Fall 2019

University of Texas Rio Grande Valley

Mechanical Engineering Department

MECE 2140 Engineering Materials Lab Laboratory Procedures

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UTRGV
Fall 2019

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General Course Description

EQUIPMENT:

- Permanently bound lab notebook with gridded pages
- Ballpoint pen
- Safety glasses
- Appropriate lab clothing

COURSE GRADE:

	Fall/Spring	Summer
Written Lab Reports/Memos	50%	65%
Final Project & Presentation or Final Exam	25%	-
Lab Notebook	15%	20%
Quizzes	10%	15%

In industry, your ability to absorb and communicate technical information in both written and oral forms will be a significant factor in your success or failure. To help you improve your skills in these areas, this class will require you to record and present the results of experiments in several different contexts.

1. **Data book of daily experimental results.** Data book records of experiments and the development of the new ideas are important in liability and patent cases. Records should include not only results, but also the details of reasoning which led to the performance of experiments. A reader should be able to reconstruct the entire thought process, which resulted in a particular product or development.
2. **Written reports or memos.** A suggested format for each is included later in the document. Remember that much of your communication in the outside world will be "informal" but it will still need to be concise, complete, and clear.
3. **Oral presentation.** You will be performing a materials selection/testing project and making an **informal** oral presentation of your analysis to the class during the final lab period. A hard copy of your presentations will be turned in at the completion of the presentation.
4. **Industrial Standards.** The ability to read standards and translate them into a course of action for a testing program is a critical skill for a practicing engineer. You will be given several opportunities to study ASTM testing standards and experimental procedures and then develop your own laboratory procedure from them.

ATTENDANCE POLICY

For this class to provide the necessary exposure and experience, it is imperative that you attend all lab sessions. If you must miss a session, see the instructor **before the fact** about observing during other class periods. Obtain any data you need from your lab partners. When you miss class, your participation grade will suffer. You will be allowed a maximum of 1 absence for the whole semester. Any student with more than 1 absence will be dropped from the class.

CLASS STRUCTURE

You will be assigned to laboratory teams of 3 to 5 students in which you will perform all lab experiments this semester. The course will consist of a series of rotations. Each group will work on a different component of the rotation each week until all have completed the rotation. Reports for each rotation will be due after the completion of the rotation.

INDIVIDUAL WORK POLICY

You will be working together in the lab environment to obtain your data and results. You are encouraged to work together in analyzing those results. **However**, the work you turn in must be **YOUR OWN**. Evidence of direct copying from another student or a text will result in loss of credit for the assignment. Repeated cases of copying will be reported to the Dean of Students and may result in dismissal from the class and loss of credit.

Evidence of copying might include things such as:

- Use of data other than that taken by the student (without proper explanation).
- Use of plots and tables other than those individually developed by the student.
- Out-of-context answers obviously taken from someone else's laboratory reports.

Written Reports

LAB REPORT FORMAT

- **Cover Page**
- **Background & Theory**
  - Introduce the theory for the lab you are conducting
    - Used to provide the reader with a reason to read the report
- **Objective**
  - Should be a single, concise paragraph stating the purpose of the experiment
    - Describe what you are trying to find and why
    - Reason you are conducting the present experiment
- **Experimental Setup & Procedures**
  - Hardware & software used to conduct the experiment
  - Depiction of experiment setup
    - Must appropriately show how to set up to record data
  - A short description of the experimental procedure
    - What steps did you take to successfully perform the lab?
    - Anyone should be able to recreate the lab from the instructions you provide in this section.
- **Results & Discussion**
  - Put the **pertinent** data obtained from your experiment in a clear, concise chart.
  - Briefly describe the theoretical analysis and data analysis procedures and present and discuss your results
    - Include any, and all, equations used to perform the analysis.
    - The analysis may be in chart and/or graph form.
    - If equations were used to calculate specific values, then a chart **and** graph are necessary.
    - Be sure to have captions for all graphs, figures, and tables.
  - Discuss trends and individual analysis results in paragraph format after each graph or chart.
- **Conclusions**
  - What were the results from the analysis that was performed on your data?
    - Use the graphs and charts to make conclusions about the stated objective.
  - How do your results compare to theory learned in class?
  - Tie your conclusions to topics you have learned in class and to everyday situations.
  - Be sure to have answers to any attached questions in your discussion.
  - Do not express feelings in the conclusion. Be technical with your conclusions. Use your knowledge to make connections and decipher data.
- **References**
- **Appendix**
  - Raw data not included in lab report

Title Page Format

THE UNIVERSITY OF TEXAS – RIO GRANDE VALLEY

COLLEGE OF ENGINEERING AND COMPUTER SCIENCE

DEPARTMENT OF MECHANICAL ENGINEERING

MECE 2140

MATERIALS LABORATORY

FALL 2015

LABORATORY SECTION # ___

GROUP # ___

LABORATORY ANALYSIS FOR

LAB NAME GOES HERE

PREPARED FOR:

INSTRUCTOR'S NAME GOES HERE

BY:

YOUR NAME GOES HERE

_____

DUE DATE: DATE GOES HERE

DATE RECEIVED: _____

TECHNICAL MEMO FORMAT

MEMO

Date: Date turned in goes here
To: Instructor's Name
From: Your name goes here
Subject: As appropriate

- Brief description of your objective and procedures followed

- Data & Results
    - Be sure to have pertinent data tables
        - Not all data should be reported in a memo. Think about what you are trying to communicate. If a data table adds no understanding, which a graph does not already give, do not include one.
    - Be sure to include clear, concise graphs or charts
- Discussion
    - Discuss the outcome of your findings
- Conclusion
    - Memos are supposed to answer a particular question. Be sure you actually answer that question.
        - Your answer should be obvious.
    - Tie your conclusions to topics and theory learned in class and to everyday situations

See the following memo format.

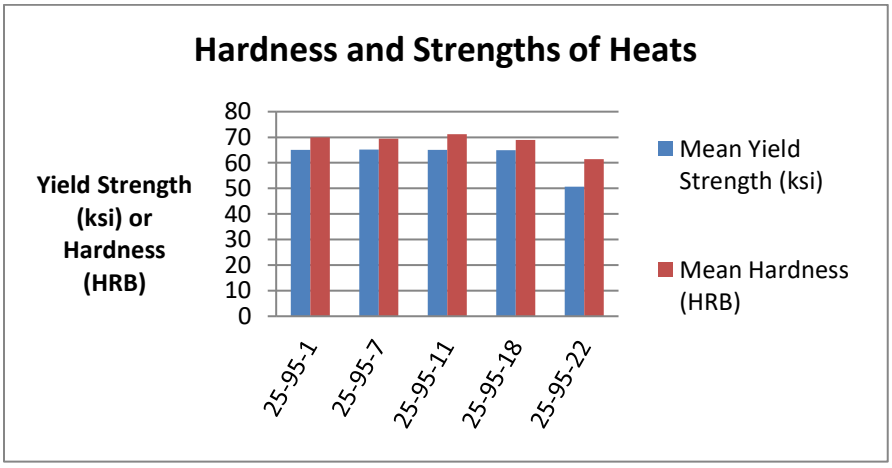
MEMO

Date: August 26, 2012
To: Instructor's Name
From: John Doe, BSME
Subject: Quality Assurance Testing of Heat 25-95

The results of testing on the quality assurance samples from heat 25-95 are summarized below. The five samples were taken from rounds rolled from different billets poured from the heat. Each sample was cut into five tensile specimens which were hardness tested (Rockwell B scale) and then loaded to failure in a tension test. Samples were allowed to air cool to laboratory temperature and were aged twenty-four hours in the laboratory prior to testing. Mill scale was removed from the hardness test regions using a water-cooled belt grinder. Tensile tests utilized a constant strain rate of 0.05"/min and testing conformed to ASTM standard E-8.

Results & Discussions:

Sample ID	Mean Yield Strength (ksi)	Standard Deviation	Mean Hardness (HRB)	Standard Deviation
25-95-1	65	2	70	3.52
25-95-7	65.2	2.32	69.5	3.05
25-95-11	65.1	2.13	71.2	3.65
25-95-18	64.9	2.58	68.9	4.02
25-95-22	50.7	2.31	61.4	2.57



Students' T-test (using a 95% confidence level) indicates that sample 25-95-22 is different from the prior samples by a statistically significant margin. Thus, the last material rolled is substantially softer than earlier products.

The most likely explanation for this is the loss of carbon in the molten metal on the top of the ladle as it sits exposed to atmosphere while the ladle is drained. Spectroscopy has been requested to verify the composition of these specimens and results should be available within the week. Should you require further information please contact me.

POINTS OF CONCERN FOR MEMOS & REPORTS

- Your lab report should be written from an objective point of view (3rd person).
    - Do not use I, we, us, etc.
    - Objective means to leave your feelings out of it.
- Present data and analysis professionally and correctly.
    - Include all equations used for your analysis.
    - A graph or table without labels and units is worthless.
        - Self-explanatory graph title
        - Axis titles with units
        - Select appropriate axis range
        - Do not randomly connect data using straight lines.
        - Use <u>different symbols</u> for different data sets.
            - Provide a legend in this case.
        - Use error bars when uncertainty is calculated.
    - Units are essential for any engineer. **MAKE SURE THEY ARE THERE!**
    - Watch out for the default graph settings in Excel or other spreadsheet programs. They are the wrong type for most engineering problems.
        - Scatter plots
            - Show the relationship among the numeric values in several data series
            - Allow plotting two groups of numbers as one series of XY coordinates
            - Typically used for displaying and comparing numeric values, such as scientific, statistical, and engineering data
            - Used when independent variable data does not have the same scale
        - Bar or column charts
            - Illustrate comparisons among individual items
            - Data ranges in values
        - Line graphs
            - Ideal for showing trends in data at **equal** intervals, i.e. time, distance, etc.
            - Used when independent variable data has the same scale
    - When you are asked to plot “A vs. B”, this means that B is the independent variable (x-axis or horizontal) and A is the dependent variable (y-axis or vertical).
    - If you do not know how to use Excel or another spreadsheet program, YouTube or Excel Help are fantastic sources to teach yourself.

- Please watch your grammar and vocabulary.
    - One of the fastest ways to raise questions about your competence is to create documents with misspelled words.
        - There is a spell checker in every word processing program on campus. **USE IT!**
        - You can install Grammarly on your computer to check your grammar in all your programs.
        - Visit the University Writing Center is located on the third floor of the Student Academic Center (STAC 3.119) in Edinburg and the third floor of the library (UBLB 3.206) in Brownsville.
        - Read your report aloud; if you cannot understand it, then your instructor will not be able to either. If your instructor cannot understand it, then you will not get any credit.
        - Read your report/memo to someone.
- Do your own work.
    - Labs are completed as a group; however, lab reports/memos are done individually. There is no hesitation from faculty to turn you in to the Dean of Students if you are caught copying, cheating, pawning someone else's work off as your own, collusion, etc.
    - Make your own charts, graphs, conclusions, etc.
        - Using someone else's work (charts, graphs, conclusions, etc.) is cheating. Their work is their intellectual property, and yours is yours. Stealing their intellectual property is dishonest, intolerable, and can get you expelled from the university.
    - If your work (homework, lab reports, projects, etc.) is stolen, do not hesitate to let your professor know when or just after you turn in your assignment.
    - Evidence of copying might include things such as:
        - Use of data other than that taken by the student (without proper explanation)
        - Use of plots and tables other than those individually developed by the student
        - Out-of-context answers obviously taken from someone else's laboratory write-up

Laboratory Notebooks

The keeping of accurate and complete laboratory notebooks is a critical basic component of most design and development jobs. The notebook is a legal record of the problems encountered and ideas developed in the course of engineering. Good records are critical to support patent claims and for defense against liability claims. It is important that the notebook be an accurate record of the thought processes and activities leading to a final product or conclusion.

Contents of a Well Written Lab Entry

- **Problem statement/objective:** Why are you doing this? What do you hope to learn?
- **Procedure:** How were specimens prepared? How were tests done? This should be complete but you may use reference to commonly accepted procedures rather than detailing the steps in a process which is frequently performed. If an ASTM procedure is followed, you may merely reference it and cite any deviations from the procedure or identify subtypes within the standard. (E.g. Type III specimens were prepared and tested according to ASTM E-9 procedures.) It is generally not wise to reference ASTM standards if you do not know what is actually in them.
- **Data & Analysis:** What did you measure, see, and hear during the testing or evaluation?
- **Discussion & Conclusions:** Discuss the significance of the data, offer interpretation, and point out any surprising results. What do the results mean? Did you fulfill your objective? Did you answer the question?

Procedural Rules for Lab Books

- Label the first page as a table of contents and fill it in as you use the notebook.
- Lab notebooks should be written in **pen**.
- Do not erase or black out errors. Line through them and continue.
- Pages should be signed and dated when finished.
- Pages which are not filled should have blank areas marked out with an X.
- Leave no blank pages.
- Legibility is mandatory, beauty is not.
- Write the records as you go during lab. **DO NOT** write on scratch paper and recopy later.
- Figures should be firmly taped in place (all four sides) not stapled.

There is not a template to follow when recording down in a laboratory notebook. You should record information and data down as you go. Do not rely on your memory to fill in your notebook after the fact.

Laboratory Schedule

EDINBURG CAMPUS

Week	Lab	Output
Unit I - Introduction		
1	Introduction, Safety, Group assignments	
	Introductory Lab	Report &/or Memo
Unit II - Characterization of a Metal/Alloy		
2	Determination of Case Depth (1,2,3,4)	Memo
3	Tensile Properties of Metals (2,3,4,1)	Graphs
4	Analysis of Failing Steel Bolts (3,4,1,2)	Memo
5	Identifying the Impact Transition Temperature of Steel (4,1,2,3)	Memo
Unit III - Thermal Properties of Materials		
6	Cure Optimization of Thermosetting Adhesives (1,2,3,4)	Memo
7	Jominy Test for Comparing Heat Treatability of Steels (2,3,4,1)	Memo
8	Creep Testing of Polymers (3,4,1,2) (See note below)	Memo
9	Construction of a Phase Diagram (4,1,2,3)	Memo
Unit IV – Mechanical Properties of Thermoplastic Polymers		
10	Rate Dependence of Thermoplastic Polymers (1&2, 3&4)	Report
11	Impact Testing of Thermoplastic Polymers (3&4, 1&2)	
Unit V - Final Project		
12	Material Testing Assignment	
13	Material Testing Assignment	
14	Final Project Presentations	Report & Slides

See next page for schedule notes.

BROWNSVILLE CAMPUS

Week	Lab	Output
Unit I - Introduction		
1	Introduction, Safety, Group assignments	
	Introductory Lab	Report &/or Memo
Unit II - Characterization of a Metal/Alloy		
2	Jominy Test for Comparing Heat Treatability of Steels (1,2,3,4)	Memo
3	Tensile Properties of Metals (2,3,4,1)	Graphs
4	Analysis of Failing Steel Bolts (3,4,1,2)	Memo
5	Identifying the Impact Transition Temperature of Steel (4,1,2,3)	Memo
Unit III - Thermal Properties of Materials		
6	Determination of Case Depth (1&2, 3&4)	Memo
7	Construction of a Phase Diagram (3&4, 1&2)	Memo
Unit IV – Mechanical Properties of Polymers		
8	Rate Dependence of Thermoplastic Polymers (1,2,3,4)	Report
9	Impact Testing of Thermoplastic Polymers (2,3,4,1)	
10	Cure Optimization of Thermosetting Adhesives (3,4,1,2)	Memo
11	Residual Stress Approximation in Pipes (4,1,2,3)	Memo
Unit V - Final Project		
12	Material Testing Assignment	
13	Material Testing Assignment	
14	Final Project Presentations	Report & Slides

SCHEDULE NOTES

- Creep Testing of Polymers (Output: Memo) can be replaced with Residual Stress Approximation in Pipes (Output: Memo).
- The numbers in parenthesis indicate the order in which each group will perform the lab for that rotation. The first number is the group to do that lab the first week; the second is the second week, etc. For example (2,3,4,1) means group 2 will do the lab the first week of the rotation, group 3 the second week, group 4 the third week, and group 1 the fourth week.
- Report means that a lab report is due for that particular lab. Memo means that a technical memo is due for that particular lab.
- Rotation V is not done in the summer sessions.

