-thaw damage.

## Experimental Procedure

1. The lab instructor will explain batching and mixing procedures.
  - Weighing of components taking into account the weight of buckets.
  - Add aggregates to mixer – mix.
  - Add cement and PFA, if applicable – mix.
  - Add water and AE, if applicable – mix for ~5 minutes.
  - When mixing is complete, dump concrete into pan.
  - Perform (1) slump test, (2) air-entrainment test, and (3) fill nine molds. (Don't forget: 1/3 volume – rod, 2/3 volume – rod, 3/3 volume – rod, level)
  - CLEAN UP!!! Make sure pans, test equipment, and trowels are completely clean! Please make sure that any waste is either put into grocery sacks (not too much!) or sprayed/pushed into the grated side of the settling tank.
2. Each lab group will be create a mix based on their design (fill in Table 2.2.1) and will determine its slump, air content, and unit weight.

**TABLE 2.2.1. Mix to be Prepared and Tested (Absolute Volume Mtd.)**

<b>Group</b>	
<b>Description</b>	
<b>Design Strength f<sub>c</sub>' (psi)</b>	
<b>Coarse aggregate (lb)</b>	
<b>Fine aggregate (lb)</b>	
<b>Portland cement (lb)</b>	
<b>Cement replacement material(lb)</b>	
<b>Water† (lb)</b>	(     )
<b>Admixture</b>	

† First value is theoretical to be used for water/cement ratio. Parenthetical value is the actual amount to add.

### 3. Slump Test

- The apparatus for this very simple test consists primarily of a hollow mold in the form of a frustum of a cone, with the dimensions shown in figure 2.2.2.
- Fill the mold with concrete in three layers of equal volume. “Rod” each layer 25 times with a 16-mm-diameter steel rod.
- Lift the mold away vertically.
- Measure the slump by determining the difference between the height of the mold and the height of the concrete over the original center of the base of the specimen. If a distinct shearing off of concrete from one side occurs (figure 2.2.3.b), disregard and start the test over.

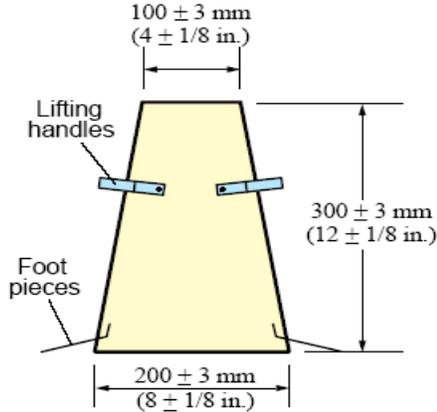


Figure 2.2.2. Slump cone.

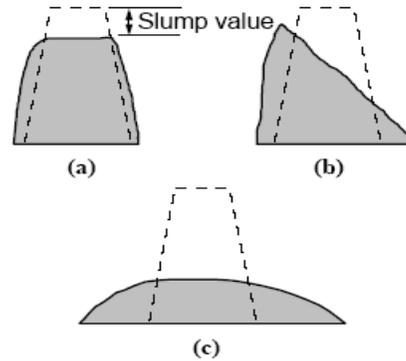


Figure 2.2.3. Types of slump: (a) true slump; (b) shear slump; (c) collapse of slump

The slump test may be considered to be a measure of the shear resistance of concrete to flowing under its own weight. Depending on the mix, three distinct types of slump may occur, as shown in Fig. A2. “True” slump consists of a general subsidence of the mass, without any breaking up. Shear slump often indicates a lack of cohesion; it tends to occur in harsh mixes (i.e., those which are deficient in fine aggregate), or in mixes prone to segregation. Shear slump may indicate that the concrete is not suitable for placement. On the other hand, normal mixes are sometimes found to display shear slump. Collapse slump generally indicates a lean, harsh, or more likely, a very wet mix.

#### 4. Air Content Test (Pressure Method)

The pressure method (ASTM C231) is the most common method for measuring the air content of fresh concrete in the field. The basis of the method is the measurement of the change in volume of the concrete when subjected to a given pressure. This change in volume is assumed to be caused entirely by compression of the air, and Boyle’s law can then be used to calculate the air content.

The chief advantage of this method is that it is not necessary to determine the specific gravities, moisture contents, or mix proportions of the components. The concrete is consolidated into the measuring bowl, struck off level to the rim, and the apparatus assembled (figure 2.2.4). After pressurizing the mix, the air content is read directly on a dial.



Figure 2.2.4. Air content test apparatus.

- **Operation of Press-Ur-Meter**

1. Weigh the base of the meter clean, empty, and wiped dry.
2. Fill the base with a sample of fresh concrete, placing it in the base by vibrating or tamping in much the same manner as the concrete is to be placed on the job. Strike off the base, level full, with a suitable straight edge. Wipe the top edge clean.
3. Weigh the filled base, and determine the weight of concrete in it. Use this weight to calculate the specific weight, which is called the unit weight. (The volume is equal to 0.25 ft<sup>3</sup>.)
4. Clamp cover on with petcocks open. *Do not exert excessive force on the brass clamps.* If the clamps do not lock with moderate force, ask your instructor for assistance.
5. Using a rubber syringe, inject water through one petcock until all air is expelled through the opposite petcock. Close both petcocks.
6. With the built-in pump, pump up air to the calibrated “initial pressure” line on the gage.
7. Wait a few seconds for compressed air to cool to normal temperature and then stabilize the gage hand at the proper initial pressure line by pumping or bleeding off, as needed.
8. Press down on the thumb lever to release the air into the base. Hold the thumb lever down for a few seconds, lightly tapping the gage with the finger to stabilize the hand on the dial. *Do not tilt this meter at any time.*

9. Read the percent of air in the concrete directly on the dial.
  10. Open the petcocks to release the pressure and then remove the cover. Clean up the base, cover, and petcock openings.
5. **Fill Molds**  
After these tests have been run the group will cast: nine standard cylinders (4 in. dia. x 8 in. long). The cylinders should be carefully labeled because they will be used in future labs to test the strength of the concrete.
6. Place all cylinders in the water tank so that they are submerged.