Laboratory Safety Rules

GENERAL SAFETY

1. If the floor around your machine is oily, protect others by cleaning up the spills immediately. Make sure no one will slip when they step on it.
2. If the fire alarm sounds, leave what you are doing in a safe manner and walk briskly (do not run) out of the building. Stay at least 150 feet away from the building until you are told by the safety officer to return to the building.
3. If you see a small fire, use the fire extinguisher to put it out. If the fire is large, let others in the laboratory know as soon as possible and use the nearest phone to call 911.
4. If someone is being electrocuted, keep away from the person and turn off the power source.
    a. Turn off the main power switch, unplug the cable, or go to the electric power panel and turn off the breakers.
    b. Do not touch the person as you may be electrocuted yourself. If you must touch, test touch with the back of your hand first so that you do not hold on when your hand clenches from a shock.
5. Locate the following:
    a. The nearest safety exit
    b. The nearest fire extinguisher
    c. The nearest telephone
    d. The electric power panels in the laboratory
    e. The nearest shower & eye wash station
6. No food or drinks in the laboratory.

DRESS CODE

1. Eye protection (safety glasses) must be worn at all times in the laboratory. Exceptions are only permitted when using optical microscopes and the SEM.
2. Protect your upper body.
    a. Loose clothing like long sleeves, ties, shirt-tails out, or skirts are not permitted.
    b. Roll up your long sleeves above your elbows, and tuck in your shirt.
    c. Delicate fabrics and flammable clothing are discouraged because flying chips and heat radiation can cause such clothes to burn.
    d. An apron will be provided if you request it.
3. Protect your lower body.
    a. Closed toe shoes must be worn. No sandals, flats, pumps, heels, etc. No part of your foot should be visible.
    b. Full length pants must be worn. No shorts, capris, etc. Jeans are preferred.
4. No jewelry is permitted on your hands. Remove any necklaces, rings, bracelets, and watches before working on machines.
5. Long hair must be tied back in a bun or inside a baseball cap. All baseball caps must be worn backwards (the bill at the back of your head).

SAFETY RESOURCES

1. Students must pay particular attention to safety in the laboratory since dangerous equipment and hazardous chemicals will be used.
2. Each student should read and sign the Technician Supervisor's red safety manual which contains information related to safety with respect to particular machines. You need to sign the manual only once in your career at UTRGV.
3. The MSDS sheets (contains safety data) for all chemicals used in the laboratory are available outside the Technician Supervisor's office.
4. You and all the university employees are responsible for your safety and the safety of the equipment and others around you.
5. Report any accident immediately to the instructor, laboratory assistant, or other staff member.

OPERATING MACHINERY

1. Do no use any equipment unless you know how to use it.
    a. Ask for permission before using it.
    b. Before using the equipment, identify the main power switch.
    c. Pay attention to any safety precautions needed around particular equipment.
2. No one should operate any machine unless another person is within sight and hearing.
3. Do not sit down while running any machine. Do not lean against the machines. Machines must not be left unattended while running.
4. Make certain the blade or spindle is completely stopped before touching your piece.
    a. Use tongs, hooks, or pliers when handling metal shavings on a running machine. Do not use gloves unless the machine is turned off.
5. Clean up any chips or scrap on the machine, work table, or floor after you are done.
6. If you take something out of a drawer or check out any instrument or tool, make sure you return it to its correct place.
7. Always note the location of the emergency stop buttons on equipment. If anything strange happens, do not hesitate to hit the button. On larger equipment (MTS, Sintech) one individual should be designated to stand near the emergency stop, ready to shut everything down.

BEHAVIOR

1. If the instructor or laboratory assistant observes a safety violation, the student will be told about it.
    a. The student must rectify the situation ***immediately***.
    b. A second violation will be provided in writing and reported to the instructor.
    c. A third violation will result in the student being asked to leave the laboratory immediately and may be removed from the class at the discretion of the instructor.
2. Extremely careless behavior that endangers the safety of others may lead to the student ***immediately*** losing privileges to use the laboratory for the semester.
3. Absolutely no horseplay will be tolerated at any time.

Laboratory Procedures

UNIT 1: INTRODUCTION

OBJECTIVE: Become familiar with the use of various measurement techniques and material testing machines while exploring the relationship between atomic bonds and material properties.

APPARATUS: Rockwell hardness tester, thermal expansion apparatus

TERMINOLOGY:

Hardness: The measure of a material's resistance to deformation by surface indentation or by abrasion.
Thermal Expansion Coefficient: The fractional change in length divided by the change in temperature.
Thermal Conductivity: The ability of a material to transmit (conduct) heat from one point to another. Inverse property is thermal resistivity.
Melting: The process by which a substance changes from the solid phase to the liquid phase.
Ionic Covalent Metallic Van der Waals

TECHNICAL BACKGROUND[1]:

Interatomic forces bind two atoms together. These forces, a net force with both attractive and repulsive components, determine the potential energy between two atoms. The bonding energy is the amount of energy (work) it would take to break the bond. The strength of the attractive forces drives materials properties. There are four types of primary bonds – ionic, covalent, and metallic, and mixed (or polar covalent).

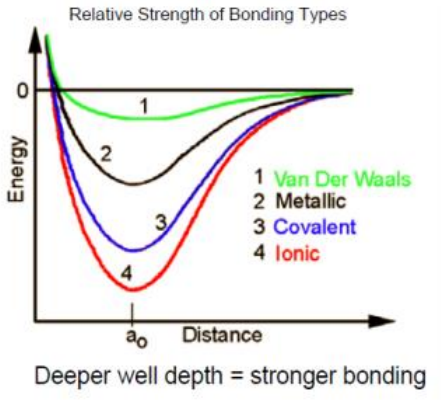


Figure 1: Bond strength for different atomic bonds

Ionic bonds exist between two adjacent and oppositely charged ions. Sodium Chloride (NaCl) and Magnesium Oxide (MgO) are two examples of ionic bonding. These bonds, generally, are the

[1] http://concept.asu.edu/toolkit/classnotes/1.2

foundation for hard and brittle materials such as ceramics and glass. Ionic bonds have relatively high bonding energies. This is apparent when looking at melting temperatures.

The sharing of electrons between neighboring atoms forms covalent bonds. Silicon and Carbon are two substances that experience this type of bonding. Polymers, semiconductors, and some ceramics are often formed from covalent bonds.

Metallic bonds involve the nondirectional sharing of nonlocalized valence electrons that are mutually shared by all the atoms in the metallic solid. Aluminum, iron, and mercury are a few examples of metallic bonds. These bonds possess a wide range of bonding energies and melting temperatures. The materials created from metallic bonds are generally good conductors.

A mixed bond is a bond with both ionic and covalent properties.

A secondary bond (or van der Waals bond) is between adjacent molecular dipoles, which may be permanent or induced. This type of bond is weak in comparison to primary bonds and is the bond responsible for keeping compounds liquid. When van der Waals bonds are broken, a liquid becomes a vapor. In polymers, the secondary bond is found between molecule chains. The molecule chain itself is comprised of covalent bonds. The van der Waals bond dominates in unoriented polymers.

In all bonds, the bond energy is defined as the work necessary to break the bond. The melting temperature is a direct measure of this material quantity as temperature (absolute) is directly proportional to the kinetic energy of the atoms in a piece of matter. When the kinetic energy of the atoms is great enough to overcome the attractive force between the atoms, the solid (primary bonds) melts or the liquid (Van der Waals bonds) vaporizes.

PROCEDURE:

HARDNESS

You will be evaluating the Rockwell hardness of various types of materials. You will need to make three measurements for each specimen and record the hardness data in Table 1. Be sure to record down the appropriate unit used to complete the Rockwell hardness tests. Please refer to the Safe Operating Procedures for the Rockwell Hardness Tester.

Table 1: Hardness Data

	Material	Hardness Test 1	Hardness Test 2	Hardness Test 3
Metals	Aluminum (Al)	HRA1	HRA1	HRA1
	Brass (Br)	HRD	HRD	HRD
	4140 Steel	HRC	HRC	HRC
Plastics	Acrylonitrile-butadiene-styrene (ABS)	HRR	HRR	HRR
	Polypropylene (PP)	HRR	HRR	HRR
	Poly(methyl methacrylate) (PMMA)	HRR	HRR	HRR

Once you have acquired your data, all values must be in the same scale for calculation and comparison purposes. Use the Hardness Conversion Table located in the laboratory to convert all metal hardness data to the same scale and record all converted values in **Error! Reference s ource not found.**. This is considered part of the analysis done on your data.

Table 2: Hardness Analysis (Conversion)

	Material	Hardness Test 1	Hardness Test 2	Hardness Test 3
Metals	Aluminum (Al)	HRA1	HRA1	HRA1
	Brass (Br)	HRA1	HRA1	HRA1
	4140 Steel	HRA1	HRA1	HRA1

It is important to make note of all hardness values measured. Usually these values are located in the appendix of the document. However, when reporting hardness information, individual values are not as important as the mean hardness of the data set. The rest of your analysis for hardness will be completed by calculating the mean hardness for each material tested. These values will be recorded in

Table 3: Hardness Analysis (Mean Calculation)

	Material	Mean Hardness
Metals	Aluminum (Al)	HRA1
	Brass (Br)	HRA1
	4140 Steel	HRA1
Plastics	Acrylonitrile-Butadiene-Styrene (ABS)	HRR
	Polypropylene (PP)	HRR
	Poly(methyl methacrylate) (PMMA)	HRR

Please take note of the formatting of the Introduction Lab handout. Similar formatting should be followed for your lab report. This will include table and chart captions and discussion of said tables and charts.

DENSITY:

You will calculate the density of various objects and determine the type of material each object is. To do this, you will be using a set of dial calipers and the analytical scale.

Weigh each object using the analytical scale. Place all values in the provided table (Table 4).

Measure the dimensions of each object using a dial caliper. See Figure 2 for information on how to read a dial caliper. Place all values in the provided data table (Table 4).

Table 4: Density Data Table

Material	Mass (g)	Length (in)	Diameter/Width (in)
Silver Metallic			
Black			
Wood			
Red			
Orange			
Yellow			
Green			
Blue			
Purple			
Dark Grey (Square)			
Light Grey			
Dark Brown			
White			
Gold			
Copper			

1. Calculate the volume of each object using the following equations. Place all values in the provided table (Table 5).

Equation 1: Volume equation for a cylindrical rod and square rod

$$V_{cyl} = \frac{\pi}{4} d^2 h \qquad V_{sq\ rod} = lwh$$

2. Calculate the density of each object using the following equation. Place all values in the provided table (Table 5).

Equation 2: Density Equation

$$\rho = \frac{m}{V}$$

Table 5: Density Analysis Table

Material	**Mass (g)**	**Length (cm)**	**D/W (cm)**	**Volume (cm^3)**	**Density (g/cm^3)**
Silver Metallic					
Black					
Wood					
Red					
Orange					
Yellow					
Green					
Blue					
Purple					
Dark Gray (Square)					
Light Gray					
Dark Brown					
White					
Gold					
Copper					

Table 6: Theoretical Density Values for Various Materials

Material Type	Material Name	Density (g/cm^3)
Composite	Cork	0.24
Composite	Pine	0.43
Composite	Walnut	0.64
Composite	Oak	0.75
Composite	Maple	0.77
Polymer	Polypropylene	0.90
Polymer	Low Density Polyethylene (LDPE)	0.92
Polymer	High Density Polyethylene (HDPE)	0.95
Polymer	Polystyrene	1.05
Polymer	Polyamide (Nylon)	1.15
Polymer	Acrylic	1.17
Polymer	Polyurethane	1.23
Polymer	Phenolic	1.32
Polymer	Polyvinylchloride (PVC)	1.37
Polymer	Polyethylene terephthalate (PETG)	1.28
Polymer	Acetal	1.42
Polymer	Chlorinated PVC (CPVC)	1.54
Metal	Magnesium	1.77
Polymer	PTFE (Teflon)	2.20
Metal	Aluminum	2.71
Metal	Titanium	4.30
Metal	Brass	8.56
Metal	Copper	8.91
Metal	Lead	11.6
Metal	Gold	19.3

THERMAL EXPANSION:

You will be determining the coefficients of thermal expansion (α) for copper, aluminum, and brass. To do this you will be utilizing the thermal expansion apparatus.

1. Measure the initial diameter (d) of the metal rods and length (L) of the experiment setup (Figure 3) using a dial caliper (Figure 2) and a ruler or tape measure, respectively. See figure below.

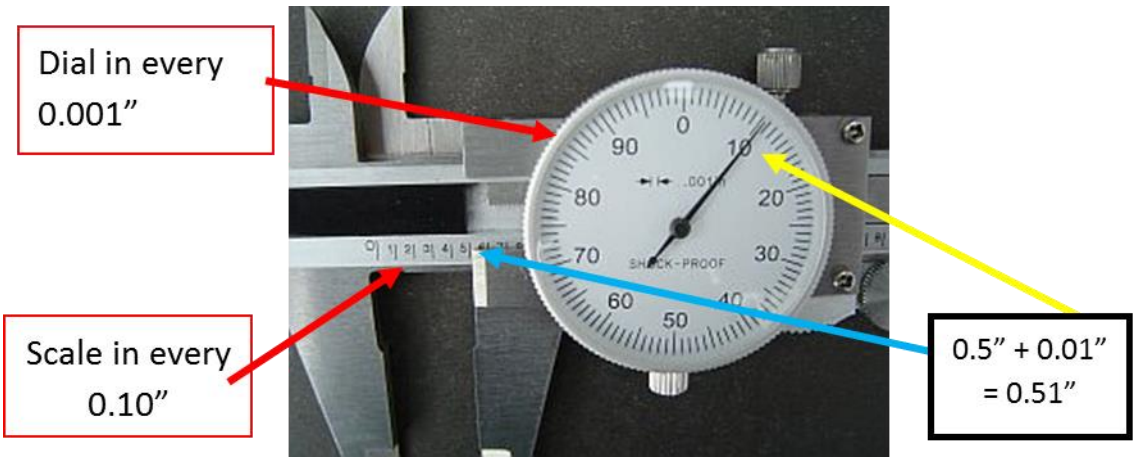


Figure 2: How to read a dial caliper

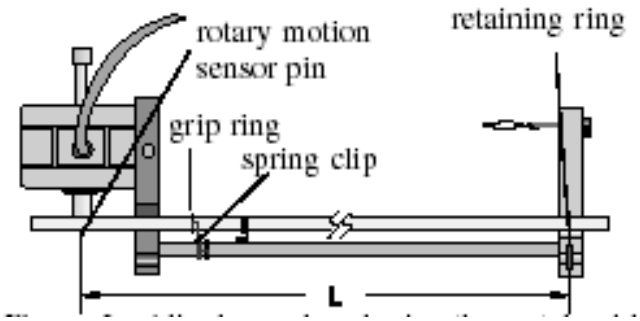


Figure 3: Thermal expansion apparatus setup. See length measurement (L)

2. Setup the first rod in the apparatus. Attach the thermistor to the rod with the spring clamp. Insulate the thermistor and rod with the slit, tubular foam wrap.

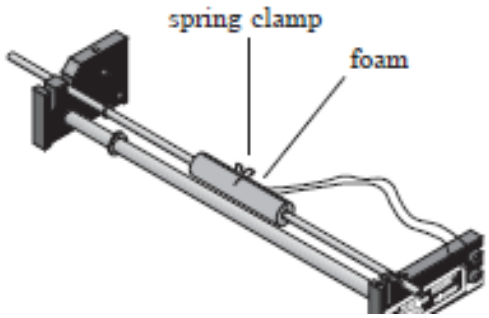


Figure 4: Insulating the rod

3. Load the Thermal Expansion Experiment in DataStudio on the computer next to the setup. Make sure all sensors are located and the program is ready to be started.
4. Place a cup beneath the outlet of the rod in the thermal expansion apparatus. One of the two tubes in a reservoir will be connected to the end of the rod in the apparatus (See Figure 5). As soon as the tube is attached to the rod, press start in DataStudio to begin acquiring data.

5. Be sure to record initial temperature of each specimen. It will be briefly displayed, so pay attention to the device.

Figure 5: Experimental Setup

6. When the temperature reading stabilizes, record the final temperature (T_f) and the expansion of the rod's length (ΔL) in Table 7.
7. Repeat the experiment for the other rods.
8. Convert the rod expansion measurement to inches, and calculate the coefficient of thermal expansion (α) for each rod using Equation 3. Record all conversions and calculations in Table 8.

Equation 3: Thermal Expansion Equation using Length

$$\Delta L = \alpha L \Delta T$$

Table 7: Thermal Expansion Data

Material	L (in)	ΔL (mm)	T_i (°C)	T_f (°C)
Aluminum				
Brass				
Copper				
Carbon Fiber Composite				
Acetal				

Table 8: Thermal Expansion Analysis

Material	L (in)	ΔL (in)	ΔT (°C)	α_L (in/in/°C)
Aluminum				
Brass				
Copper				
Carbon Fiber Composite				
Acetal				

Coefficients of thermal expansion for metals are very small. Usually a common factor is removed from the values and is reported back as µm/m/°C or µin/in/°C. This is shown in Table 9 as $x10^{-6}$/°C. It is understood that the common factor of 0.000001 was removed from all values in the table. Also, the dimensional part of the coefficient of thermal expansion is unitless since a length is being divided by a length. So the actual coefficient of thermal expansion for copper is 0.000017 in/in/°C. You are able to report 17 because $x10^{-6}$/°C is in the row header. This could also be shown as µin/in/°C since µ is typically representative of 10^{-6}.

Table 9: Coefficient of Thermal Expansion Analysis

Material	$\alpha_{Theoretical}$ ($x10^{-6}$/°C)	$\alpha_{Experimental}$ ($x10^{-6}$/°C)	Percent Error (%)
Aluminum	23		
Brass	19		
Copper	17		
Carbon Fiber Composite	3		
Acetal	19		

MELTING TEMPERATURES:

Below is a chart showing different melting temperatures for various materials.

Table 10: Summary Chart of Melting Temperatures

Material	Melting Temperature (°C)	Material Type
Mercury	-38.86	Metal
Poly(methyl methacrylate)	105	Plastic
Poly(vinyl chloride)	212	Plastic
Tin	232	Metal
Polyetheretherkeytone	334	Plastic
Aluminum	660	Metal
Steel	1425	Metal
Silicon Dioxide	1715	Ceramic
Magnesium Oxide	2798	Ceramic
Tungsten	3400	Metal

OUTPUT LAB REPORT:

Results & Discussion:

Convert all metal hardness measurements to the same scale using the conversion chart posted in the lab. Calculate the mean hardness for each material. Make 2 bar graphs of the mean hardness values (1 for metals and 1 for plastics). Two bar graphs are necessary because the data sets are not in similar hardness scales.

Convert all dimensions to the appropriate units in order to calculate density in g/cm^3. Calculate the density of each object and compare it to the values found in Table 6. Determine the material type and name of each object. Then calculate the percent error of your density calculation to the theoretical value.

Calculate all the variables needed to determine and calculate the experimental coefficient of thermal expansion for each rod. Create a bar graph comparing the experimental and theoretical coefficients of thermal expansion for the different materials. Evaluate the error in the results with respect to the given theoretical values using the following equation.

Equation 4: Percent error equation

$$\%\ Error = \left(\frac{Experimental - Theoretical}{Theoretical}\right) \times 100$$

Conclusions:

Determine how the bond types are associated with the different material properties. Discuss how bond types affect thermal expansion, thermal conductivity, melting, density, and hardness. Furthermore, comment on why ceramics have higher melting temperatures than most metals and why some metals melt at lower temperatures than some plastics.

Please take note of the formatting of the Introduction Lab. Similar formatting should be followed for your lab report. This will include table and chart captions and discussion of said tables and charts.

OUTPUT TECHNICAL MEMO:

For the technical memo, convert all metal hardness measurements to the same scale using the conversion chart posted in the lab. Calculate the mean hardness for each material. Make 2 bar graphs of the mean hardness values (1 for metals and 1 for plastics). Two bar graphs are necessary because the data sets are not in similar hardness scales.

Convert all appropriate units in order to calculate density g/cm^3. Calculate the density of each object and compare it to the values found in Table 6. Determine the material type and name of each object. Then calculate the percent error of your density calculation to the theoretical value. Create a table that states the name of each object, calculated density, material type, theoretical density, and the percent error value.

Calculate all the variables needed to determine and calculate the experimental coefficient of thermal expansion for each rod. Create a bar graph comparing the experimental and theoretical coefficients of thermal expansion for the different materials. Evaluate the error in the results with respect to the given theoretical values using Equation 4.

In a couple of sentences, discuss how bond types affect thermal expansion, thermal conductivity, melting, and density.

Please take note of the formatting of the Technical Memo. Similar formatting should be followed for your first laboratory memo. This will include table and chart captions and discussion of said tables and charts. Make sure that it is only ONE page long.

UNIT 2: ENGINEERING CHARACTERIZATION OF A METAL

INTRODUCTION: The behavior of engineering materials is usually characterized by several different test methods. A complete understanding of the engineering properties cannot be obtained from a single test or procedure. This unit will introduce a standard group of procedures, which might be used to characterize a metal or alloy.

APPARATUS: Metallographic equipment, microhardness tester, Rockwell hardness tester, Charpy pendulum impact tester, temperature bath, universal testing machine, and microscopes

OBJECTIVES: Measure a standard set of material parameters commonly used to characterize a material for engineering design. Then relate these parameters to the microstructure and processing history of the material and compare them with other materials with different compositions or processing histories.

ASTM STANDARDS: E-384 Microindentation Hardness of Materials
E-8 Tension Testing of Metallic Materials
E-3 Preparation of Metallographic Specimens
E-112 Determining Average Grain Size
E-18 Rockwell Hardness Testing
E-140 Standard Hardness Conversion Tables for Metals
E-23 Notched Bar Impact Testing of Metallic Materials

BACKGROUND: This unit consists of four characterization procedures performed in a rotation by each group each week.

A. Case Depth Analysis
B. Tensile Properties of Metals
C. Analysis of failing Steel Bolts
D. Impact Transition Temperature of Metals

Refer to the following sections for instructions and background on the individual units.

Ferrous materials are identified by one of three number schemes. We will be utilizing the ASTM standard nomenclature for all specimens. In this scheme, the first two digits of the four-digit identifier indicate the alloy family. The third and fourth numbers indicate the carbon content. To obtain the weight percent carbon, divide the last two digits by one hundred.

Examples:

1018 steel 10: plain carbon steel (no alloying)
18: 18/100 = 0.18 wt% carbon

4140 steel 41: alloy steel
40: 40/100 = 0.40 wt% carbon

Part A: Determination of Case Depth

INTRODUCTION: This rotation involves the basic characterization of the hardness of a heat-treated component. Many manufactured ferrous components undergo processing to produce a hardened surface. This process will harden the material to some depth below the surface. This hardened region is called the case.

ASTM STANDARD: E-384 Microindentation Hardness of Materials

OBJECTIVE: Determine the depth of case hardening in a heat-treated drive train component.

TERMINOLOGY:

Case Depth Microhardness Map Heat Treatment Diffusion

PROBLEM BACKGROUND: Your company has experienced field failures with a heat-treated drive train component. The design engineers specified a case depth of 4 mm with a minimum hardness of 40 HRC. You are given a mounted sample of the component and must determine if this part meets these specifications and provide evidence.

TECHNICAL BACKGROUND: Many engineering components are specially treated to produce a harder outer casing. Components such as gears, splines, drive shafts and bearings are often surface hardened by carburizing, nitriding or other processes which increase the concentration of elements that harden. In quenched components, the natural thermal gradient in the part generally insures that the surface will be harder than the bulk. The depth of this harder region can be critical to the performance of a component and is often specified.

Microhardness testing is a hardness measurement made using a special optical instrument. The area sampled by a microhardness tester is much smaller than that of Rockwell type testers and the position control is extremely fine. In fact, individual features such as grains and inclusions can often be analyzed using the microhardness tester. The instrument can be used to map the hardness profile across a component. This permits the identification of the work-hardened zone or the depth of hardening in a case hardened component.

The Vickers technique also differs from the Rockwell type machines in that it uses a dead load to push a diamond indenter into the surface of the specimen. The depth of penetration is determined by measuring the diagonals of the pyramidal indentation after load removal rather than the depth of travel during the load application. Thus, the technique can be applied to specimens that are mounted in softer materials such as acrylic or phenolic with no appreciable error in measurement.

The Shimadzu HMV-G21D Microhardness Tester uses a diamond pyramid indenter to perform the Vickers test and may be used to determine a wide range of hardness values through adjustment of the applied load. Vickers hardness (*HV*) is based on the relation:

Equation 5: Vickers hardness equation

$$VH = 0.1891\left(\frac{F}{d^2}\right)$$

where, *F* = Test force (N), *d* = average of two diagonal lengths (mm). If appropriate tables are available, the Vickers hardness number can be converted to other common hardness values.

***The modern digital microhardness tester in the UTRGV laboratory performs the VH calculation automatically when the optical micrometer is utilized. It will also perform an automatic conversion to one other hardness scale*.**

Similar to the Vickers technique, the Knoop hardness test follows the same methodology but with a rhombic-based pyramidal-shaped diamond indenter. Knoop hardness (*HK*) is based on the relation:

Equation 6: Knoop hardness equation

$$HK = 1.451\left(\frac{F}{d^2}\right)$$

where *F* = Test force (N), *d* = length of the long diagonal of the indentation (mm). If appropriate tables are available, the Knoop number can be converted to other common hardness values.

PROCEDURE: Cut the specimen with the wet saw to allow work on a face perpendicular to the original surface contour. Polish the cut surface using standard metallographic preparation techniques. Fine polishing is not necessary. Use microhardness tests to produce a map of the hardness profile near the surface of the tooth. Make measurements across the entire tooth in 0.5 mm increments (1 turn on the microhardness tester). See the safe operating procedures for the Shimadzu HMV-G21D Microhardness Tester.

Readings are best made in a lightly etched condition to aid in locating structures of interest. If structures are not being tested then the surface need merely be polished. Heavy etching should be avoided since it could adversely affect test results.

NOTEBOOK:

1. Table of position, average diagonal length, Vickers hardness, Rockwell hardness (HRC), and hardness calculations (HV).
2. Microhardness map
3. Estimate of depth of the hardened case.

OUTPUT TECHNICAL MEMO:

Write a technical memo following the aforementioned format. Your company has experienced field failures with this component. The design engineers specified a case depth of 4 mm with a minimum hardness of 40 HRC. Determine if the part meets this specification and provide evidence. You should include the actual depth of this case and the microhardness map in support of your conclusion. Provide recommendations if needed.

Part B: Tensile Properties of Metals

INTRODUCTION: The tensile test is the most commonly used method of estimating engineering parameters for a material. It is a simple, uniform stress state test which is easily analyzed.

ASTM STANDARD: E-8 Tensile Testing of Metals

OBJECTIVE: To determine standard engineering material parameters for several alloys and examine the difference between elastic and plastic deformation.

PROBLEM BACKGROUND: Your boss is asking you to determine the mechanical properties of specific types of metal and provide evidence of your findings.

TECHNICAL BACKGROUND: The most commonly used material characterization test is a uniaxial tension test. In the tension test, a specimen is subjected to a continuously increasing tensile displacement (or load) while simultaneous measurements are made of the elongation of the specimen and the applied load. The measurements are used to construct an engineering stress-strain curve for the test.

The engineering stress is the average longitudinal stress in the specimen which is given by:

$$\sigma = \frac{P}{A_o}$$

where P = load and A_o = original specimen cross-sectional area

The engineering strain used to construct the curve is the average linear strain found from:

$$\varepsilon = \frac{(L - L_o)}{L_o}$$

where $(L - L_o)$ = elongation of the gage length, and L_o = the original gage length

Several parameters are commonly used to describe the shape of the stress-strain curve. These include Young's modulus (E), yield strength (S_y), tensile strength (UTS), percent elongation, and reduction in area (ROA).

Young's Modulus (elastic or tensile modulus) is the slope of the linear portion of the stress strain curve. Below are general values for the modulus of different materials.

Table 11: Young's Modulus for Metals

Materials	Modulus (Msi)
Steel	30
Aluminum	10
Brass	15

Tensile Strength, or ultimate tensile strength is the maximum applied load divided by the original cross-sectional area of the specimen.

Yield Strength is the load corresponding to a small arbitrarily specified plastic strain (generally 0.002) divided by the original cross-sectional area of the specimen. The actual elastic limit is extremely difficult to determine, thus the strength at 0.2% plastic elongation is the preferred engineering parameter for describing the onset of plastic deformation. Yield strength is generally more sensitive than the tensile strength to the effects of heat treatment, processing, and the method of testing.

Percentage Elongation (or strain to failure) is the ratio of the increase in the length of gage section of the specimen to its original length, expressed in percent:

$$\%\, Elongation = \frac{(L_f - L_o)}{L_0} \times 100$$

where, L_f = gage length at fracture, and L_o = original gage length
The elongation of the specimen is uniform along the gage length up to the maximum load. When neck formation begins, the strain is no longer uniform.

Reduction in Area: The percentage reduction in area is the ratio of the decrease in the cross-sectional area after fracture to original area.

$$\%ROA = \frac{(A_o - A_f)}{A_o} \times 100$$

A high percentage elongation or reduction of area indicates the material has a significant ability to deform without fracture. This ability is commonly called ductility.

Total Work of Fracture (Tensile Fracture Energy) is the total amount of energy needed to fracture a material in tension. The area under a stress-strain curve will give this value. An approximation can be calculated using the following formula:

$$U = \left(\frac{S_y + UTS}{2}\right)\varepsilon_f$$

PROCEDURE:
Measure specimen diameter and gage length and check them for surface flaws. Carefully test the tensile specimens following the ASTM standard using the Sintech UTS. See safe operating procedures for the Sintech UTS. It is always good practice to check the calculated modulus and strength of the first specimen as soon as it has been tested - to be sure your results are reasonable- before testing the second. Steel has a modulus near 30 Msi and it changes very little with alloy or carbon content.

NOTEBOOK:

1. Table of Young's Modulus, yield strength, strain to failure, and UTS
2. Calculate and record the % ROA, % elongation, and tensile fracture energy for each alloy.
3. Graphically compare theoretical modulus to experimental modulus for all materials.
4. Graphically compare % ROA and % elongation for each material.
5. Graphically compare the tensile fracture energy
6. Compare the results of the differing metals. Report back the effects of carbon content on the UTS for steel, the ductility of the materials, and other general observations.

OUTPUT GRAPHS:

Produce a stress vs strain graph including all the materials tested. Also, using additional pages, include single stress vs strain curves for each material with manual analysis for each specimen as done in class.

Part C: Analysis of Failing Steel Bolts

INTRODUCTION: The materials scientist has several tools which are used to characterize the microstructure of materials. These are vital since the macroscopic behavior of materials is dependent on the microstructure

APPARATUS: Rockwell hardness tester, metallographic preparation equipment, digital microscope

ASTM: E-18 Rockwell Hardness Testing
E-3 Preparation of Metallographic Specimens
E-112 Determining Average Grain Size
E-140 Standard Hardness Conversion Tables for Metals

OBJECTIVE: Master basic metallographic and microstructural measurement skills while exploring the relationship between microstructure and hardness.

TERMINOLOGY:
Metallograph: optical microscope designed for metallurgical examination, usually, the specimen is placed above the objective lens on a platform (inverted microscope).

Photomicrograph (or micrograph): photograph taken through a microscope. You must always indicate the magnification if a micrograph is to be useful.

Etching: microstructure is often difficult to observe on a highly polished specimen. The differing resistance of the phases and the phase/grain boundaries to acid attack make it possible to highlight the phases by coating or dipping the material in an acid solution for a time. Samples must be thoroughly washed and dried before they are placed in a microscope to protect fragile optical instruments from corrosion.

Grade: A metric used to characterize mechanical material properties of bolts, specifically strength

Grain Grain Size Grain Boundary Hardness

PROBLEM BACKGROUND: Your company is having problems with a batch of bolts stripping as they are tightened to the specified torque levels. You are given examples of the bolts as well as examples from prior batches that performed adequately. Determine the metallurgical factors that may be contributing to this change in performance.

TECHNICAL BACKGROUND Metallographic techniques permit the examination of the microstructure of engineering materials. The microstructure may consist of various phases, grains, grain boundaries, dislocations, fibers, particles, voids, cracks etc. Since mechanical properties are determined by the microstructure, metallography is a valuable tool in analyzing novel materials and in determining the cause of failure of structures.