### Analysis and Results

- Record all data in the spaces provided in Table 2.2.2. In your eventual laboratory report include your values from Tables 2.2.1 and 2.2.2.

**TABLE 2.2.2. Mix Properties**

<b>Group</b>	
<b>Description</b>	
<b>W/C ratio</b>	
<b>Slump (mm)</b>	
<b>Air content (%) (uncorrected)</b>	
<b>Air content (%) (corrected)</b>	
<b>Weight of concrete (lb)</b>	
<b>Vol. bucket (ft<sup>3</sup>)</b>	0.25
<b>Unit weight (lb/ft<sup>3</sup>)</b>	
<b>Unit weight (kN/m<sup>3</sup>)</b>	

- Email the lab instructor all of your data for this lab so that it can be compiled with all other groups.

---

## Compression Testing of PCC

### Standards

- *ASTM C39: Compressive Strength of Cylindrical Concrete Specimens*

### Purpose

- To determine the density, compressive strength, modulus of elasticity, Poisson's ratio, and strain to failure of cylindrical PCC specimens.

### Equipment and Materials

- *Satec* Testing Machine
- Balance
- Metal caps with rubber inserts (for 1-D strain)
- Cylindrical concrete specimens (removed from mold)
- Safety glasses

### Experimental Procedure

1. Remove specimens from water tank and used supplied tools to remove the plastic mold.
2. Measure and record the mass of the specimen. Calculate the mass density. [*See worksheet.*]

$$\rho = \frac{m}{V} \quad (2.3.1)$$

where:

$\rho$   $\equiv$  mass density, lb/ft<sup>3</sup>

$m$   $\equiv$  mass of specimen, (lb)

$V$   $\equiv$  volume of specimen, ft<sup>3</sup>

3. Place the metal caps with rubber inserts over the ends of the specimen (figure 2.3.1). The use of these particular caps is *not* ASTM standard, which calls for capping with a sulfur and silica compound.



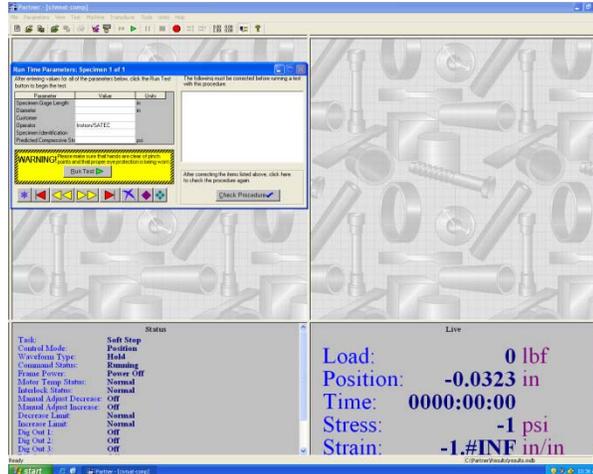
**Figure 2.3.1. Concrete specimen with caps.**

4. Place the capped specimen into the test chamber, making sure that the ends of the caps are parallel with the test plates (figure 2.3.2).



**Figure 2.3.2. Specimen in test machine.**

5. Using the manual controls, raise the specimen so that the test plates *barely* touch the specimen (caps).
6. Enter all relevant information into *Partner* (figure 2.3.3).
  - Gage Length = 8 in.
  - Diameter = 4 in.
  - Customer → use your group initials/name
  - Specimen ID → “Day 7 #1” and so forth...
  - Predicted compressive strength → from your mix design

Figure 2.3.3. Screenshot of *Partner* (compression).

7. Click “Check Procedures” → No errors.
8. Run program. The test is entirely automated.
9. When the test is complete and the specimen has failed, you need to save two items: your test results (file → export → save results as text file); and your data points (for the graph) (file → export → save data point as text file). Copy the data to your own disk. Take out all major pieces of your specimen. **Do not throw them away!** Set them off to the side for analysis.
10. Using the brush and broom, clean out the test chamber and sweep up the floor.

### Analysis and Results

- Plot the data using *Microsoft Excel*. This plot should look the same as the one that plotted during the test.
- Identify the compressive strength,  $f'_c$ ; and the strain to failure,  $\epsilon_f$ .
- Calculate the (28-day) modulus of elasticity of your concrete mix.

$$E_c = 33(w^{1.5})\sqrt{f'_c} \text{ psi} \quad (2.3.1)$$

where:

$E_c$  ≡ modulus of elasticity, psi

$f'_c$  ≡ compressive strength, psi

$w$  ≡ unit weight of concrete, lb/ft<sup>3</sup>

- Examine the pieces of each specimen. Note the type of failure that occurred (Fig. 2.3.4) and the appearance of the concrete. Did fracture occur through Portland cement,

aggregate, or both? A digital camera or a cell phone with photo capability would be an asset here.