Grain Size Determination

There are a number of methods for determining the average grain size in a polished and etched metallographic specimen.

1. **ASTM Grain Size**: Ferrous alloys are rated on a Logarithmic scale based upon the expression $a = 2^{n-1}$, where n is the American Society for Testing and Materials (ASTM) grain size and a is the number of grains per square inch when viewed at a magnification of 100x. Nonferrous grain sizes have generally been based upon a linear diameter scale and have been expressed as average grain diameter in inches or in millimeters. If your micrograph is not taken at 100x, you can convert to get the ASTM grain number using the following equation:

Equation 7: Conversion Equation for Grain Number at 100x Magnification

$$N_m \left(\frac{M_m}{100}\right) = 2^{n-1}$$

2. **Direct comparison with standards**: The grain sizes viewed at 100x can be directly compared to standard micrographs prepared by ASTM.

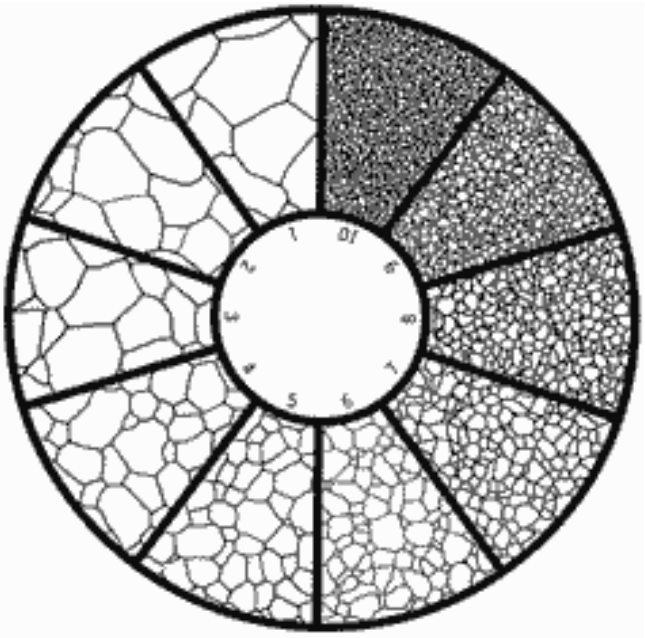


Figure 6: Actual grain size at 100x magnification for direct comparison

3. **Measurement of Average Grain Diameter**: Direct measurement of the average diameters of a large number of grains is a frequently used method. You can do this digitally in the lab.

4. **The Jeffries Method**: In this method, the number of grains falling within, and on, a circle 79.8 mm in diameter (5,000 mm^2 area) drawn on a ground glass screen, is determined. This method is extremely tedious if used properly.

5. **Alternative Method**: Diagonals are drawn across the microstructure. The number of intersections between a diagonal and grain boundaries are counted. The grain size may be determined using the equation:

Equation 8: Grain Diameter Equation for the Alternative Method

$$Grain\ Diameter = 1.68\left(\frac{L}{NM}\right)$$

where, L is the diagonal length, N is the number of intersects, and M is the magnification at which the grain size is measured.

Hardness (Rockwell)

Hardness usually implies a resistance to deformation. In metals, it refers to the material's resistance to permanent or plastic deformation. In materials science, it will generally refer to the resistance to the depth of permanent deformation due to a surface indentation.

Hardness tests (Rockwell, Brinell, Knoop, and others) are frequently used to monitor the quality of material coming into and/or out of a manufacturing facility. Though hardness numbers are not directly useful to the engineer, they can be used to estimate engineering parameters such as yield strength and ductility. Thus, they provide a quality control parameter for the design engineer to specify which can be easily measured.

The Rockwell type hardness uses the depth of indentation under load as a measure of hardness. A minor load of 10 kg is first applied to the sample. This step minimizes requirements for surface preparation. The major load (selected based upon the scale being used) is then applied and the depth of indentation is recorded by the machine. The result is an arbitrary hardness number. A high hardness material will allow little penetration. The dial (or digital readout) is configured so that a small penetration corresponds to a high hardness number. Thus, a high hardness number means a hard material.

Brinell and Vickers hardness numbers have units of kg/m^2, however Rockwell numbers have no units. Though it is arbitrary, the Rockwell scale is the most widely used because of the huge existing base of data linking hardness values to heat treatments, yield, and ultimate strength.

There are a number of Rockwell scales available. They include the A, B, and C scales as well as superficial scales R-15-N and R-30-N and a number of others. Each scale is obtained by an appropriate use of different indenters (steel ball or diamond brale) and major loads (15, 30, 45, 100, 150 kg). Superficial scales are used when the specimen being tested is very thin or when a thin coating on a substrate needs to be characterized. See the attached chart for details of the different scales.

It is sometimes useful to compare the relative hardness results of materials for which values are known on different Rockwell scales. In these situations, an equivalence table (such as the one posted on the wall of the laboratory) will permit the approximate conversion from one scale to another.

Note: Always identify the Rockwell scale you are using when presenting data. The numbers alone are meaningless.

PROCEDURE:

Cut specimens suitable for mounting and hardness testing from the provided bolts using the **abrasive cutoff saw**. See safe operating procedures for operational instructions for the Buehler ABRASIMET Cut-off saw.

Depiction of cuts to be made on each bolt

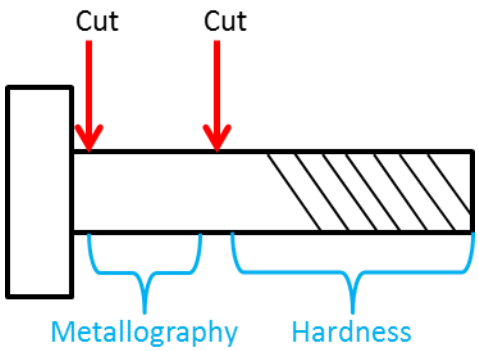


Figure 7: Depiction of cuts to be made on each bolt

Metallography

1. Mount specimens in bakelite using the **hydraulic mounting press**. (Put both specimens in one mount). See safe operating procedures for operational instructions for the Buehler Mounting Press.
2. **Polish** samples. Refer to the polishing SOP for details about Polishing of Metallographic Specimens.
3. Etch the specimens using Nital solution. Quench the etched sample with methanol.
4. Examine the specimen surface using the digital microscope. Survey the specimen and choose a representative area.
5. Take a micrograph (for the technical memo) and make a sketch (in lab notebook) of representative areas of the specimens. You will evaluate grain size using 2 of the 5 aforementioned methods.

Hardness

You will be evaluating the Rockwell hardness of the specimens using a **Rockwell Hardness Tester** (see SOP for operational instructions). Each test specimen requires five readings. It is common practice with the Rockwell test to take six measurements and throw out the first reading

to permit fixtures and the specimen to seat firmly. Use the smooth shank portion of the bolt for Rockwell testing.

POSSIBLE QUESTIONS:

Does the grain structure vary within the bolt?
Does hardness vary with location and/or orientation in the bolt?
Can you explain the grain structure of the bolt in terms of the manufacturing process?
Are there compositional differences between the two bolts?
How does the grain structure differ in the two bolts?

NOTEBOOK:

1. Record all experimental results and observations (including a description of the bolts evaluated). Be sure to include important details of procedures but don't write exhaustive accounts of the process.
2. Indicate how many photomicrographs were taken.
3. Indicate the grain sizes determined based on the various methods used.
4. Calculate the average and standard deviation of the hardness results using the following equations. Note: n is the number of samples, x_i is the individual sample values, $\bar{x}$ is the mean calculation, σ is the standard deviation calculation.

Equation 9: Equation for Mean Calculation

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Equation 10: Equation for Standard Deviation

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

5. Discuss bolt grades.
6. Discuss the differences between the two bolts based on the testing done.

OUTPUT TECHNICAL MEMO:

Write a technical memo following the aforementioned format. Your company is having problems with a new batch of bolts which are failing in service. You are to determine the metallurgical differences between the failing and adequate bolts and report on the likely source of the problem and recommend appropriate action. You should include hardness data and graphical results, micrographs, grain size data and results (**by at least two methods**), and any other relevant observations in support of your findings.

Part D: Identifying the Impact Transition Temperature

INTRODUCTION: Steel alloys are among the materials that exhibit an important behavior: as the temperature is reduced below some critical level, they undergo a rapid decrease in impact toughness as measured by Charpy or Izod impact tests. The actual temperature of the transition varies from alloy to alloy and with processing history.

OBJECTIVE: Determine the ductile to brittle transition temperature for a metal using the three specified methods.

ASTM STANDARD: E-23 Notched Bar Impact Testing of Metallic Materials

TERMINOLOGY: Ductile to Brittle Transition Temperature (DBTT). Metals having a BCC or HCP crystal structure experience a transition in their dominant fracture mode from ductile to brittle (cleavage) fracture at a characteristic temperature. This temperature depends on the particular composition, thermal history, and deformation history of the metal. Below this temperature the metal will absorb very little energy in fracture. Above this temperature, it is unlikely to fail by cleavage and will absorb much more energy during failure. The identification of the DBTT can be based on three different criteria that are discussed in the ASTM standard.
Notch Ductile Brittle Lateral Expansion

PROBLEM BACKGROUND: Your company is planning to build equipment for arctic applications and is considering this alloy. Determine if this alloy will be suitable for arctic applications and provide evidence.

TECHNICAL BACKGROUND:

Early efforts to understand the brittle failure of metallic materials utilized the Charpy or Izod type impact fracture test specimen. The most common approach to preventing brittle fracture in service was to utilize knowledge of the ductile to brittle transition temperature. This temperature is determined by testing a series of specimens at progressively lower temperatures. In theory, brittle fracture would be prevented by limiting service to temperatures above the DBTT. In practice, there are several problems with the approach. The primary danger in using this approach is the likelihood of underestimating the DBTT because of limitations in the design of the specimens themselves. The Charpy and Izod specimens are small, blunt notched designs that will give unrealistically low values for the DBTT in some materials. However, the test is still widely used and can be valuable if applied with care.

Methods of DBTT Determination:

1. Temperature at the energy midway between the brittle and ductile plateaus.
2. Temperature at the midpoint of the transition in the lateral expansion vs temperature plot.
3. Temperature at which 50% of the fracture surface is brittle and 50% is ductile. This is also known as the fracture appearance transition temperature (FATT).

PROCEDURE:

You will be testing a few specimens of an alloy that will also be tested by the other groups in your lab. All of the results will be combined to give everyone a large enough data set for useful analysis. Each group will be given 2 specimens. You will notch both specimen using Blacks Charpy Notch Machine. You will test all of them at the same temperature using the Satech pendulum impact tester and record your average values on the results chart. See Safe Operating Procedures for **SATECH Pendulum Impact Tester** and **Blacks Charpy Notch Machine.** Test temperatures (in Celsius) will be as follows:

Table 12: Temperature assignments per group

Fall/Spring	Group			
Section	1	2	3	4
Even #s	-20	0	30	60
Odd #s	-10	15	45	80

Summer	Group			
Section #	1	2	3	4
Morning	-20	0	30	60
Afternoon	-10	15	45	80

Recording Lateral Expansion:

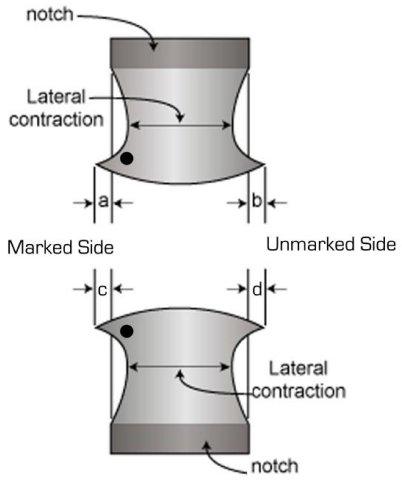


Figure 8: Depiction of Lateral Expansion Calculation

Lateral expansion can be determined by summing the larger expansion of the marked side and the larger expansion of the unmarked side, regardless of sign. For Example, if a > c and d > b, then you would add a and d to calculate the lateral expansion: LE = a + d.

NOTEBOOK:

1. Record fracture energy, lateral expansion, and surface appearance of your samples.
2. How to identify the DBTT using all three methods (must include graphs)

ADDITIONAL: Enter your data for each specimen (temperature, energy, lateral expansion, fracture appearance (as percent ductile) on the sheet provided for all labs. The data will be accumulated throughout the rotation to be used in your memo. The data per temperature will

need to be averaged and a standard deviation calculated. The averages will be used for graphing and determining the DBTTs.

OUTPUT TECHNICAL MEMO:

Your company is planning to build equipment for arctic applications and is considering this alloy.

a) Determine the ductile to brittle transition temperatures **by all three methods** (each method may yield slightly different results) for 1018 steel. Provide supporting documentation.
b) Is this material suitable for operating conditions near -40C?

NOTE: In order to complete this memo, you must include the information collected from ALL GROUPS in ALL MATERIALS LABS.

Table 13: Data table for impact testing of metals

	Temperature (°C)							
	-80	-50	-20	0	20	50	75	100
Fracture Energy (ft-lb)								
Lateral Expansion (in)								
Fracture Appearance (%Ductile)								

UNIT 3: THERMAL ANALYSIS OF MATERIALS[2]

INTRODUCTION: Temperature will affect all materials in a various manners. It is important to know how a material will behave when subjected to various temperatures. Some materials require elevated temperatures to solidify, while other materials will fail when subjected to elevated temperatures. In this rotation, you will explore material behavior when subjected to a heat treatment process.

EQUIPMENT: Horizontal and vertical band saws, creep stand, Thermolyne furnace, jominy end quench fixture, Rockwell hardness tester, differential scanning calorimeter

ASTM STANDARDS:
- E-1928 Estimating the Approximate Residual Circumferential Stress in Straight Thin-Walled Tubing
- A-255 End-Quench Test for Hardenability of Steel
- D-2990 Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics
- E-793 DSC for heat of fusion

OBJECTIVE: Explore how to characterize a material's thermal properties using basic tests.

BACKGROUND: This unit consists of four characterization procedures performed in a rotation by each group each week.

A. Cure Optimization of Thermosetting Adhesives
B. Jominy Heat Treatability of Steel
C. Creep Testing of Polymers
D. Construction of a Phase Diagram

All materials have thermal properties. These properties characterize materials based on temperature. Some mechanical properties of materials are dependent on temperature as well. Refer to the following sections for instructions and background on the individual units.

[2] http://concept.asu.edu/toolkit/classnotes/6.2

Part A: Cure Optimization of Thermosetting Adhesives

INTRODUCTION:
You are developing an adhesively bonded system for assembly of some metal components. An epoxy based adhesive film has been selected because of its superior toughness and environmental resistance. You need to determine the optimum cure time and temperature.

OBJECTIVE: Determine the appropriate cure time at several temperatures for maximum adhesive strength for two different adhesives.

ASTM STANDARDS: ASTM D1002: Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading

TECHNICAL BACKGROUND: Adhesive joints may fail in one of three modes: adhesive, cohesive, or adherend. In adhesive failure, the boundary between the adhesive and the bonded object(s) fails. In cohesive failure, the adhesive itself fails, remaining bonded to the adherend (s). In adherend failure, the adhesive is strong enough that the bonded components themselves fail.

PROCEDURE: Each group will perform a component of a larger study; data will be pooled to create a complete picture of the curing properties of this system.

Table 14: Temperature assignments for each group

Group #	Temperature (°C)
2	120
3	125
4	135
1	140

Cut 1 inch by ½ inch pieces of the adhesive film and fabricate single lap shear specimens using the steel adhesive test coupons provided. Clamp the specimens using binder clips, being careful to center the clips over the lap joint. Preheat the oven to the specified cure temperature based on your group number. Place the coupons on a steel sheet in the preheated oven. Remove a coupon thereafter at the appropriate time and test it in the Sintech UTS.

NOTEBOOK:

1. Data (including peak load and failure mode) for both adhesives
2. Calculate shear strength from the peak load.
3. Plot shear strength as a function of cure time for your data
4. Report optimal cure time for your temperature and discuss differences between the two materials (strength and failure mode)

TECHNICAL MEMO:

Plot shear strength as a function of cure time for all temperatures for both adhesives. Report the optimal cure time and optimal cure temperature for maximum strength with minimum time.

Table 15: Data table for Cure Optimization of Thermosetting Adhesives

		New Adhesive (Red)		Old Adhesive (Beige)	
Temp (℃)	Cure Time (min)	Peak Load (lb)	Failure Mode	Peak Load (lb)	Failure Mode
120	30				
	45				
	60				
	75				
125	30				
	45				
	60				
	75				
135	30				
	45				
	60				
	75				
140	30				
	45				
	60				
	75				

Part B: Jominy Test for Comparing Heat Treatability of Steel

INTRODUCTION: Steel alloys are an extremely versatile group of materials. Chief among the sources of this versatility is the ability to control the microstructure of components through judicious heat treatment. Not all alloys are easily hardened by heat treatment so hardenability is a basic property of a ferrous alloy which should be characterized.

OBJECTIVE: Produce hardenability curves for various alloys. Describe the effects of carbon and alloy content on hardenability.

ASTM STANDARD: A-255 End-Quench Test for Hardenability of Steel
E-18 Rockwell Hardness Testing

TERMINOLOGY: Hardness, Austenitize, Austenite, Heat Treatment, Quench, Anneal, FCC, BCC, Phase Diagram

TECHNICAL BACKGROUND: The Jominy end quench test is commonly used to characterize the fundamental hardenability of alloys. The test uses end quenching (water only applied to the very end of a cylinder) to produce a continuously decreasing quench rate along the length of the cylinder. Very near the end, the material will experience nearly instantaneous quenching and will thus have the maximum achievable hardness. Material along the cylinder will cool more slowly with increasing distance from the end and will thus be progressively softer. For this lab, normalizing of specimens before heat treating will be neglected (this is an option if supplier and customer agree).

PROCEDURE:

1. Refer to the ASTM standard for the details of the procedure (water flow rates, heating times, grinding procedure, hardness testing, data recording, water temperature etc.) and the method for estimating hardenability.
2. Austenitize the specimen by placing in preheated oven set at the appropriate temperature for 30-40 minutes.

Table 16: Austenitizing temperature of steel based on carbon content

Carbon Content	Austenitizing Temp. ^{o}F(^{o}C)
<0.25	1700 (925)
0.26-0.36	1600 (870)
>0.37	1550 (845)

3. Remove from furnace and quickly place in end-quench fixture in the sink.
4. Allow to cool to room temperature.

5. Grind a lengthwise flat strip to prepare a clean surface for hardness testing using the Leco Belt Grinder. See safe operating procedures for the LECO Belt Grinder. To do this, you will need to determine the width (c) of the strip that will remove approximately a depth (h) of 0.015" of material.

Equation 11: Equation for Chord Length

$$C = 2\sqrt{R^2 - (R-h)^2}$$

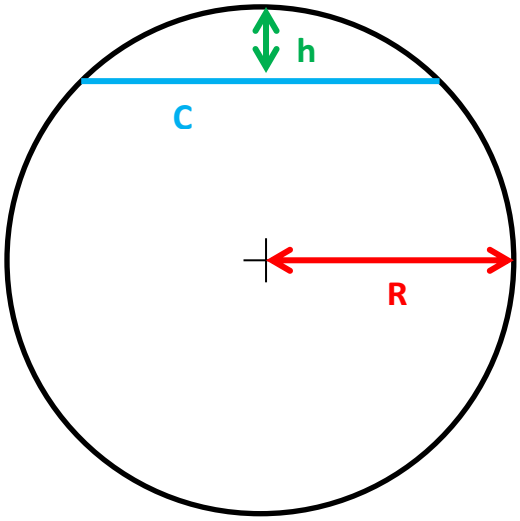


Figure 9: Depiction of variables for chord length calculation

3. Place specimen in special Jominy test fixture on Rockwell Hardness Tester and measure hardness beginning at the quenched end for two inches along the specimen length. See safe operating procedures for the Rockwell Hardness Tester.
    a. First 0.5" of bar perform a test every 1/16" (one turn)
    b. From 0.5 to 2 inches test every 1/8" (two turns)

NOTEBOOK:

1. Hardness data (in correct scale)
2. Graphically represent hardness as a function of position
3. Discuss findings and determine case depth.

OUTPUT TECHNICAL MEMO:

Plot the hardness curves for **ALL the alloys** studied by your class. Indicate which alloy would provide for the deepest case (35 HRC or above) and which would provide the highest surface hardness. Discuss the hardenability of each material.

Table 17: Suggested table to record hardness data in lab notebook.

		Rockwell Hardness			
		1018 Steel	4140 Steel	1045 Steel	8620 Steel
Cooling Rate (°F/s)	Position (in)	HR	HR	HR	HR
490	0.0625				
305	0.125				
195	0.1875				
125	0.25				
77.0	0.3125				
58.0	0.375				
42.0	0.4375				
33.0.	0.5				
21.4	0.625				
16.3	0.75				
12.4	0.875				
10.0	1				
8.3	1.125				
7.0	1.25				
	1.375				
5.1	1.5				
	1.625				
	1.75				
	1.875				
3.5	2				

Part C: Creep Testing of Polymers

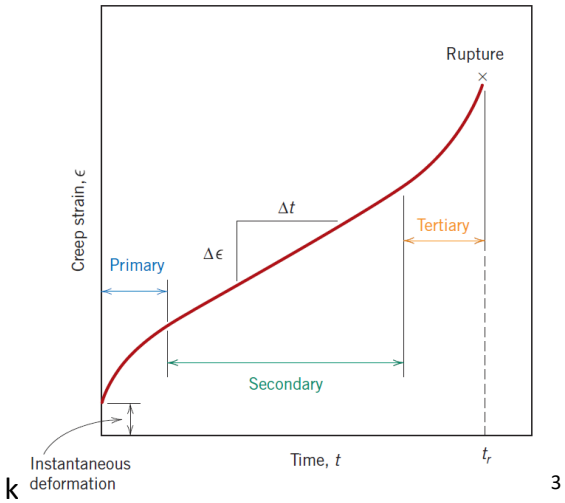
INTRODUCTION: At elevated temperatures, metals and polymers can undergo continuously increasing deformation at a constant applied stress. This is called creep deformation.

OBJECTIVE: Use testing data to determine specific creep constants and develop a master creep curve for a polymer.

ASTM STANDARD: D-2990 *Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics*

BACKGROUND: Creep in metals and ceramics is a diffusion driven process in which the material restructures in response to applied stress in a process of strain energy minimization. In polymers, creep is primarily due to the relaxation of molecules, that is, the unfolding and stretching of the polymer chains. This is a diffusion-like process as the energy of unfolding is thermal (as in atomic diffusion), the movements are random, and neighboring molecules must be out of the way (vacancies). Thus, both these processes can be modeled with similar expressions.

In creep testing, a constant load is applied to a specimen (usually in tension but can be in compression or bending) and the displacement of the specimen is monitored. The strain is plotted with respect to time. Most creep curves look like the figure below. The slope of the linear portion of the curve is the velocity of strain, $\frac{d\varepsilon}{dt}$ or $\dot{\varepsilon}$, or strain rate.



k 3

Figure 10: Typical creep curve of strain versus time at constant load and constant elevated temperature. The minimum creep rate Δε/Δt is the slope of the linear segment in the secondary region. Rupture lifetime t_f is the total time to rupture.

[3] Callister, William D. and Rethwisch, David G. Materials Science and Engineering: An Introduction, 9th Edition. Wiley & Sons, Inc. 2014

The velocity of strain depends on stress and temperature and is described by the expression

Equation 12

$$\dot{\varepsilon} = K_1 \sigma^n e^{\frac{-Q_c}{RT}}$$

For constant temperature (steady state), this reduces to

Equation 13

$$\dot{\varepsilon} = K_2 \sigma^n$$

The material constants n and K_2 are easily determined from a plot of $\ln(\dot{\varepsilon})$ vs $\ln(\sigma)$. The slope of the resulting line is n and the y-intercept will be K_2.

PROCEDURE:

Load five polycarbonate samples into the creep machine and set the oven to your assigned test temperature.

Table 18: Temperature and Load Assignment

Polymer	Group 1	Group 2	Group 3	Group 4
Polycarbonate	120°C	130°C	140°C	150°C
Polypropylene	90°C	100°C	110°C	120°C

Station	1	2	3	4	5
Load	2 N	5 N	7 N	10 N	15 N

Refer to the Safety Operating Procedures in Appendix A for DAQ and Load Application Mechanism Procedures.

NOTEBOOK:

To help with data analysis, Excel output file needs to be cleaned. If noted, the output file contains many blank cells in between data points. To erase these blank cells, press F5, select *"Special"*, checkmark *"Blanks"*, and click *OK*. Once blank cells are selected right-click and delete.

The resulting columns are Time, Temperatures 1-5, and Displacements 1-5, referring to sample stations.

Plot Displacement vs Time. In Excel, determine the steady-state creep rate for each specimen at your temperature.

Plot strain rate vs stress on a $log - log$ plot to determine linearized model constants for your temperature.

OUTPUT TECHNICAL MEMO:

Using data from other groups, determine the activation energy (Q_c) and the pre-exponential (K_1) for polycarbonate.

Create a log-log graph of strain rate vs stress for all temperatures. Predict the strain rate at 90°C and 110°C.

Table 19: Data table for Creep Testing of Polymers

Temperature (°C)	Strain Rate (in/in/s)	Stress (psi)	n	K_2	Q_C	K_1

Part D: Construction of a Phase Diagram[4]

INTRODUCTION: Phase diagrams are a widely used tool to determine the phases present, chemical composition, or phase fraction of an alloy given the temperature and composition. The Differential Scanning Calorimeter (DSC) is a member of a family of instruments that measure some property of a material as a function of temperature. The instrumentation suite in the materials laboratory includes four instruments: Differential Scanning Calorimeter (DSC), Simultaneous Differential Scanning Calorimeter/Thermogravimetric Analyzer (SDT, TGA/DSC), Thermomechanical Analyzer (TMA), and Dynamic Mechanical Analyzer (DMA).

Table 20: Thermal Analysis Techniques and Measured Properties

Technique	Property Measured as Function of Temperature
DSC	Heat capacity to 700°C
SDT, TGA/DSC	Weight and/or heat capacity to 1500°C
TMA	Thermal Expansion
DMA	Mechanical properties (stiffness, damping)

The measurement of heat capacity provides a means to detect the temperature(s) at which a material begins and finishes melting. Thus, the DSC can be used to construct a phase diagram for an alloy family.

OBJECTIVE: Construct a phase diagram of a given alloy by obtaining temperatures at melting and solidification using a differential scanning calorimeter.

ASTM STANDARD: E793 Enthalpies of Fusion and Crystallization by DSC

TERMINOLOGY: Solidus Line Liquidus Line Eutectic Point

TECHNICAL BACKGROUND: An equilibrium phase diagram is a map of the phase composition of all possible alloy ratios in a material system. The simplest diagrams are binary systems; they involve two elements or components. Phase diagrams are usually determined utilizing equilibrium conditions, meaning, extremely slow heating and cooling rates are utilized. Tests to find the onset of phase transformations usually use heating or cooling rates of fractions of a degree per day or slower. In this laboratory experiment, you will be using heating/cooling rates that are much faster than equilibrium rates. Thus, your diagram will be a dynamic phase diagram with the temperature of transformations shifted by the kinetic effects of rapid heating/cooling. In an equilibrium diagram, the onset of melting (on heating) and the end of solidification (on cooling) occur at the same temperature. Similarly, the beginning of solidification (on cooling) and

[4] http://concept.asu.edu/toolkit/classnotes/5.2

the end of melting (on heating) also will be the same. Kinetic effects cause these temperatures to shift. The greater the difference the greater the effect of heating/cooling rate.

The liquidus line is a boundary on a diagram above which only the liquid state exists.

The solidus line is the boundary below which all of the material will be solid.

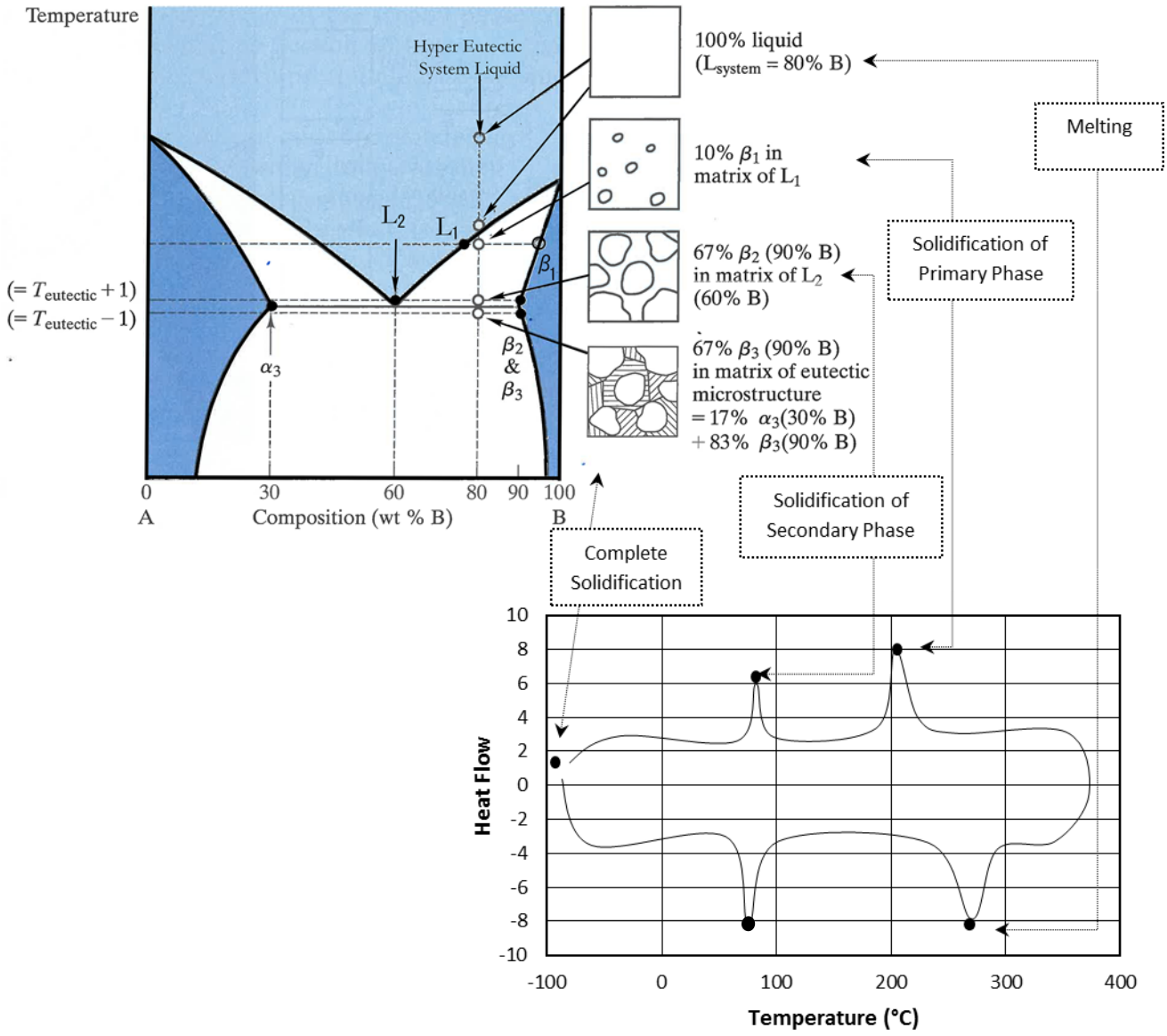


Figure 11: Relationship between microstructural changes and a DSC trace

When you have complete solubility of one component in the other, an Isomorphous Binary Phase Diagram is created. Bismuth (Bi) – Tin (Sn) System exhibits a limited solubility with no intermediate compounds which exhibits limited solubility generating a Binary Eutectic Phase

Diagram. The Bi-Sn system is widely used in electrical applications including the 40/60 solder. As a low melting alloy Bi-Sn can be a good substitution for the Lead (Pb)-Tin (Sn) solder system.

PROCEDURE:

Cut a 10mg sample of the given alloy and run a heat/cool loop in the differential scanning calorimeter. The heat up will be at 20°C/min up to 300°C, and the cool down will be at 10°C/min to room temperature. Open your run in Universal Analysis and find your solidification peak(s). Utilize the linear-peak integration tool in Universal Analysis to determine the peak solidification temperature(s) upon cooling.