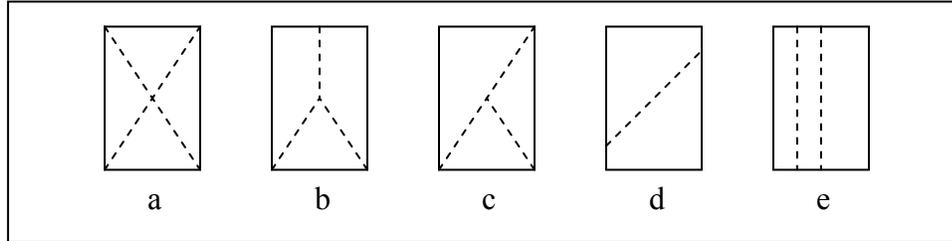


Figure 2.3.4. Types of specimen fracture (a) cone, (b) cone and split, (c) cone and shear, (d) shear, (e) columnar. [ASTM]

**Concrete Density**

Radius, ft	Length, ft	Volume, ft <sup>3</sup>	Mass, lb	Density ( $\rho$ ), lb/ft <sup>3</sup>
1/6				
1/6				
1/6				
<b>Average Density</b>				

## PCC Tensile Strength

### Standards

- *ASTM C496: Splitting Tensile Strength of Cylindrical Concrete Specimens*

### Purpose

- To determine the tensile strength of cylindrical PCC specimens.

### Equipment and Materials

- *Satec* Testing Machine
- Cylindrical concrete specimens (removed from mold)
- Supplementary bearing bar
- Wood strips
- Safety glasses

### Experimental Procedure

1. Place specimen horizontally into test chamber of *Satec* machine on a wooden strip. Place another wooden strip and supplementary bearing bar on to the top of the specimen and raise specimen so that the top of the bar just touches the top compression plate (figure 2.4.1).



Figure 2.4.1. Specimen setup.

2. Enter all relevant information into *Partner* (figure 2.4.2).

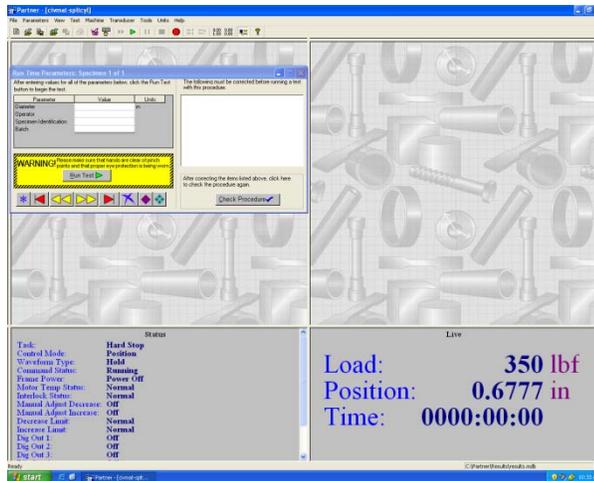


Figure 2.4.2. Screenshot of *Partner* (split-cylinder).

3. Click “Check Procedures” → No errors.
4. Run program. The test is entirely automated.
5. Upon completion of the program, save your test results (file → export → save results as text file) in your section’s folder on the desktop. There is no need to save the plot.
6. Repeat for two more specimens.

### Analysis and Results

- Find the tensile strength using the following formula:

$$f_{ct} = \frac{2P_f}{\pi Ld} \quad (2.4.1)$$

where:

$f_{ct}$  ≡ tensile strength, psi

$P_f$  ≡ load at failure, lb

$L$  ≡ length of specimen, inches

$d$  ≡ diameter of specimen, inches

## Lab Report 2 Guidelines

### Format

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- **Introduction**
- **Background**
  - Describe PCC as a construction material. Make sure you define terms (i.e. properties) clearly.
  - **Design**
    - Summarize your design requirements
    - Describe your design process and justify your decisions. Add any equations, etc. as you see fit.
    - Summarize your final design and complete Table 2.1.

**TABLE 2.1. PCC Mix Designs (Absolute Volume Mtd.)**

<b>Group</b>	
<b>Description</b>	
<b>Design Strength <math>f'_c</math> (psi)</b>	
<b>Coarse aggregate (lb)</b>	
<b>Fine aggregate (lb)</b>	
<b>Portland cement (lb)</b>	
<b>Cement replacement material(lb)</b>	
<b>Water<sup>†</sup> (lb)</b>	(      )
<b>Admixture</b>	

<sup>†</sup> First value is theoretical to be used for water/cement ratio. Parenthetical value is the actual amount to add.

- **Materials and Methods**
  - **PCC Mixing**
    - Describe the mixing process: materials, apparatus, and methods.
    - Describe the curing of the specimens and why it is done.
  - **PCC Testing**
    - Describe the initial tests of fresh PCC: slump, air-entrainment, and unit weight.
    - Describe how the density (of cured concrete) was found
    - Describe the compression and split-cylinder tensile tests.

- **Data/Data Analysis**

- **Data**

- Include all relevant raw data (i.e. length, diameter, cross-sectional area) in a neat and orderly fashion. You don't need to print out any "data points" – they will be used for the plots.
    - For both the 7- and 28-day compressive strengths, you should plot the stress-strain curves in Excel (or similar program). You only need one graph that will have the curves for all six specimens. From this (or the results file), you can find the compressive strength (peak) for each specimen. Make sure to have graph labeled (with units) and specify each specimen in the legend. ***[Please do not use the color yellow in any part of your graph as it is hard to see.]***
    - In another graph, find the elastic modulus for all six specimens.
    - For the tensile test, you only have to include the peak load (or failure load).
    - Include any pictures that you took here.

- **Data Analysis**

- All relevant calculations should go here – include formulae.
    - Calculate the averages for the following quantities: density, 7-day compression strength, 7-day strain to failure, 28-day compression strength, 28-day strain to failure, elastic modulus (for 7 & 28-day), and the tensile strength.
    - Quantitatively compare the 7-day compressive strength to that of the 28-day.
    - Quantitatively compare the 7-day elastic modulus to that of the 28-day.
    - Quantitatively compare the tensile strength to the 28-day compressive strength.
      - For example: the three comparisons above could be something such as "the 7-day compressive strength is xx.x% of the 28-day."
    - Fill out Table 2.2.

**Table 2.2. Final PCC Mix Data (All sections)**

<b>Group</b>	
<b>w/c</b>	
<b>Slump (in)</b>	
<b>Air Cont (%)</b>	
<b>Unit Weight (lb/ft<sup>3</sup>)</b>	
<b>Ave. <math>\rho</math> (lb/ft<sup>3</sup>)</b>	
<b>Ave. 7-Day <math>f'_c</math> (psi)</b>	
<b>Ave. 7-Day <math>\epsilon_f</math></b>	
<b>Ave. 7- Day <math>E_c</math> (psi)</b>	
<b>Ave. 28-Day <math>f'_c</math> (psi)</b>	
<b>Ave. 28-Day <math>\epsilon_f</math></b>	
<b>Ave. 28- Day <math>E_c</math> (psi)</b>	
<b>Ave. <math>f_{ct}</math> (psi)</b>	

- **Discussion**

- Discuss the mixing process and any immediate problems or concerns.
- Discuss the initial test results (slump and air-entrainment) and how they compare to your design's expected values.
- Discuss overall mechanical properties: density, strengths, elastic moduli, etc.
- Discuss the types of compressive failure.
- Discuss age of specimen (relating to compressive strength and stiffness).
- Discuss tensile strength versus compressive strength.
- Discuss error.
- Overall, what did you learn? How did the actual strength of your specimens compare to expected strength of your design? What would you do differently if you had to design another mix for the same criteria?
- **Conclusion**
- **Appendix**
  - Please attach the design homework assignment to the end of your report.

# **Bituminous Materials**

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## HMA Binder Tests

### Standards

- *ASTM D4402: Viscosity Determination of Unfilled Asphalts Using the Brookfield Thermosel Apparatus*
  - *ASTM P246: Determining the Rheometer Properties of Asphalt Binder for Specification Purpose Using a Dynamic Shear Rheometer (DSR)*
- 

### 3.1.1 Viscosity Test of Asphalt Binder

#### Purpose

- To determine the apparent viscosity of asphalt binder from 38°C to 260°C using the Brookfield Thermosel apparatus

#### Background

The viscosity is needed to ensure proper handling of the asphalt binder and for equality control and quality assurance. It is also used to determine the mixing and compaction temperature of asphalt concrete. This test is used for the *Superpave* performance grading of asphalt binders.

---

### SAFETY WARNING

- Extreme caution should be used in this lab. ***All materials are very hot!***
  - Any person working directly with the binder will wear heat resistant gloves at all times.
  - Be careful – do not rush! Pay attention to detail!
  - Space is limited. Please place all belongings in the lab next door.
- 

#### Equipment and Materials

- Rotational Viscometer (Figure 3.1.1)
- C25 Spindle
- Thermosel system consisting of thermo-container and sample chamber, SCR controller and probe
- PG 52-34 asphalt binder
- Safety glasses
- Gloves

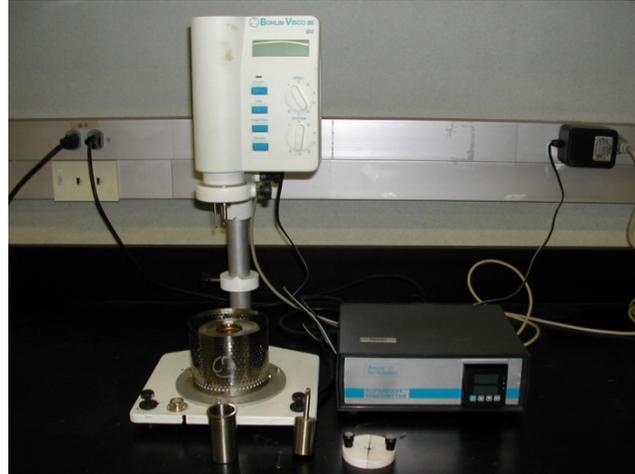


Figure 3.1.1. Rotational viscometer and accessories.