NOTEBOOK:

1. Record your specimen information
2. Draw a copy of the DSC scan showing the analysis
3. Comment on the magnitude of the kinetic effect

OUTPUT TECHNICAL MEMO:

Construct one phase diagram for the alloy system using the peak solidification temperatures collected by ***all laboratory groups.*** Label the phases of the resulting phase diagram. Estimate the eutectic composition and temperature and the maximum composition for both alpha and beta phases. Comment on the relationship between the endothermic and exothermic reactions of the DSC trace obtained during lab and the microstructural changes.

NOTE: In order to complete this memo, you must include the information collected from ALL GROUPS in ALL MATERIALS LABS.

Table 21: Data table for Construction of a Phase Diagram lab

Composition (Wt% Bi)	Solidification Peak 1 (C)	Solidification Peak 2 (C)
0		
10		
20		
30		
43		
50		
60		
70		
80		
90		
100		

Part E: Residual Stress Approximation in Pipes

INTRODUCTION: The stress state in a component is the sum of all stress producing processes. In addition to external loads, stress may be caused by thermal gradients, uneven diffusion, and processing history. Stresses which exist in a material after it has been processed into a component but while it is still not under external load are called residual stresses.

OBJECTIVE: Calculate and compare the approximate residual stress in metal and polymer piping.

ASTM STANDARD: E-1928 Estimating the Approximate Residual Circumferential Stress in Straight Thin-Walled Tubing

TERMINOLOGY: Extrusion Cold Rolling Residual Stress Mean Circumference

BACKGROUND: Most fabricated components have stresses locked in by the manufacturing process. These stresses are usually created by mechanical forming processes which produce uneven plastic deformation in the part or by large thermal gradients during processing which may induce localized yielding in the material. These stresses are rarely significant contributors to gross failure due to overload. However, they are often key contributors to the failure of components at relatively low applied stress when the parts are seeing cyclic loading or when they are in aggressive chemical environments. A number of techniques are available for measuring these stresses. Among the easiest stresses to measure are the circumferential stresses in extruded pipe.

It is possible to estimate the engineering parameters for most ferrous and polymer piping by splitting rings of the pipe and measuring the resulting deformation. This analysis assumes a linear stress distribution through the pipe and does not address all of the safety concerns regarding the cyclic loading or thermal exposure of piping. However, it does provide good insight into the effects of manufacturing on the residual stress state.

In order to further understand how piping develops residual stresses, it is important to understand two major manufacturing processes. Polymer piping is generated by a process called extrusion, in which a material is melted and then pushed through a die. See the following YouTube videos for further information:

https://www.youtube.com/watch?v=WaB-dsB1Kfk

https://www.youtube.com/watch?v=wE_KTLlrdMA

Metal piping is usually made by solid extrusion or by rolling. Rolling is classified according to heating. If the material is heated past its recrystallization temperature, then it is considered hot rolling. Most pipes are manufactured by cold rolling, meaning they are heated to a temperature

below recrystallization and then formed over a die or rolled and welded. See the following YouTube videos for further information:

https://www.youtube.com/watch?v=rr9nCoZeEOg

https://www.youtube.com/watch?v=QKAg1yMZIpY

PROCEDURE:

Table 22: Material Assignment

Group #	Material	
1	Steel	Polyethylene
2	Copper	Poly-vinyl Chloride (PVC)
3	Brass	Polypropylene
4	Aluminum	Acrylonitrile Butadiene Styrene (ABS)

Mark each pipe ½" from one end and cut using the horizontal band saw or Buehler ABRASIMET Cut-off saw.

Take the half-inch pipe specimens and mark the pipe rings provided at two opposite points. Measure the outside diameters of the pipe rings using calipers. Take four measurements (every 45° from your initial mark) and find the average.

To facilitate these measurements, create a 1" diameter circle in your quad-notebook and draw 45° lines, as seen in Figure 12. Use these lines to create your markings on your half-inch pipe specimen.

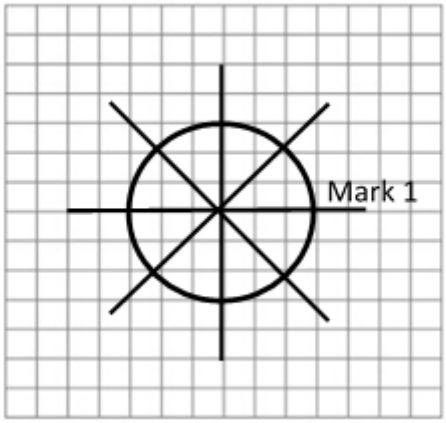


Figure 12: Markings for diameter measurements.

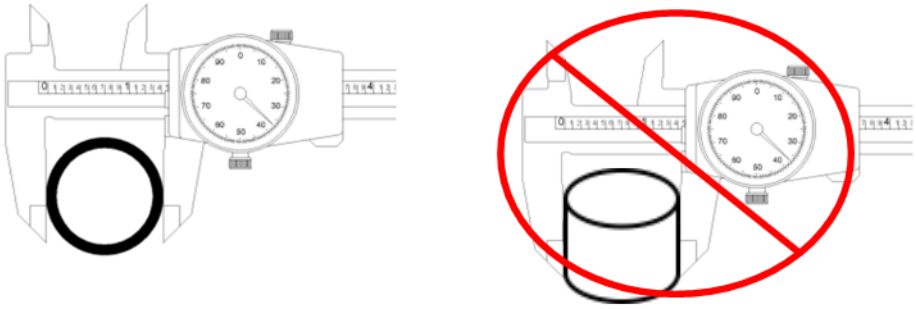


Figure 13: Appropriate and inappropriate use of a dial caliper with a cylindrical specimen.

Your caliper should be utilized parallel to the opening of your cylinder, not perpendicular, see Figure 13.[5] Measure all your points, then using the same points of measurement measure the thickness of the pipe walls. Find the average.

For the polymer pipe segments, use the vertical band saw to cut through the wall lengthwise on one of your initial measurement marks. For the metal pipe segments, make a similar cut using the Buehler ABRASIMET Cut-off saw. Take the time to notice the behavior of the pipe. Does the pipe open or close?

After the cuts have been made, repeat the diameter measurements for all the pipes.

Determine the change in circumference using the averages of the measurements. Use the following information to calculate the peak residual stresses:

Modulus of Elasticity, E, and Poisson's Ratio, ν, for the materials tested:

Table 23: Material properties of pipes made of various materials

	Material	Modulus of Elasticity	Poisson's Ratio
Polymer Pipe	Polyethylene	100 x 10^3 psi	0.46
	Poly-vinyl Chloride (PVC)	410 x 10^3 psi	0.42
	Polypropylene	165 x 10^3 psi	0.43
	Acrylonitrile Butadiene Styrene (ABS)	203 x 10^3 psi	0.35
Metal Pipe	Steel	29 x 10^6 psi	0.28
	Copper	16 x 10^6 psi	0.34
	Brass	14 x 10^6 psi	0.34
	Aluminum	10 x 10^6 psi	0.33

To calculate the peak residual stresses in the polymer pipe, use the following equation:

Equation 14: Residual Stress equation for polymer pipes

$$\boldsymbol{\sigma = \frac{\Delta C E t}{4\left[r + \frac{t}{2}\right]^2}}$$

where, ΔC = mean change in circumference of split ring
t = mean wall thickness
r = initial inner piper radius
E = modulus of elasticity

[5] http://www.lancasterschools.org/cms/lib/NY19000266/Centricity/Domain/1055/DialCalipers.pdf

For the metal pipe, the peak residual stress may be estimated from:

Equation 15: Residual Stress equation for metal pipes

$$\sigma = \frac{Et}{[1-v]^2}\left(\frac{D_f - D_0}{D_f D_0}\right)$$

Where, D_0 = mean outside diameter
D_f = mean outside diameter after the split
t = wall thickness
ν = Poisson's ratio
E = modulus of elasticity

NOTEBOOK:

1. Create a table for each sample.
2. Record the raw measurements and calculated peak residual stress (and sign) at the inner and outer surfaces.
3. Discuss results and why the signs are different for the two differing materials.

OUTPUT TECHNICAL MEMO:

Report the peak residual stress in each type of pipe. Be sure to indicate the sign (compressive or tensile) at the inner and outer walls. Explain the relationship between the residual stresses and the manufacturing processes. Graphically compare the residual stresses calculated between all four of the polymers and all four of the metals.

NOTE: In order to complete this memo, you must include the information collected from ALL GROUPS in your lab.

UNIT 4: ENGINEERING CHARACTERIZATION OF A POLYMER

INTRODUCTION: Polymeric materials have begun to see significant use in engineering applications (as opposed to packaging, or light duty uses) and thus knowledge of their engineering properties and general behavior is critical for the engineer.

The laboratory unit will consist of two rotations over a two week period:

1. Mechanical Properties of Thermoplastic Polymers: Rate Dependence
2. Mechanical Properties of Thermoplastic Polymers: Impact Testing

EQUIPMENT:

MTS 610 Servo-hydraulic tester, Izod impact tester

OBJECTIVE:

Measure a variety of engineering parameters and characterize the state of a polymeric solid. Then relate these results to real concerns in designing with polymeric materials.

BACKGROUND:

Polymers are seeing increasing use as engineering materials. Their ease of processing, light weight, low cost, and flexibility have resulted in more widespread application in areas which were previously considered the province of "structural" materials alone. High performance thermoplastics, filled engineering thermoplastics, and reinforced thermosets and thermoplastics are now being extensively applied in automotive, electrical, chemical, and home appliance products. Thus, the engineering characteristics of these materials have become a much greater concern.

The term polymer refers to a general class of materials which consist of long chains of molecules of covalently bonded atoms. The most common materials are based on a backbone of carbon with hydrogen, chlorine, fluorine, alcohol and other atoms or groups attached to the primary chain. Solid polymers used in bulk are called plastics and can be broken into two general sub-categories: thermoplastics and thermosets. In a thermoplastic (TP) the molecules are not chemically bound to each other but instead rely on entanglements, hydrogen bonding and other intermolecular interactions for their cohesion. Thermoplastics are easily formed and can be melted down and molded into new products with a very small expenditure of energy. Thermosets (TS) are formed when molecules are covalently bonded, usually by reaction with a "cross-linking agent". Once a thermoset has been formed it cannot be reshaped without breaking it down into constituent atoms (depolymerizing) and completely starting over.

The materials studied in this lab are a mixture of thermoplastics and thermosets. They may include:

Table 24: Engineering Polymer list

Material		Purpose
Polypropylene	PP	commodity TP used in containers
Polyethyleneterpthalate	PET	commodity TP used in soda bottle
Acrylic or Polymethylmethacrylate	PMMA	amorphous TP, plexiglass
Polycarbonate	PC	amorphous engineering TP - optical applications
Blends		synergistic combinations polymers (PC/ABS etc.)
Polystyrene	PS	amorphous commodity TP with good stiffness, very low cost
High Impact Polystyrene	HIPS	PS toughened with rubber particles
Styrene-Butadiene Copolymer	SB	"K resin"
Acrylonitrile-butadiene-styrene	ABS	amorphous engineering copolymer TP
Acrylonitrile-styrene-acrylate	ASA	Engineering copolymer TP
Nylon 6,6 or Nylon 6	PA66 or PA6	
Acetal or Polyoxymethylene	POM	
Bisphenol A or DGEBA Epoxy		standard thermosetting material, epoxy refers to the chemistry of the crosslinkable functional group
Filled Polymers		Any of the above thermoplastics may be blended with particles or short fibers to reduce the material cost and stiffen the material

Because of their chemical makeup and molecular structure, the performance of plastic components is greatly influenced by processing history, temperature, and notch and rate sensitivity of the polymer. These characteristics will be the basis for the investigations in this laboratory.

Part A: Mechanical Properties of Thermoplastic Polymers: Rate Dependence

INTRODUCTION: Polymer mechanical properties are strongly dependent on strain rate. The spaghetti-like structure of polymers leads to a strong rate dependence in their modulus, yield strength, and other mechanical properties. They are subject to viscoelastic (time-dependent elastic) deformation which is observed in the rate dependence in standard tests as well as time-dependent creep behavior. You will examine this dependence using tensile testing.

EQUIPMENT: MTS 610 test frame, dial calipers, test specimens

OBJECTIVE: Characterize the tensile behavior of the material provided including the effect of test rate on ultimate tensile strength, modulus, and strain to failure. Also, gain experience with the tensile behavior of several classes of polymers.

ASTM STANDARDS: D-638 Tensile Properties of Plastics

TERMINOLOGY: Semicrystalline Amorphous Glassy Rubbery

BACKGROUND: The most commonly used material characterization test is a uniaxial tension test. In the tension test, a specimen is subjected to a continuously increasing tensile displacement (or load) while simultaneous measurements are made of the elongation of the specimen and the applied load. The measurements are used to construct an engineering stress-strain curve for the test.

In polymers, tensile properties are strongly dependent on the rate of testing. The tensile behavior is determined by the relative speed of molecular motions required by the applied strain compared to the natural rate of relaxation or motion of those molecules. Therefore, parameters like degree of crystallization, rigid fillers, or the presence of strong Van der Waals forces will affect the ability of molecules to relax under the applied strains and thus will determine the relative stiffness, strength, and ductility of a polymer.

Several parameters are commonly used to describe the shape of the stress- strain curve. These include modulus (E), yield strength (S_Y) which is often called the flow stress in polymers, tensile strength (UTS), percent elongation, and reduction in area (ROA).

Tensile Strength, or ultimate tensile strength is the maximum applied load divided by the original cross-sectional area of the specimen:

Yield Strength or Flow Stress is usually defined for polymers as the load at which necking begins, usually a local maximum early in the test. Semi crystalline materials will tend to have a more clearly defined peak since yielding is due to the breakup of crystallites. Yield strength is generally more sensitive than the tensile strength to the effects of rate, processing, and the method of testing.

Percent Elongation is the ratio of the increase in the length of gage section of the specimen to its original length, expressed in percent:

Equation 16: Percent Elongation of a material

$$\%\ Elongation = \left(\frac{L_f - L_o}{L_o}\right) \times 100$$

where, L_f = gage length at fracture L_o = original gage length

The elongation of the specimen is uniform along the gage length up to the formation of a neck. When neck formation begins, the strain is no longer uniform.

Total energy of fracture is the total work required to break the tensile bar. It can be calculated by the test system software via numerical integration of the area under the stress-strain curve. For metals, the area is often estimated by multiplying the average of the yield strength and ultimate tensile strength by the total strain at failure. In general, that will not work with polymers. If the software is not used to calculate the work, you will need to estimate it manually by following the instructions outlined in Riemann Sum Method for Calculating Work of Fracture.

PROCEDURE:

Use one of the bars to establish a baseline behavior for the material by testing at a constant crosshead rate of 2 in/min. Use the tested specimen along with the remaining 3 specimens to investigate the rate dependence of the material by testing them at other rates which are order of magnitude increments (factor of 10) higher and/or lower than 2 in/min (i.e. 0.2 in/min, 20 in/min, 200 in/min etc.).

Because the loads applied in testing are relatively small and the test frame is extremely stiff, the machine errors from not using an extensometer will be relatively small. The remaining error is due to the inaccuracy in the gage measurement.

Specimens of other materials should be run at one of the intermediate rates (2 in/min). Observe differences in deformation processes and failure modes.

Note: The gage length of the tensile bars is approximately 2". Taking this into account, the strain rates are as follows:

Table 25: Test speed and strain rate conversion

Test Speed (in/min)	Strain Rate (in/in/min)
0.2	0.1
2	1
20	10
200	100

NOTEBOOK:

1. Table of material, test rate, modulus, ultimate tensile strength, and % elongation
2. Graphically represent modulus and UTS as a function of test speed for polymers used to characterize property rate dependence.
3. Graphically compare % elongation and UTS for all materials tested at 2”/min.
4. Discuss findings and compare results for amorphous and semi-crystalline materials.

LAB REPORT:

This will be a single lab report for both Parts A and B. See lab report section of Part B for information.