### Experimental Procedure

1. Turn on the Thermosel power and set the proportional temperature controller to 135°C.
2. Wait 1-1/2 hours (or until equilibrium temperature is obtained) with the spindle in the chamber (check control lamp) [*Instructor*].
3. Raise the main viscometer arm and remove the sample chamber (**hot!**) and add the volume of binder specified for the spindle. For our case, you need to add approximately 15 ml (about ¼ of the chamber).
4. The liquid level of the binder should intersect the spindle shaft at a point approximately 3 mm (1/8 inch) above the upper conical body of spindle.
5. Using the extracting tool, carefully place the loaded chamber back into the Thermosel so that the notch in the bottom of the chamber fits over the key in the Thermosel.
6. Lower the main arm of the viscometer.
7. Couple the spindle to the viscometer using the clip and cover the chamber with the thermal lid.
8. Allow the asphalt binder to come to the equilibrium temperature (~5-10 minutes).
9. Start the viscometer at a 20 rpm setting (Speed 1, System 2).
10. Wait 60 seconds and then record three readings, each 60 seconds apart, of the following data:

Data	Symbol	Unit
Viscosity	$\eta$	Pa·s

Shear Rate	$\gamma$	1/s
Shear Stress	$\tau$	Pa
Temperature	T	°C
Torque	M	mN·m
Frequency	$f$	Hz

11. **Clean everything** that you used properly.

### Analysis and Results

- Data from three readings:

	Reading #1	Reading #2	Reading #3
Viscosity (Pa·s)			
Shear Rate (1/s)			
Shear Stress (Pa)			
Temperature (°C)			
Torque (mN·m)			
Frequency (Hz)			

### 3.1.2 Dynamic Shear Rheometer Test of Asphalt Binder

#### Purpose

- To determine the complex shear modulus ( $G^*$ ) and phase angle ( $\delta$ ) of asphalt binders using the dynamic shear Rheometer.

#### Background

The complex shear modulus is an indicator of the stiffness resistance of asphalt binder to deformation under load. The complex shear modulus and phase angle define the resistance to shear deformation of the asphalt binder in the viscoelastic region. This test is used for the *Superpave* performance grading of asphalt binders.

#### Equipment and Materials

- Dynamic shear rheometer (Figure 3.1.2)
- Test plates
- Temperature controller (water bath)
- Control and data acquisition system
- Miscellaneous items such as specimen mold, specimen trimmer, environmental chamber, reference thermal detector, and calibrated temperature detector

**Experimental Procedure**

1. Heat the asphalt binder to 160°C. (*Instructor*)
2. Carefully clean and dry the surfaces of the test plates so that the specimen uniformly adheres to both plates. Bring the chamber to approximately 45°C so that the plates are preheated prior to the mounting of the test specimen. (*Instructor*)
3. Place the asphalt binder sample in the DSR using the following method:
4. Move the test plates together to squeeze the asphalt mass between the two plates. Move the plates until the gap between the plates equals the test gap (1.00 mm) plus 0.05 mm. Trim the specimen by moving a heated trimming tool around the upper and lower plate perimeters while trimming excess asphalt.
5. After trimming is completed, decrease the gap by 0.05 mm. The thickness should now equal the desired test gap of 1.00 mm.
6. Bring the specimen to the test temperature  $\pm 0.1^\circ\text{C}$ . Start the test after the temperature has remained at the desired temperature ( $64.0^\circ\text{C} \pm 0.1^\circ\text{C}$ ) for at least 10 minutes.
7. Start the data acquisition software. When the test temperature has been reached, condition the specimen by applying the required shear strain for 10 cycles at a radial frequency of 10 rad/s. Shear strain values vary from 1% to 12 % (*Instructor*) depending on the stiffness of the binder being tested. High strain values are used for hard binders. The Rheometer measure the torque required to achieve the set shear strain and maintain this as the maximum torque during the test.
8. The data acquisition system automatically calculates  $G^*$  and  $\delta$  from the test data acquired when properly activated.
9. Save the results as .txt files.
10. Clean everything you used properly.

**Analysis and Results**

- Identification and description of binder tested
- Test temperature and sample dimensions, including thickness
- Stress level
- $G^*$  and  $\delta$
- $G^*/\sin \delta$
- Strain amplitude
- Linearity

## HMA Gyrotory Compaction Test HMA Specific Gravity Tests Tensile Strength

### Standards

- *ASTM D2726: Bulk Specific Gravity of Compacted Bituminous Mixtures*
- *ASTM D2041: Theoretical Maximum Density (Rice Method)*

### Purpose

- To gain familiarity with procedures used in the SUPERPAVE mix design process.

### Equipment and Materials<sup>†</sup>

- 4500 g of aggregate (60% coarse, 40% fine) – placed in the oven at a constant temperature of 165 °C to dry.
- Asphalt binder PG 52-34 (Preheated to 160 °C)
- Mixing bowls
- Spatulas
- Gyrotory compactor
- Gyrotory compaction molds
- Specific gravity testing equipment
- Split-cylinder test apparatus
- Safety glasses

<sup>†</sup>See figure 3.2.1 for partial display.



Figure 3.2.1. Partial display of materials used.

### Overview

Each lab group will prepare a 4.5 kg batch of hot mix asphalt with asphalt content in the range of 4% to 7% by mass. From this mix, two gyrotory compaction specimens will be created, and one Rice specific gravity measurement will be taken. On the gyrotory compaction specimens, their bulk unit weight and bulk specific gravity will be measured; finally, the tensile strength of the compacted specimens will be

measured using a split cylinder test. The Rice specific gravity test measures the specific gravity of the mix that would be achieved if all air-voids could possibly be compacted out, and is designated  $G_{mm}$ . The bulk specific gravity of the mix that is measured is denoted by  $G_{mb}$ . For a given mix,  $G_{mb}$  will generally be smaller than  $G_{mm}$ , because the compacted specimen typically has some air-voids in it. From both,  $G_{mm}$  and  $G_{mb}$ , the air-void content of the mix (VTM) can then be calculated.

### **SAFETY WARNING**

- Extreme caution should be used in this lab. ***All materials are very hot!***
- Any person working directly with the HMA will wear heat resistant gloves at all times.
- Be careful – do not rush! Pay attention to detail!
- Space is limited. Please place all belongings in the lab next door.

### **Experimental Procedure**

1. Place the mixing bowl on the balance and tare.
2. Pour the aggregates (~4500 g) into the bowl and record the actual mass ( $m_{agg}$ ).
3. Multiply the actual mass of aggregate and multiply this by the percent binder by mass that you are specified to add ( $m_{binder}$ ). Tare the scale.
4. Form a crater in the aggregates and pour the proper amount of asphalt into the crater.
5. Remove the mixing bowl from the scale and mix using a mechanical mixer (figure 3.2.2). Mix the specimen until the aggregate is thoroughly coated (usually 60-90 seconds on speed 1).



Figure 3.2.2. Hobart™ mixer.

6. Measure out two pie pans of 1150 g (be sure to tare the pans before adding mix). These will be used to make two compacted specimens. Measure out a third pan of 1150 g of loose mix (record this mass as  $M_{\text{HMA}}$ ). Spread the mix around in the third pan and break up any large chunks. Place in front of the fan to cool for ~20 minutes. This will be used for the Rice test procedure.
7. Gyratory Compactor
  - *Mold Setup*
    1. Remove the mold and caps from the oven. **\*\*VERY HOT!!\*\***
    2. Make sure there is a cap at the bottom of the mold.
    3. Place a paper in the bottom of the mold.
    4. Place the 1150 g of HMA into the mold using the spoon. Use the spatula to sift it around.
    5. Drop another paper into the mold.
    6. Carefully slide the top cap over until it drops straight into the mold. The instructor will show a technique.
    7. The order in the mold from top to bottom should be: cap – paper – HMA – paper – cap.
  - *Computer Setup*
    1. Go to the computer next to the compactor and open the program **GYROTALK**.
    2. Click “Download”
    3. Using the file tree, find the folder “Lab Class (2006)”
    4. Give an identifying filename and click “Enter”.

- *Compacting*
  1. Place the mold carefully on the edge of the shelf and slide the bottom flange of the mold through the slots into the main chamber. There is a notch in the top flange that should seat over a pin. Close the door (figure 3.2.3).



Figure 3.2.3. Troxler™ gyrotory compactor.

2. On the display, the number of gyrations should be set to 75, if not press “Setup” then “1” and finally “75”.
  3. Press “Start”.
  4. Upon completion, follow the instructions shown on the display.
  5. Slide the mold out of the main chamber and over the corresponding circle on the shelf.
  6. Press “Enter”.
  7. The specimen is then extruded. Because the specimen is still very hot, it is weak and will crumble easily. Carefully take the specimen and set it over in front of the fan to cool for ~20 minutes.
8. Determine the maximum specific gravity of the loose mix ( $G_{mm}$ ) using the Rice test procedure below (figure 3.2.4).



Figure 3.2.4. Rice specific gravity apparatus.

- *Rice Specific Gravity Measurement*

1. Weigh out approximately 2000 grams of asphalt mix and allow it to cool in a pan to a temperature of 25°C. Record the precise weight of the mix as  $W_{HMA}$ . Using a spatula, chop up any large clumps of your mix, trying to get all of the coated aggregate specimens as separated as is possible in a few minutes time. Allow the mix to cool 20-30 minutes.
2. Fill the container until it is overflowing. Place the lid on and push it down firmly. Dry the outside of the container, and then measure its mass,  $D$ . Empty all but about  $\frac{1}{4}$  of the water from the container.
3. Place the ~2000 grams of asphalt mix into container. The container should be about half full.
4. Place the lid back onto the container and set it into the vibration harness and set the vibration level between 9 and 10. Pull a vacuum of 30 mmHg (using the dial on the gauge to keep it constant) on the contents for approximately 15 minutes. (Here, the objective is to remove trapped air from the submerged mix.)
5. Fill the container to overflowing and press the lid down firmly. Dry the outside of the container and then re-weigh,  $E$ .
6. Compute the Rice specific gravity  $G_{mm}$  of the mix as follows:

$$G_{mm} = \frac{W_{HMA}}{D - E + W_{HMA}} \quad (3.2.1)$$

9. Determine the bulk specific gravity of the compacted mix ( $G_{mb}$ ) by weighing the compacted mix in the air, in the water, and in SSD condition (see below).

- *Bulk Specific Gravity Measurement*

1. Take the compacted specimen and measure its weight,  $A$ .
2. Take the same specimen and measure its weight when submerged in water,  $B$ .
3. Take the specimen out of the water: Briefly dry it off as demonstrated by the instructor and then re-weigh. This gives the SSD (saturated surface-dry) weight,  $C$ .
4. The bulk specific gravity of the specimen  $G_{mb}$  is given by the following formula:

$$G_{mb} = \frac{\text{(weight in air)}}{\text{(SSD weight)} - \text{(submerged weight)}} = \frac{A}{C - B} \quad (3.2.2)$$

The corresponding bulk unit weight of the specimen is simply

$$\gamma_{mb} = G_{mb} \gamma_w \quad (3.2.3)$$

10. Measure the tensile strength of the compacted specimen using a split-cylinder test (figure 3.2.5).



Figure 3.2.5. Split-cylinder test apparatus.