Part B: Mechanical Properties of Thermoplastic Polymers: Impact Testing

INTRODUCTION: Polymeric materials are sometimes subjected to rapid stress loading or impact loads. The Izod impact test is a common test for assessing a material's ability to withstand these loads. The impact toughness of a polymer depends on crystallinity and crystal structure. Generally, crystallinity and voids will decrease impact resistance. [6]

EQUIPMENT: Benchmaster Izod Notch Machine, Izod Pendulum Impact Tester, nippers, dial calipers

OBJECTIVE: Characterize the impact behavior of various classes of polymers.

ASTM STANDARD: D-256: Determining the Izod Pendulum Impact Resistance of Plastics

BACKGROUND: At high strain rates and in the presence of a notch, most polymers will behave in a largely brittle manner. The impact test is a measure of polymer performance under the most extreme conditions. There are still significant differences in toughness between the semi-crystalline and amorphous polymers. The rubbery materials will be tougher than glassy materials, but the differences are often much less than the toughness seen in the tensile tests.

PROCEDURE:

Cut the flex bars of various thermoplastic materials to the appropriate length designated in Figure 6 of the ASTM standard. Measure the dimensions (length, width, thickness) using dial calipers to be sure the specimen fall within the given tolerances; record in notebook.

Notch half of the samples for each material using the Benchmaster IZOD Notching Machine (see Safe Operating Procedures). Measure notch to be sure the specimen falls within tolerances specified in the ASTM Standard (dimensions A and E). If a specimen falls out of tolerance, place an asterisk on the final impact data.

Test specimen using Izod Impact Tester (see Safe Operating Procedures).

NOTEBOOK:

1. Table of material, length, width, thickness, impact energy, and calculated impact strength.
2. Graphically compare the impact energy for both notched and unnotched samples for each material.

ADDITIONAL:

[6] http://polymerdatabase.com/polymer%20physics/ImpactTest.html

Enter your data on the sheet provided for all lab sections. The information will be accumulated throughout the rotation. The averages and standard deviations will be used for the technical memo.

LAB REPORT FOR PARTS A & B:

Collect <u>all</u> impact data by <u>all</u> groups in <u>all</u> laboratories.

Graphically show the effect of testing speed on tensile properties (modulus and UTS). Comment on any implications for tensile testing of polymers. Graph a stress-strain curve depicting the effects of strain rate.

Compare all polymers tensile tested at 2 in/min. Graph a stress-strain curve depicting the differences due to material type and graphically compare UTS and % elongation.

Graphically compare the ***average (from all groups in all labs)*** impact fracture energy of the notched and unnotched polymers tested.

Graphically compare the UTS and impact energy for the polymers tested. Comment on the relationships between UTS, % elongation, and fracture energy.

Calculate the tensile fracture energy of the polymers tested at 2 in/min by using a Riemann sum method (see Appendix B Riemann Sum Method for Calculating Work of Fracture). Compare the total energy to fracture in tension with the impact energy for the polymers tested by graphing tensile energy as a function of impact energy. Comment on the relationship between the two variables.

Comment on how well the procedure used in Lab correlates with ASTM practices defined in D 638 and D256.

Table 26: Data table for notched polymer specimen impact test

NOTCHED SPECIMEN									
PC		ABS		HIPS		PP		HDPE	
Impact Energy (ft-lb)	Width (in)	Impact Energy (ft-lb)	Width (in)	Impact Energy (ft-lb)	Width (in)	Impact Energy (ft-lb)	Width (in)	Impact Energy (ft-lb)	Width (in)

Table 27: Data table for unnotched polymer specimen impact test

UNNOTCHED SPECIMEN									
PC		ABS		HIPS		PP		HDPE	
Impact Energy (ft-lb)	Width (in)	Impact Energy (ft-lb)	Width (in)	Impact Energy (ft-lb)	Width (in)	Impact Energy (ft-lb)	Width (in)	Impact Energy (ft-lb)	Width (in)

UNIT 5: MATERIALS RESEARCH PROJECT

INTRODUCTION: Often times, in industry, you will have to generate or follow testing standards, be it voluntary or industrial, to determine specific information about a material or a material's adequacy for specific circumstances. This is where knowledge of different types of material characterization tests and ASTM standards can be useful.

OBJECTIVE: Conduct a materials research project approved by your instructor. A non-metal project is preferred, but not mandatory. This project cannot be one of the labs already performed in this laboratory.

BACKGROUND: You have learned about many types of material testing to characterize material properties. You must utilize those tests and any more that you come across in your research to satisfy a project objective. Your objective should be a task that can be accomplished in two lab periods. You will need to generate a testing plan to satisfy the objective, complete the testing, analyze and interpret the data, and generate conclusions. You will present your findings to your class in the form of a PowerPoint presentation. Your presentation should follow the same outline as the lab report format. A presentation template that you must use is provided at http://faculty.utrgv.edu/samantha.ramirez/MECE2140.htm. One person from your group will submit the slides in Blackboard (for grading) before you begin your presentation. Your technical content will be graded during your presentation, be sure you clearly explain your rationale for your testing and analysis and give a complete and thorough discussion of the analysis and conclusions or applications. You will also submit a final report in Blackboard. This document will follow the same format for a lab report and must be worked on by all in the group. See the below timeline for due dates:

Table 28: Final Project Timeline

Date	Assignment	Notes
Last week of Unit III	Reminder announcement for proposal	
First week of Unit IV	Final Project Proposal	Once approved, you can begin working on the project.
Night before Study Day or Friday of Finals Week	Final Project Presentation due in Blackboard	A Final Project Report may be required by your instructor.
Study Day or Friday of Finals Week	Final Project Presentation	

Appendix A: Safe Operating Procedures (SOP)

BUEHLER MOUNTING PRESS

HAZARDS

1. Serious burns from heating elements, mold parts, and hot sample mounts.
2. Pinching by hydraulic jack handle or mold components.
3. Eye injury in case of component failure or improper mold alignment during load application.

REQUIRED SAFETY EQUIPMENT

1. Goggles or Safety Glasses (for all involved personnel)
2. Heat protective gloves (for operator)
3. Tongs

OPERATING PROCEDURE

1. Switch on the heating element - using switch mounted on cord. Red light on heating element should light. When light goes out, element is at molding temperature.
2. Load Specimen in mold:
    a. Place small cylinder inside the hollow tube - beveled end to outside
    b. Place the sample and enough Bakelite to fully cover the specimens in the tube.
    c. Place the larger cylinder in the cylindrical - beveled end to the outside.
3. Pick up the above structure and place it on the platform. Be careful to pick up the structure from the bottom so that the cylindrical insert does not fall through.
4. Lower the heating element over the cylindrical tube, once it is up to temperature. The heating element is up to temperature when the light on the handle goes out. **(CAUTION: Heating element is extremely hot make sure that you are wearing gloves.)**
5. Align the ram rod and the large cylindrical piece. Raise the platform by pumping the handle until the pressure needle moves to the preload line. Maintain this pressure for five minutes. **(CAUTION: Be careful not to pinch your hands.)**
6. Pump the handle to increase the pressure until the needle reads between the two red semi-discs. Hold at this pressure for 20 minutes. The pressure may drop as the polymer melts, so close observation is needed in order to maintain constant pressure. If pressure does drop, resume pumping handle until pressure is once again in the desired range.
7. Lower platform by turning release knob at base of jack handle counterclockwise.
8. Raise heating element and place cooling fins around cylindrical tube. **(CAUTION: Extremely hot, wear gloves)**
9. Allow to cool for 5-10 minutes.
10. Remove the sample from cylindrical tube. **(CAUTION: Be careful sample may still be hot, wear gloves or use tongs.)**
11. Clean equipment and turn off heating element.

POLISHING OF METALLOGRAPHIC SPECIMENS

HAZARDS

1. Abrasion of fingers during polishing

2. Eye injury due to foreign body
3. Chemical burn or irritation from etchant solutions
4. Inhalation injury from reacting or evaporating chemicals

REQUIRED PROTECTIVE EQUIPMENT

1. Safety glasses (all personnel) during polishing
2. Chemical goggles and gloves during etching
3. Fume hood for etching

PROCEDURE

COARSE POLISH

1. Specimens should generally be mounted in a polymer mounting material to allow easy handling and to insure that a flat surface is produced by the polishing process.
2. Polishing begins with the manual strip polishers. Check the quality of the exposed polishing paper. If the paper is saturated with abrasion product or the abrasive has been worn away, loosen the clamps at the bottom of the unit, pull the paper through the base to expose fresh paper, and tear off old paper. Only change the paper if necessary.
3. Turn on water supply to strip polisher. The flow rate should be adequate to flush abrasion product from the polishing surface.
4. Begin polishing with the coarsest paper. Polishing strokes should be in one direction and the specimen should not be rotated. Only moderate pressure is necessary.
5. Periodically inspect the specimen surface. Continue polishing until the surface consists entirely of polishing marks running in the same direction. (Hint: your job will be easier if you gradually decrease the applied pressure as the polishing progresses on each paper)
6. Wash specimen thoroughly to remove any polishing debris.
7. Turn specimen 90^{o} and polish on the next finer strip of paper. Polish until all scratches from previous steps have been obliterated by current step. Repeat steps 5-7 for each successively finer paper.
8. When you have finished the manual coarse polishing. Thoroughly clean the specimen with water.

FINE POLISH

Fine polishing is accomplished using the fabric wheel polishers. **CAUTION: The wheels throw off droplets of water containing abrasive and abrasion products. Wear safety glasses at all times**.

1. Set the wheel speed. The higher the speed the more rapid the polish. However, specimen control becomes more difficult at high speeds.
2. Shake the appropriate squeeze bottle of polishing compound mixed with water. Start with the larger (10-20 micron) abrasive particles on the left wheel. Spray a quantity of compound onto the wheel.
3. Place the specimens on the wheel and begin to polish
    a. Only gentle pressure is required. If lint begins to pull out of the wheel, you are using too much pressure.
    b. Rotate the specimen as you hold it on the wheel.
    c. The wheel needs a steady but slow supply of distilled water to ensure good suspension of abrasive and abrasion products. A drop every 2-3 seconds is adequate.
4. When all the scratches have been removed, rinse the specimen thoroughly and finish polishing using the fine abrasive on the right wheel.

ETCHING

1. Specimens should already be mounted in a polymer material and polishing completed through the final stage and the surface to be etched dry and free of dirt or oil.
2. Etching is done by either immersing the specimen in the etchant or by painting the etchant on the surface using a cotton swab. **CAUTION: Etchants are corrosive. Wear goggles and gloves when handling them**.
3. After allowing the appropriate etching time, the etchant should be "killed" by rinsing the surface. Use water with water or alcohol to match the primary liquid in the etchant. Do not touch the etched surface since oils from the hand can ruin the surface.

Table 29: Suggested etchants for different metals

Material	**Etchant**
Zinc	50% concentrated hydrochloric acid in water, swabbed
copper alloys	Alcoholic ferric chloride ($FeCl_3$), immersed
copper alloys	Aqueous ferric chloride, immersed
Aluminum alloys	Mixed acids, immersed
Steels & irons	2% Nital (2% nitric acid by volume in alcohol), immersed

BUEHLER ABRASIMET CUT-OFF SAW

HAZARDS

1. Pinch hazard from protective cover
2. Abrasion/Cut hazard from abrasive wheel during speciment loading

REQUIRED PPE

1. Safety glasses

PROCEDURE

1. Specimen to be sectioned should be firmly locked down in the vise.
2. Check wheel for chips or major misalignment. If the blade is chipped do not attempt to make a cut.
3. Close cover, pull out on emergency stop button until it clicks and press start button to start motor and water pump. Cooling water should begin to flood the cutting area. If the water does not flow **DO NOT ATTEMPT A CUT**.
4. Gently lower the saw blade to contact. A gentle continuous pressure is all that is needed for the saw to cut. Too high a pressure can break the blade. The production of smoke is a sign that the feed speed is too high or there is inadequate cooling -- lessen the pressure and see if the smoke abates.
5. When the cut is complete, raise the saw and press the stop button. Wait until the blade stops turning before opening the cover.

LECO BELT GRINDER

HAZARDS

1. Pinch hazards between back-stop and belt
2. Abrasion of fingers against belt
3. Projectile hazard from specimens torn loose on the wheel

REQUIRED PPE

1. Safety glasses
2. All safety guards must be in place on machine.

PROCEDURE

1. The area behind the machine should be clear of personnel at all times while grinder is in operation.
2. Specimens must be mounted or large enough to permit them to be ground without bringing fingers into dangerously close proximity to the grinding belt.
3. Start the grinder by pulling the emergency stop button all the way out.
4. Adjust the water flow using the black knob to provide a steady sheet of water over the belt.
5. If the belt is drifting to one side of the rollers, adjust the belt tracking knob to center and stabilize it.
6. Hold the specimen firmly and press it against the supported section of the belt. Large specimens may be braced against the back stop.

ROCKWELL HARDNESS TESTER

HAZARDS
Pinch hazard between anvil/specimen/indenter head

REQUIRED PPE
Safety glasses

PROCEDURE:

1. Specimens to be tested must be free of rust, oil, and dirt.

2. The specimen should be securely supported on one of the available test anvils. Specimens cannot be encased in plastic or other softer material during testing but must rest directly on the anvil.

Table 30: Anvil selections based on specimen configuration

Specimen	**Anvil**
Flat	Flat
Cylindrical	V-anvil
Oversized	Point

3. Select the appropriate scale, major load setting, and indenter. Refer to the summary table mounted on the instrument for details.

4. Turn the hand wheel at the base of the anvil pillar to raise the specimen to contact with the indenter. Watch the preload indicator and stop turning when the LED preload scale is fully illuminated and you hear a click**.**
5. When the reading is completed, back the specimen away from the indenter and move it to select another test area. Indentations should be separated by more than 5 indenter diameters.

Negative readings or values below 20 on any scale indicate that the selected scale is too aggressive. Change to a scale with a lower major load and/or less aggressive indenter and try again.

Hardness tests should be completed in the same general area.

SHIMADZU HMV-G21D MICROHARDNESS TESTER

HAZARDS:
Pinch hazard between anvil/specimen/indenter head

REQUIRED PPE:
Safety glasses

PROCEDURE:

Note: Never rotate the turret by hand!

1. Remove the dust cover, clear and lower the Sample stage, and power-up the instrument.
2. Once the [Ready] light on the instrument is lit steady, right click the **[HMV-G]** icon on the desktop and select run elevated to open the **[HMV-G Main Menu]**.
3. Click the [Test] icon.
4. If not already selected, Click the [X40] icon on the left toolbar. Do not use the [X10] until the [X40] objective has been focused to avoid striking the indenter with the sample.
5. Place polished specimen on the Sample stage.
6. Use the stage elevation handle to raise the Sample stage *SLOWLY!*
7. Be sure to bring the area into focus and use the objective to locate the desired location for testing.
8. On the **[Group Conditioning]** Pane, click Edit.
9. Expand the **[Basic Conditioning]** Pane.
    a. **[Sample Name]** 12 characters or less.
    b. **[Sample No.]** 12 digits or less.
    c. **[Memo]** Enter comment 20 characters or less.
    d. **[Force]** Set at HV0.3 (2.942N).
    e. **[Hold Time]** 10 sec.
    f. **[Lens]** select initial condition (X40).
    g. Ignore the **[Assistant Function]**.
    h. **[Image Saving]** and **[With marker & scale]** selected.
    i. **[Pass-Fail]** optional.
10. Expand the **[Sample Conditioning]** Pane.
    a. **[Sample Shape]** Select [Flat].
    b. **[Auto reading mode]** Select [for abrasion or etching surface].
11. Click [Commit] on the **[Test Button]** Pane to confirm the setup.
    Note: There should be NO movement on the table when the indentation is being done.
12. Click [Test] on the **[Test Button]** Pane to create the indentation.
13. Once finished, the turret will return to the X40 objective and the indentation will be read automatically.
14. Make fine adjustments to the cursor by clicking the respective [Cursor Movement] Arrows under the **[Read Result]** Tab page. Note the hardness reading adjusts accordingly.
15. Adjust the Sample stage for the next reading, refocus if necessary.
16. Repeat steps 12 – 15 for each additional measurement.
17. To export the measurements, Click [Edit] menu and select [Copy (all results)].

18. Open MS Excel.
19. Click [Paste] on the toolbar and select [Use Text Import Wizard].
20. Select [Delimited] and then select [Tab] and [Comma] and press finish.
21. Save the file.
22. Shutdown the microscope:
    a. Lower the Sample stage.
    b. Remove specimen.
    c. Exit **[HMV Test]** software.
    d. Close **[HMV-G Main Menu]**.
    e. Turn instrument off using button on the back panel.
    f. Place dust cover on instrument.