- *Test Frame Setup*

1. Power everything on and make sure the stop button is out.

2. Place the specimen into the split-cylinder harness and place the harness in the center of the test frame.
  3. Press the “UP” button to move the lower crossbar up and “STOP” when it is ~ 2 cm from the upper crossbar.
  4. Center the harness again and setup the LVDT displacement gauge.
  5. Press “UP” again then “STOP” when the top of the harness just makes contact with the upper crossbar. *This will happen quickly.*
  6. Press “SETUP” then “F2” for “Run Test”. Press “F1” for the “Marshall” test.
  7. The test is then automated and will begin to lower once the specimen has failed.
  8. Press “STOP”.
- *Computer Setup*
    1. Open the program *Humboldt Download*.
    2. Click on “Import Wizard”.
    3. Follow the instructions:
      - COM 1
      - HM3000
      - Single Download
    4. On the test stand, press “F3” for “Review Data”, and then press “F1” for “Print Data”.
    5. In the program, click “Finished”.
    6. You can now review the download:
      - Channel 1 → Load
      - Channel 2 → Displacement
    7. Click “Save Selected Project”.
    8. Find the folder “Lab Class (2006)” and give a filename. Press “Enter”.

The tensile strength is given by the formula below where  $P$  is the maximum force,  $h$  is the height of the specimen (available from the gyratory compaction test), and  $d$  is the diameter (10 cm).

$$\sigma_{t,ult} = \frac{2P}{\pi hd} \quad (3.2.3)$$

### Analysis and Results

- Calculate  $G_{mm}$ ,  $G_{mb}$ ,  $\gamma_{mb}$ ,  $\sigma_{t,ult}$ , and VTM.

$$VTM = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \cdot 100\% \quad (3.2.3)$$

<b>Group(s):</b>	<b>Day:</b>	<b>Time:</b>
<b>Binder Content = _____ %</b>		
<b>m<sub>agg</sub>, g</b>		
<b>m<sub>binders</sub>, g</b>		
<b>Rice Specific Gravity Test</b>		
<b>m<sub>HMA</sub>, g</b>		
<b>D, g</b>		
<b>E, g</b>		
<b>G<sub>mm</sub></b>		
<b>Bulk Specific Gravity Test</b>		
	<b>Specimen #1</b>	<b>Specimen #2</b>
<b>A, g</b>		
<b>B, g</b>		
<b>C, g</b>		
<b>G<sub>mb</sub></b>		
<b>γ<sub>mb</sub></b>		
<b>Air-Void Content</b>		
<b>VTM, %</b>		
<b>Indirect Tensile Strength</b>		
<b>D, mm</b>		
<b>H, mm</b>		
<b>P, lbs</b>		
<b>σ<sub>t,ult</sub>, psi</b>		
<b>σ<sub>t,ult</sub>, kPa</b>		

## Lab Report 3 Guidelines

### Overview:

In this set of labs, we dealt with HMA in which the binder used was PG52-34. In the first lab, we tested the binder to find its viscosity. In the second and final lab, each lab section tested a mix with different binder content (4, 5, 6, and 7% by weight as a percentage of the aggregate weight). In each lab section one group measured the Rice specific gravity of their mix. The other groups in each section: (1) compacted a sample using the gyratory compactor, recording height versus gyration data; (2) measured the bulk unit weight (or bulk specific gravity) of their compacted specimen; and (3) measured the tensile strength of their specimen.

- **Introduction:**

This should just be a paragraph outlining what you did in the labs and will go into further detail later in the report.

- **Background:**

Briefly introduce HMA as a civil engineering material. Define key terms, and introduce the tests that you performed with any applicable equations.

- **Materials and Methods**

- Explain the mixing and testing procedure.

- **Data/Data Analysis**

All relevant data (viscosity of binder, Rice specific gravities, bulk specific gravities, and ultimate tensile strengths for each mix) for the four different hot-mix asphalt (HMA) mixes tested over the past month can be obtained from the website. For data analysis, quantitatively compare the properties for each mix.

- **Discussion**

- Discuss the viscosity properties of the binder at 135.0°C and why the viscosity was measured at this temperature.
- Compare and discuss each mix in terms of Rice specific gravity, bulk specific gravity, air-void content, and ultimate tensile strength.
- From a pavement engineering standpoint, it is desired that the compacted mix have an air-void content of 4% as this has been empirically correlated with optimal durability. Discuss the suitability of each mix in this regard.

# **Fiber-Reinforced Plastic Composites**

## Tensile Testing of FRP Composite Materials

### Standards

- *ASTM D3039: Tensile Properties of Polymer Matrix Composite Materials*

### Purpose

- To determine the affect that fiber orientation has on the following: stress-strain relationship, yield strength, modulus of elasticity, and the failure strength.
- Compare the experimental results to the calculated theoretical results.

### Equipment and Materials

- *Tinius-Olsen* load frame (Figure 4.1.1)
- Computer with *LabVIEW*<sup>®</sup>
- Extensometer
- Caliper to measure original dimensions of specimen
- Permanent marker
- Specimens: CFRP with three different fiber orientations ( $0^\circ$ ,  $\pm 45^\circ$ ,  $90^\circ$ )
- Safety glasses

### SAFETY WARNING

- Extreme caution should be used in this lab. ***The FRP specimens splinter when they fail.***
- All persons should wear safety glasses at all times.
- Be careful – do not rush! Pay attention to detail!



Figure 4.1.1. Lab setup

### Theoretical Properties

- The fiber and matrix properties are given in Table 4.1.

**Table 4.1. FRP Constituent Properties**

Fiber (Grafil 34-700)	Matrix (Epoxy)
$\phi_f = 0.65$	$(1 - \phi_f) = 0.35$
$E_f \approx 250 \text{ GPa}$	$E_m \approx 3.3 \text{ GPa}$
$\sigma_{ult,f} \approx 1700 \text{ MPa}$	$\sigma_{ult,m} \approx 5 \text{ MPa}$

- Estimate the properties of the composite when it is loaded in the fiber direction by using the Voigt (or upper) bound.

$$E_{long} = \phi_f E_f + (1 - \phi_f) E_m. \quad (4.1.1)$$

$$\sigma_{ult,long} = E_{long} \varepsilon_{fail,long} \quad (4.1.2)$$

$$\varepsilon_{fail,long} = \varepsilon_{fail,f} = \frac{\sigma_{ult,f}}{E_f} \quad (4.1.3)$$

- Estimate the properties of the composite when it is loaded in the transverse direction by using the Reuss (or lower) bound.

$$E_{trans} = \frac{E_f E_m}{(1 - \phi_f) E_f + \phi_f E_m}. \quad (4.1.4)$$

$$\sigma_{ult,trans} = \sigma_{ult,m} \quad (4.1.5)$$

$$\varepsilon_{fail,trans} = \left[ \frac{\phi_f}{E_f} + \frac{(1 - \phi_f)}{E_m} \right] \sigma_{ult,m} \quad (4.1.6)$$

### Experimental Procedure

- Place the specimen in the testing machine. (Figure 4.1.2)



**Figure 4.1.2. Specimen mounted in grips.**

2. Attach the extensometer to the specimen, securing it tightly. Carefully remove the pin by rolling it back and forth.
3. Type initial data into the *LabVIEW*<sup>®</sup> program. Run *LabVIEW*<sup>®</sup>.
4. After the *LabVIEW*<sup>®</sup> program has started collecting data, start the testing machine. (We will go over this in more detail in class.)
5. Continue applying the load until the specimen breaks. At this point, stop *LabVIEW*<sup>®</sup>.
6. Obtain the data/results file from the computer and copy it to your own disk.

### **Analysis and Results**

- Plot the stress versus strain curve using Excel.
- Use a trend line to obtain the modulus of elasticity,  $E$ .
- Determine the ultimate strength,  $\sigma_{ult}$ .
- Determine the strain to failure,  $\epsilon_{fail}$ .

Name: \_\_\_\_\_

Date: \_\_\_\_\_

**Material Properties**

	<b>Fiber</b>	<b>Matrix</b>
<b>Material</b>		
<b>E, GPa</b>		
<b><math>\sigma_{t,ult}</math>, MPa</b>		
<b><math>\phi</math> (volume fraction)</b>		

**Effective Elastic Modulus**

<b>Orientation</b>	<b><math>E_{Theoretical}</math></b>	<b><math>E_{Experimental}</math></b>	<b>% Difference</b>
<b>Longitudinal</b>			
<b>Transverse</b>			

**Effective Ultimate Strength**

<b>Orientation</b>	<b><math>\sigma_{Theoretical}</math></b>	<b><math>\sigma_{Experimental}</math></b>	<b>% Difference</b>
<b>Longitudinal</b>			
<b>Transverse</b>			

**Effective Strain to Failure**

<b>Orientation</b>	<b><math>\epsilon_{Theoretical}</math></b>	<b><math>\epsilon_{Experimental}</math></b>	<b>% Difference</b>
<b>Longitudinal</b>			
<b>Transverse</b>			

Qualitatively compare and discuss the results.

Briefly discuss the results from the  $\pm 45^\circ$  specimens.

1. Class notes: 53:086. C.C. Swan. University of Iowa. 2006
2. Materials for Civil and Construction Engineers. M.S. Mamlouk and J.P. Zaniewski. Addison-Wesley. 1998.
3. Materials for Civil & Highway Engineers, 4<sup>th</sup> Ed. K.N. Derucher, G.P. Korfiatis, and A.S. Ezeldin. Prentice Hall. 1998.
4. Mechanics of Materials, 6<sup>th</sup> Ed. R.C. Hibbler. Pearson Prentice Hall. 2005
5. Design and Control of Concrete Mixtures, 13th Ed., Portland Cement Association. 1988.
6. Reinforced Concrete: Mechanics and Design, 3<sup>rd</sup> Ed. J.G. MacGregor. Prentice Hall. 1997.
7. Construction Materials: Their Nature and Behaviour, J.M. Illston (Ed.). E&FN Spon. 1996.
8. Laboratory Notes for Mechanical Behavior of Materials, J.W. Phillips. University of Illinois. 2003.
9. *LabVIEW, Version 7.1*. Austin, TX: National Instruments.
10. *Partner, Version 6.0b*. Grove City, PA: Instron Corporation.