SATECH PENDULUM IMPACT TESTER

HAZARDS

Pinch/smash hazard between pendulum and anvil
Projectile hazard from broken specimen pieces as well as the swinging tup

REQUIRED PPE

Safety glasses
Specimen placement tongs

PROCEDURE

All personnel should be behind the safety line during testing.

1. Remove stop pin on top of pendulum stand and rotate control lever all the way right to the locked position.
2. Replace stop pin.
3. Raise the pendulum to the right until the latching mechanism catches (you can feel it click). Be sure the pendulum path is clear, step back from machine and let go of the pendulum.
4. Load the test specimen using tongs with self-centering alignment blocks.

Table 31: Notch direction

Specimen	Notch Direction
Charpy	Faces away from the tup
Izod	Faces the tup

5. Set indicator arrow to maximum energy for the chosen scale.
6. When all personnel are clear, push the control lever to the left to release the pendulum.
7. After the pendulum has completed one swing (breaking the specimen), remove the stop pin and push the control lever all the way to the left to apply the brake.

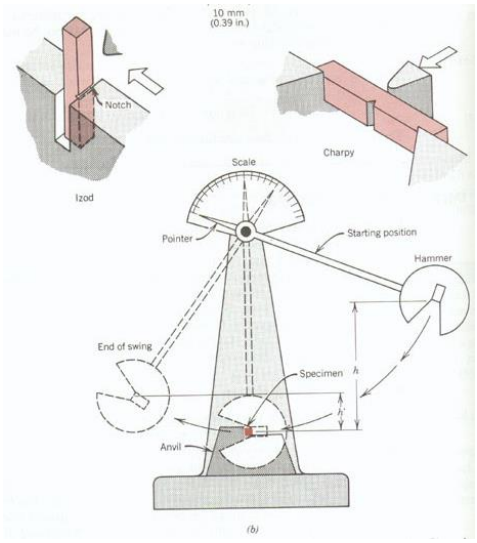


Figure 14: Depiction of notch direction

BLACKS CHARPY NOTCH MACHINE

HAZARDS

Pinch hazard between broach and base
Abrasion/Cut hazard from broach during speciment loading
Projectile hazard from specimens torn from the broach

REQUIRED PPE

Safety glasses
No loose clothing

PROCEDURE:

1. Raise the broach and fit the support pin.
2. Insert the test piece.
3. Clamp the test piece in position by tightening the rear clamping screws.
4. Apply slight coating of cutting oil using the wooden handle lubricant brush.
5. Remove the support pin while holding the handle.
6. Draw the broach down and cut the notch rotating the hand wheel at an even rate until all the broach teeth have passed the test piece. **DO NOT RAISE THE BROACH.** Raising the broach before removing the piece may damage both the broach and test piece.
7. Release the rear clamp screws and remove the notched test piece.
8. Raise the broach and fit the support pin.
9. Clear away the swarf from the broach and the locating block by brushing using the brushes supplied.

Daily maintenance:

Clean rack & body ensuring debris does not get between them.

DYNATUP DROP TOWER IMPACT TESTER

HAZARDS

Pinch/smash hazard between falling tup and specimen or stops
Projectile hazard from broken specimens

REQUIRED PPE

Safety glasses
Safety guards must be in place for testing

PROCEDURE:

1. Raise and latch impact head. Place brace assembly on unit, below raised impact tup. **Never put your hand under a raised tup without the brace assembly in place!**
2. Remove access door on instrument guard if necessary.
3. Position specimen on appropriate fixture.
4. Replace access door on instrument guard.
5. Remove brace assembly.
6. When software indicates ready to test - pull down on latch on cross head to release impact head.

DIAMOND BAND SAW

HAZARDS

Cut hazard from saw blade
Projectiles from cut components or blade failures

REQUIRED PPE

Safety glasses

PROCEDURE

1. Check water level in sponge reservoir. Fill if necessary.
2. Be sure blade is clear of any obstructions and turn on saw.
3. Specimens to be cut should be large enough to permit ample clearances between fingers and the blade.
4. Use the miter unit or other pusher assemblies to steady parts and provide additional clearance between fingers and the saw.
5. Slowly push the specimen into the blade. **Do Not Apply Heavy Pressure**!
6. Turn off saw before retrieving small cuttings.
7. **Never put your hand between the blade and the body of the saw while the blade is turning.**

FTS SYSTEMS MULTI-COOL TEMPERATURE BATH

HAZARDS

Cold or heat "burns" from specimens or thermal bath medium
Ingestion of silicon oil in bath

REQUIRED PPE

Safety glasses
Thermal protection gloves

All specimens should be handled with tongs.

PROCEDURE

1. Check fluid level. Oil should be ½" below the gasket at the fluid's highest operating temperature. For Syltherm, T_{max} = 200°C.
2. Place sample in the reservoir using specimen handling tongs. Do not drop specimens as you may damage the canister.
3. Turn on the stirrer using switch on front panel. Never operate system without the stirrer activated.
4. Increase the idle speed to some value greater than 100 using the arrow keys.
5. Set the desired temperature.
6. Specimens generally will need to soak 3-5 minutes after reaching the desired temperature to assure uniform internal conditions.

SINTECH UTS

HAZARDS:

Crush & Pinch hazards during fixturing and machine operation
Projectiles produced by broken specimens
Sharp edges of broken specimens

REQUIRED PPE

Safety glasses must be worn at all times

PROCEDURE

Note the location of the emergency stop button.

1. Install appropriate fixtures
2. Set cross head limit stops (black and yellow rings on round post) to prevent contact between test fixtures.
3. Turn on computer and start Testworks Software.
4. Select the type of test to be performed from the method window
5. Calibrate the load cell and extensometer (if used). This must be done before you begin to load specimens or the load read out will not function.
6. Click on the "Test" button. You will be prompted to enter specimen dimensions by the software, be sure you have taken the measurements before you load them into the test frame.
7. Load specimen to be tested, attach extensometer (if used).
8. Run the test. When the specimen has broken and the crosshead stops, remove the pieces from the fixtures. Be careful of the sharp edges in the fracture area of the broken parts.
9. After each test, return the crosshead to its zero position.
10. Repeat the process with the next specimen.
11. When testing is completed, dispose of broken specimens (scrap barrel or trash) and shut down the program.

Notes on Extensometers

Extensometers are extremely expensive instruments and should be handled with care. To protect them, most tensile test procedures will pause during testing for gage removal. When the machine stops, carefully remove the gage. Clicking "OK" in the program will resume the test.

BENCHMASTER IZOD NOTCHING MACHINE

HAZARDS:

Pinch hazard between vice clamp
Abrasion/Cut hazard from notcher during specimen loading
Projectile hazard from specimens torn from the notcher

REQURIED PPE:

Safety glasses
No loose clothing

PROCEDURE:

1. Place specimen in vice
2. Zero the vertical position
3. Raise the base to desired depth
    a. Scale on handle is 0.001”
4. Move vice behind (to right of) notching blade
5. Turn on machine using switch
6. Move specimen through the notching blade
7. Shut off machine once specimen is completely through the notching blade
8. Remove sample

IZOD IMPACT TESTER

HAZARDS:

Pinch/smash hazard between pendulum and striker
Projectile hazards from broken specimen pieces as well as the swinging tup

REQUIRED PPE

Safety glasses

PROCEDURE:

1. Raise and latch pendulum.
2. Place specimen in the vice.
    a. If specimen is notched, face the notch towards the striker.
3. Run a test on the data acquisition system.
4. Enter the width of the sample. (This is the thickness of flat specimen.)
5. Unlatch pendulum when display says to.
6. Characterize failure mode (Complete, hinge, partial, non-break)
7. Record down impact energy.

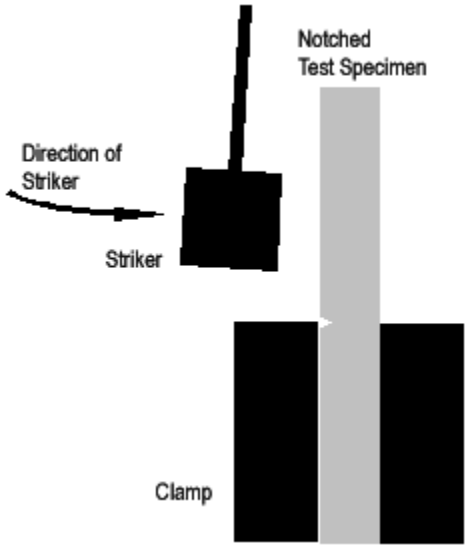


Figure 15: Depiction of specimen setup

CREEP TESTING OF POLYMER MATERIALS

HAZARDS

1. Injury due to falling weights
2. Burn from heated fixtures

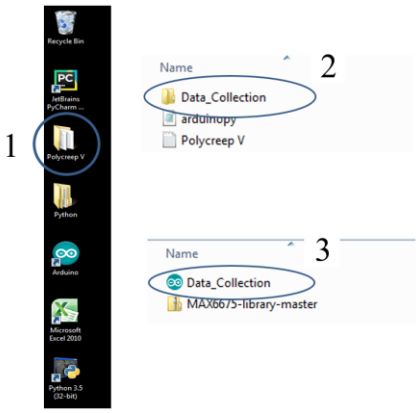
REQUIRED PROTECTIVE EQUIPMENT

1. Safety glasses (all personnel) for the entire test
2. Gloves when handling fixtures

PROCEDURE

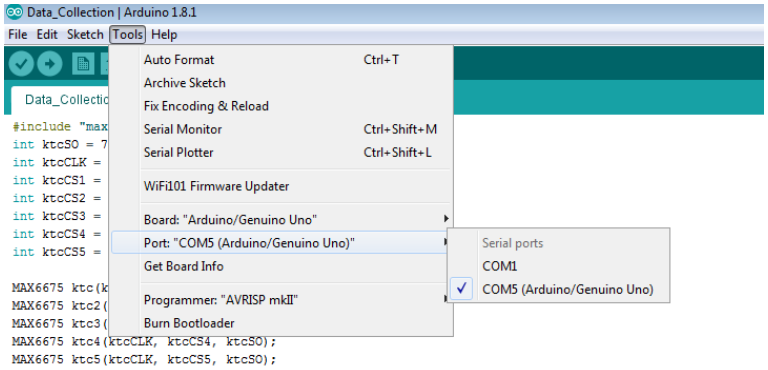
SETTING UP DATA ACQUISITION SYSTEM

1. To begin the data recording process, in the Desktop you will find a folder called *Polycreep V* [1]. Open the folder and open secondary folder titled *Data_Collection* [2]. Finally open the Arduino file of the same title [3].



DO NOT MODIFY ARDUINO CODE!!!

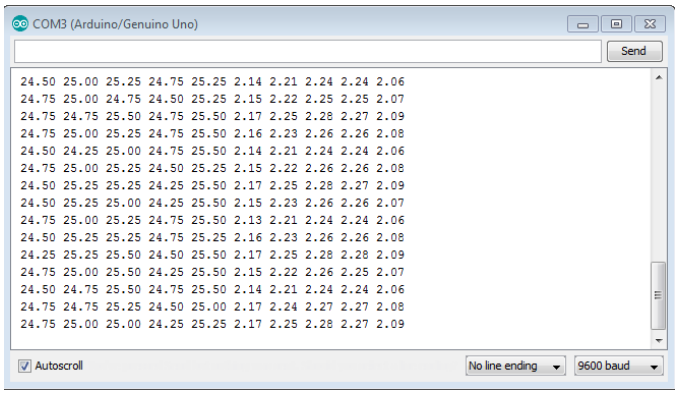
2. Verify that the right port is selected under the tools selection. Select the COM port that reads *Arduino/Genuino Uno*, remember the COM# number.



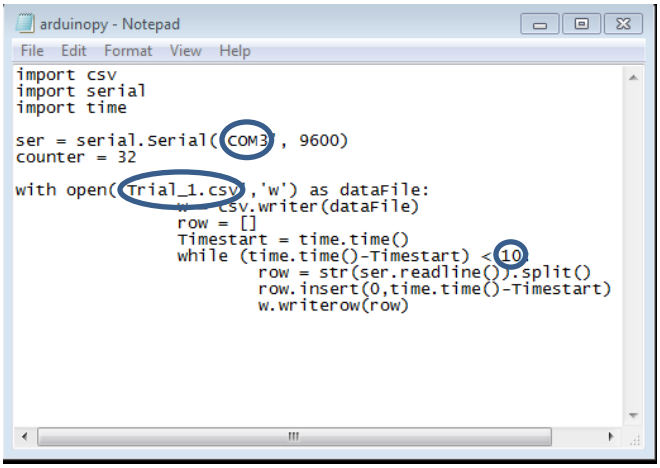
3. Click the *UPLOAD* icon to compile code into Arduino. After it has compiled code and sent to Arduino, click on the Serial Monitor (pictured below).

If the Arduino compiler shows any errors, contact TA/Professor.

The following figure shows real time data for thermocouple Temperatures 1-5 and Linear Potentiometers 1-5, respectively.



4. In the *Polycreep V* folder open text file titled *arduinopy*, the text file is pictured below.



The *arduinopy* file will be modified in accordance to testing requirements. Three things need to be changed/verified; the COM port, output file name, and the test time, referenced above.

- The COM port should match that of the Arduino program.
- The output file name should be '*Tuesday Lab Group 1'*, depending on lab day, and group number.

- The test time should be set to a default $20\ minutes = 1200\ seconds$. The input number is in seconds.

Finally, save the file under the same name, *arduinopy*.

LOAD APPLICATION MECHANISM

1. Prepare weight stacks to load each specimen to a different stress.
2. Loads should differ by at east $250\ g$.
3. With the weight mechanism at its highest position, load the weights on to their respective stations.
4. Once loaded, zero and lock the potentiometer clips onto the displacement rods.

When the oven has reached steady state temperature on the Arduino Serial Monitor start data acquisition by following the next steps.

Run computer command prompt. Type the following commands to run the *arduinopy.py* code.

1. *cd Desktop*
2. *cd Polycreep V*
3. *python arduinopy.py*

Slowly lower the weight mechanism thus applying weight to the samples.

Allow data acquisition until the specimens have all achieved a maximum displacement of $4\ inches$ *or* for a maximum time of $20\ minutes$ at which point Python will stop gathering data.

After Python is finished, the output Excel file will be saved in the *Polycreep V* folder.

Appendix B: Analysis Procedures

IMPORTING TEXT FILES INTO EXCEL

To import text files into Excel:

1. Open Excel
2. Click on Open
3. In the bottom right-hand corner, change the option from All Excel Files to All Files.
4. Open the appropriate text file.
5. Follow the instructions from the Text Import Wizard
    a. All text files from the Materials Lab will be delimited.
    b. The delimiter is what is separating your data
        i. MTS text files use commas as delimiters
        ii. Thermal Analysis text files use tabs as delimiters
    c. General format is fine for importing
6. Click on Finish

RIEMANN SUM METHOD FOR CALCULATING WORK OF FRACTURE

Importing test files

1. Open Excel
2. Open text file
    a. Follow instructions from Import Wizard
3. In the 2nd row of data in a new column (E3 in the table below), apply the equation for area of a trapezoid
    a. $A = \frac{1}{2}(y_2 + y_1)(x_2 - x_1)$
4. Add all trapezoid areas (E8 in the table below)
    a. This is your work of fracture

Table 32: Example Excel file with equations

	A	B	C	D	E
1	Load (lbf)	Extension (in)	Stress (psi)	Strain (in/in)	Trapezoidal Area (psi)
2	100	.1	=A1/A_o	=B1/L_o	
3	200	.2	=A2/ A_o	=B2/L_o	=0.5*(C2+C1)*(D2-D1)
4	300	.3	=A3/ A_o	=B3/L_o	=0.5*(C3+C2)*(D3-D2)
5	400	.4	=A4/ A_o	=B4/L_o	=0.5*(C4+C3)*(D4-D3)
6	500	.5	=A5/ A_o	=B5/L_o	=0.5*(C5+C4)*(D5-D4)
7	600	.6	=A6/ A_o	=B6/L_o	=0.5*(C6+C5)*(D6-D5)
8					=sum(E3:E7)